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DOMINANT TECHNOLOGIES IN “INDUSTRY 4.0”
BUSINESS & “INDUSTRY 4.0”
SOCIETY & „INDUSTRY 4.0”

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Fabrication of a sensor-based connected device for IoT applications

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Abstract: We report the results of measuring carbon dioxide (CO₂) concentrations 140 times a day in habitable spaces using Sigfox along with temperature, humidity, and atmospheric pressure measurements. We design and fabricate a printed circuit board to integrate the sensor with an Arduino processor. Using the developed sensor, we estimate that if one adult male performs light work for 1 h in a typical living room [3.17 m (width 3.17 m) × 7.4 m (length 7.4 m) × 2.6 m (height 2.6 m) = volume 61.4 m³], the carbon dioxide CO₂ concentration will increase by approximately 200 ppm. In the future, the developed sensor could be used for detailed human behavior studies in the context of CO₂ concentrations.

Keywords: CARBON DIOXIDE SENSOR, INTERNET OF THING, SIGFOX, GAUSSIAN

1. Introduction

Knowledge and information have not yet been exchanged in the information society (Society 4.0), leading to issues due to a lack of interdisciplinary cooperation. Society 5.0 would connect all people and things with the Internet of Things (IoT) to share various types of knowledge and information.

Against this background, using the Sigfox network and the Internet, we developed IoT devices equipped with temperature, humidity, barometric pressure, and other sensors to measure different physical data [1-5].

Herein, we analyzed CO₂ characteristics using the Gaussian program. We fabricated printed circuit boards using laser processing to integrate an optical CO₂ sensor that is less affected by organic matter. Finally, we developed an IoT system using Sigfox communication.

2. Materials and Methods

2.1 CO₂ Sensor

We used the MH-Z19C NDIR infrared gas module (Zhengzhou Winsen Electronics Technology Co., Ltd., Zhengzhou, China) (Fig. 1), a common type, small-size sensor, using the nondispersive infrared (NDIR) principle to detect CO₂ in the air, with good selectivity, nondependence on oxygen, and long life [6].

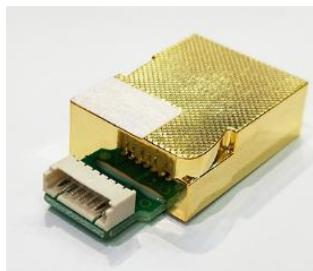


Fig. 1 Photograph of the CO₂ sensor module (MH-Z19C)

Table 1 is a list of the CO₂ sensor module's main parameters. Table 2 shows the detection range and accuracy of the module.

2.2 PCB fabrication

We created CAD designs of printed circuit boards to incorporate the CO₂ sensor module into a connected device (Fig. 2). We used laser-based prototyping equipment (Photolaser U4, LPKF, Germany) to fabricate the boards based on the CAD designs [7].

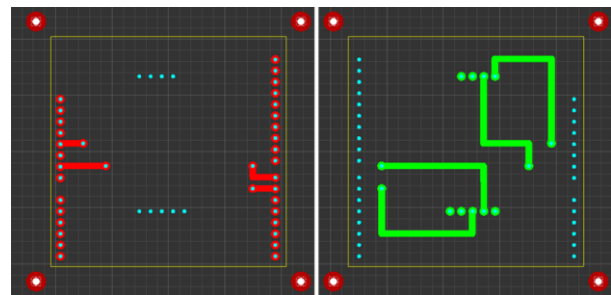


Fig. 2. Circuit layout drawing using CAD

Table 1 Main parameter of CO₂ sensor module.

Model No.	MH-Z19C
Detection Gas	CO ₂
Working voltage	5.0 ± 0.1V DC
Average current	< 40mA (@5V power supply)
Peak current	125mA (@5V power supply)
Interface level	3.3 V (Compatible with 5V)
Detection Range	400~10000ppm(optional)
Output signal	Serial Port (UART) (TTL level 3.3V)
	PWM
Preheat time	1 min
Response Time	T ₉₀ < 120 s
Working temperature	-10 ~ 50 °C
Working humidity	0 ~ 95% RH (No condensation)
Storage temperature	-20~60 °C
Weight	5 g
Lifespan	> 10 years

Table 2 Detection range and accuracy of CO₂ sensor module.

2.3 Arduino Assembly

The Sigfox shield for Arduino V2S2 was plugged into the Arduino UNO Rev3 to turn it into an IoT device, and the CO₂ sensor was also plugged into the Sigfox shield to complete it (see Fig. 3) [8].

In the IoT device, a temperature/humidity/barometric pressure sensor (BOSCH BME-280) was used. The sensor specifications [9] are as follows:

- Operating temperature range: -40°C to +85°C (rated)

- Humidity: 0%–100% (relative humidity)
- Atmospheric pressure: 300–1100 hPa
- Temperature accuracy: $\pm 1^{\circ}\text{C}$ (0°C 65°C)
- Humidity accuracy: $\pm 3\%$ RH (25°C , absolute accuracy tolerance)
- Barometric pressure accuracy: ± 1.0 hPa (0°C 65°C , absolute accuracy)

A sketch (see Fig. 4) developed for the Arduino UNO Rev3 in the IoT device using the Arduino IDE is used to control the CO₂ concentration measuring instrument.



Fig. 3 Photograph of CO₂ sensor for an IoT system with Sigfox

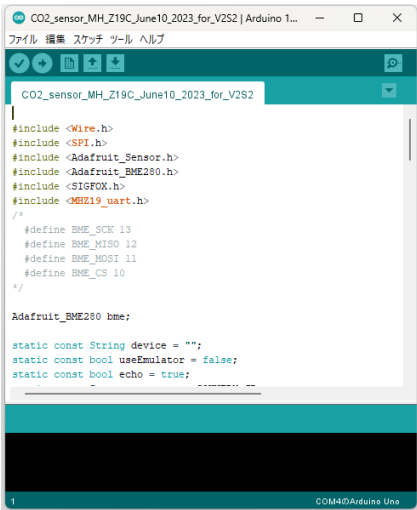


Fig. 4. Example of the Arduino sketch employed in this study

2.4 ThingSpeak and Matlab/Simulink

The overview of IoT devices ThingSpeak, and Matlab/Simulink is shown in Fig. 5. ThingSpeak data processing comprises analytics, and of actions. Analytics include Matlab analysis, Matlab visualizations, and Plugins. Actions include ThingTweet, TimeControl, React, TalkBack, and ThingHTTP. Here, a CO₂ concentration sensor is the smart connected devices in Fig. 3.

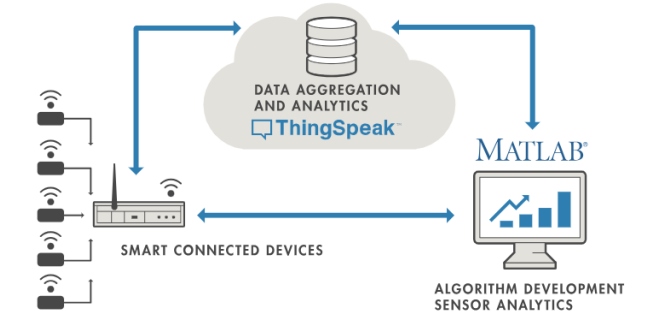


Fig. 5. Overview of IoT devices, ThingSpeak, and Matlab/Simulink [10]

2.5 Sigfox Implementation

Figure 6 shows example of Sigfox shield for Arduino V2S2 callback. Temperature, humidity, atmospheric pressure data are send to ThingSpeak from smart connected device using callback shown in Fig. 6.

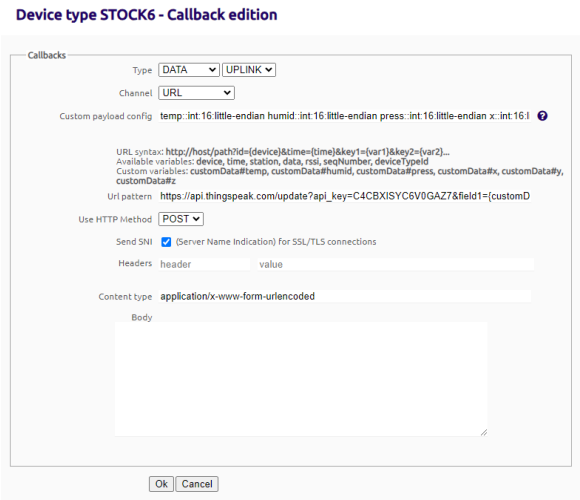


Fig. 6. Example of Sigfox shield V2S2 for Arduino Callback

Fig. 7 shows the ThingSpeak channel setting example. The graphs of various data such as temperature, humidity, etc. are drawn based on channel setting.

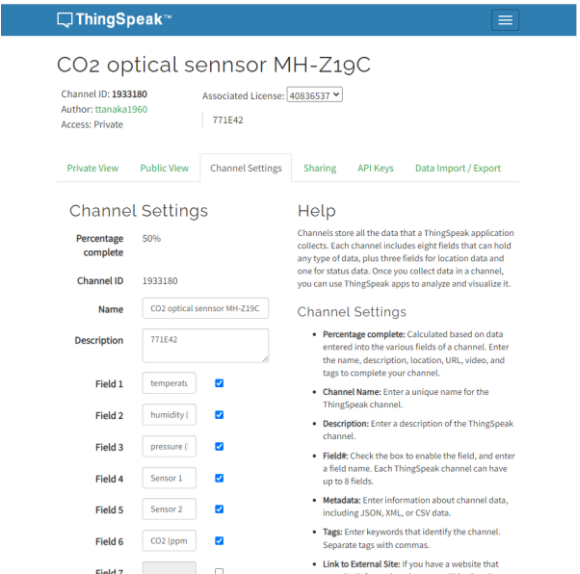


Fig. 7. ThingSpeak channel setting example

3. Results and Discussion

Figure 8 shows a printed circuit board processed using the LPKF ProtoLaser U4.

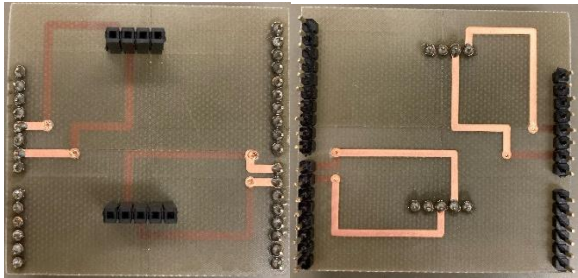


Fig. 8 Photograph of circuit layout

Figure 3 shows a CO₂ sensor for an IoT system with Sigfox, created by combining Arduino UNO, Sigfox shield for Arduino, and a processed printed circuit board with a CO₂ sensor module (MH-Z19C) mounted on it.

The developed IoT device was installed 80 cm above the floor in an N1-607 at the Hiroshima Institute of Technology. The house's basic environmental data were acquired using a data processing method using ThingSpeak [11]. Data obtained using the IoT device (September 30, 2023) are shown for temperature (Fig. 9), humidity (Fig. 10), pressure (Fig. 11), and CO₂ concentration (Fig. 12).

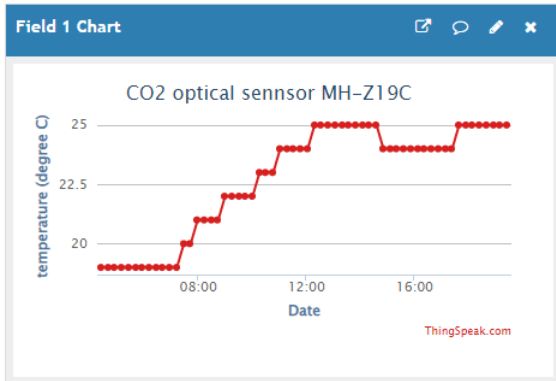


Fig. 9 Temperature data from CO₂ sensor for an IoT system with Sigfox

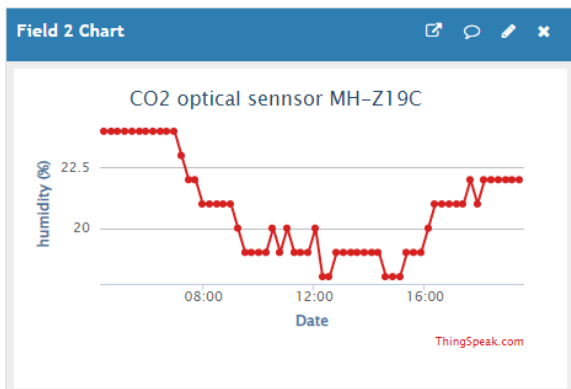


Fig. 10 Humidity data from CO₂ sensor for an IoT system with Sigfox

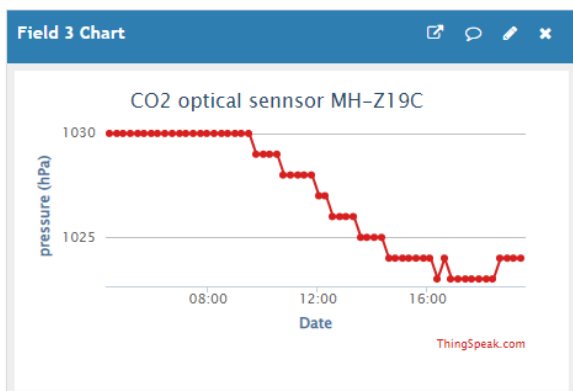


Fig. 11 Pressure data from CO₂ sensor for an IoT system with Sigfox

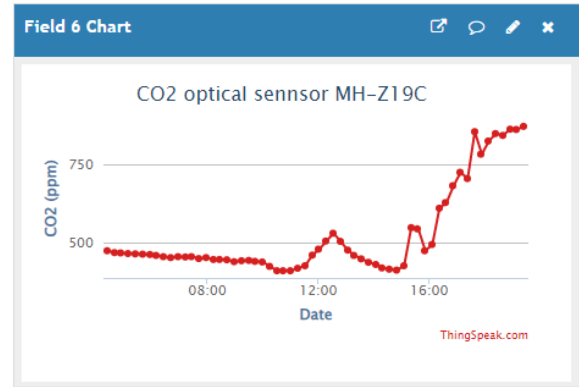


Fig. 12 CO₂ concentration from CO₂ sensor for an IoT system with Sigfox

As mentioned above, a human being in room N1-607 releases 0.02 m³ of CO₂ per hour. The volume of N1-607 is wide 3.17 m × length 7.4 m × height 2.6 m = 61 m³ and should increase by 327 ppm (=0.02 m³/61 m³). However, the current increase is approximately 140 ppm/h from 18:00 to 20:00 (Fig. 3). The lower-than-expected CO₂ concentration may be due to the accuracy of human CO₂ emissions and the high location of the sensor. Moreover, 1 kg of CO₂ is produced by the human body per day [12]. The volume of 1 kg of CO₂ is approximately 0.5 m³ or approximately 0.02 m³ per hour. According to the Ministry of Health, Labor and Welfare, 30 m³ per person per hour has a certain level of rationality as the amount of ventilation required to improve “closed spaces with poor ventilation.” This value suggests that the ratio of CO₂ generation and ventilation per person per hour is 0.02/30 = 0.000666 666 ppm and that this value is reasonable [13].

In the future, it will be necessary to consider human CO₂ emissions, sensor installation height, and indoor position.

4. Summary

Sigfox was used to measure the CO₂ concentration 140 times a day in habitable rooms or spaces where people live, in contrast to the 96 daily measurements conducted in an earlier study. The developed IoT device was installed 80 cm above the floor in an N1-607 at the Hiroshima Institute of Technology. The house's basic environmental data were acquired using a data processing method using ThingSpeak. It should increase by 327 ppm (=0.02 m³/61 m³) of CO₂ concentration. However, the current increase is approximately 140 ppm/h from 18:00 to 20:00. The lower-than-expected CO₂ concentration may be due to the accuracy of human CO₂ emissions and the high location of the sensor. In the future, it will be necessary to consider human CO₂ emissions, sensor installation height, and indoor position.

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We thank Enago (www.enago.jp) for the English language review and Altner Co., Ltd., who provided us with some of the IoT devices used in this research. The computation was performed using the computer resources offered under the category of General Projects by the Research Institute for Information Technology, Kyushu University.

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10) ThingSpeak for IoT https://thingspeak.com/pages/commercial_learn_more/

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12) [https://www.man-es.com/discover/decarbonization-glossary---man-energy-solutions/carbon-dioxide-\(co2\)---decarbonization-glossary-man-energy-solutions](https://www.man-es.com/discover/decarbonization-glossary---man-energy-solutions/carbon-dioxide-(co2)---decarbonization-glossary-man-energy-solutions)

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Supplementary Information

S1. Properties of CO₂

The characteristics of carbon dioxide are published in the NIST Webbook [1]. Select content is shown below.

- Formula: CO₂
- Molecular weight: 44.0095
- IUPAC Standard InChI: 1S/CO₂/c2-1-3 Copy
- IUPAC Standard InChIKey: CURLTUGMZLYLDI-UHFFFAOYSA-N Copy
- CAS Registry Number: 124-38-9

Fig. S1 shows the chemical structure of CO₂.



Fig. S1. Chemical structure of CO₂

Next, we calculated CO₂ characteristics using the Gaussian program installed on a large-scale computer at Kyushu University. First, an input file (Fig. S2) was created using Avogadro [2] as one of the data sets for the Gaussian program.

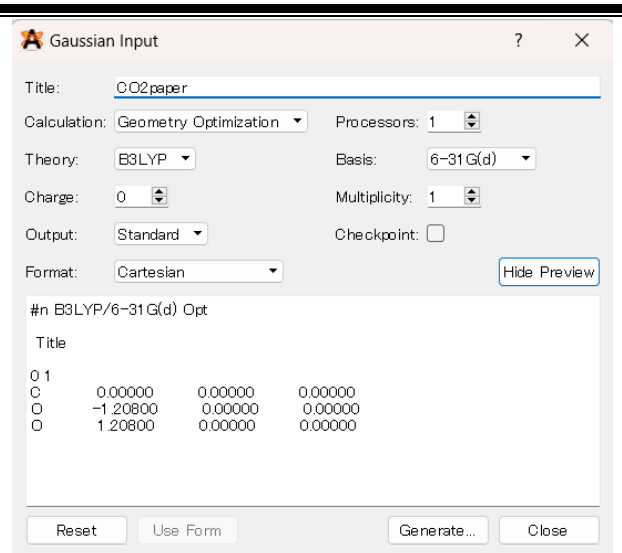


Fig. S2. Gaussian Input file

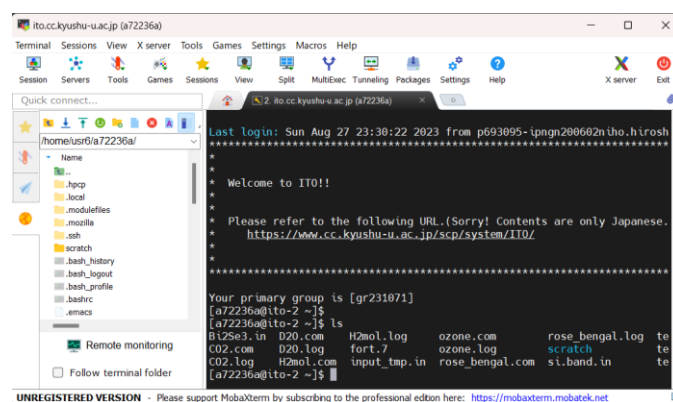


Fig. S3. Using MobaXterm, we connected to the Kyushu University Large Computer Center

Using MobaXterm, we connected to the Kyushu University Large Computer Center and calculated CO₂ using the Gaussian program and Gaussian input file (Fig. S2). Fig. S4 shows the results.

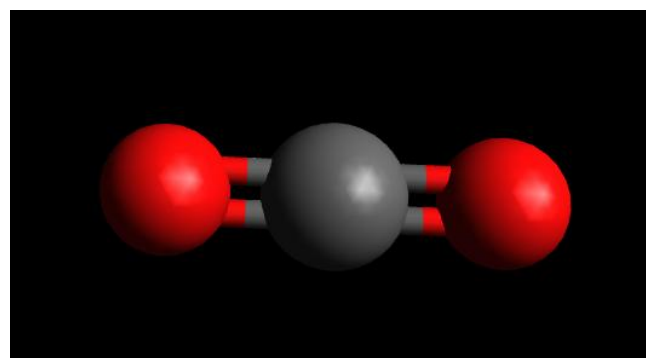


Fig. S4 Chemical structure of CO₂

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- 1) <https://webbook.nist.gov/cgi/cbook.cgi?Source=1927LOW%2FERI2729-2734&Units=SI&Mask=7>
- 2) Avogadro: an open-source molecular builder and visualization tool. Version 1.XX. <http://avogadro.cc/>

EBL in the Industry 4.0 Era

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Abstract: In this work, electron beam lithography (EBL) is presented as an important technology shaping the future of semiconductor manufacturing within the Industry 4.0 initiative. The EBL contribution to the ongoing evolution of electronic devices and technologies is discussed in the context of the Industry 4.0 initiative. Semiconductor technologies are foundational to the implementation of Industry 4.0, playing a critical role in enabling advanced computing, communication, sensing, and control systems. They facilitate the creation of intelligent, interconnected, and automated systems in the Industry 4.0 initiative. In addition, we present some of our results in the field of EBL research. The focus is on investigating the electron beam resist profile depending on various process parameters. The influence of electron beam lithography parameters, such as electron energy, resist thickness, and exposure dose, on the resist sidewall shape (profile) is studied for the PMMA (polymethyl-methacrylate) positive electron beam resist. Simulation results based on measurements along the resist profile depth are presented and discussed. The aim of this work is to develop and validate models for predicting and precisely controlling resist profiles in thick PMMA layers applied in the fabrication of electronic devices.

Keywords: SEMICONDUCTOR TECHNOLOGIES, ELECTRON BEAM LITHOGRAPHY, POLYMETHYL-METHACRYLATE PMMA

1. Introduction

For the implementation of Industry 4.0, semiconductor technologies are foundational to the digital transformation of manufacturing, because they facilitate the creation of intelligent, interconnected, and automated systems in the Industry 4.0 landscape. There are many semiconductor technologies applied in Industry 4.0: Integrated Circuits (ICs), Microprocessors and Microcontrollers, Sensors and Actuators, Field-Programmable Gate Arrays, Radio-Frequency Identification (RFID), Communication Technologies, Power Electronics, Memory Technologies, Analog and Mixed-Signal ICs, and System-on-Chip (SoC).

So, the innovation in smart manufacturing processes in Industry 4.0 depends on advances in semiconductor research and development. One of the important microfabrication techniques in semiconductor manufacturing is electron beam lithography (EBL), particularly in the production of integrated circuits (ICs). EBL can play a significant role in Industry 4.0 by contributing to the advancement of micro- and nanofabrication processes. EBL enables the miniaturization of components, contributing to the development of smaller and more efficient devices in various industries. The application of EBL in the fabrication of Microelectromechanical Systems (MEMS) devices and sensors, which are applied for the Internet of Things (IoT) and sensor networks, allows to get the required precision in these components.

Here are several ways in which EBL can be relevant to Industry 4.0: Miniaturization and Advanced Manufacturing, IC and MEMS, Additive Manufacturing and 3D Printing, Photonics and Optoelectronics, Research and Development of Advanced Materials. EBL is used in the fabrication and characterization of nanomaterials, contributing to the development of advanced materials with unique properties. These materials can find applications in various industries, including energy, healthcare, and electronics. EBL is used in the development of high-density data storage devices and advanced computing components.

EBL is used for mask and wafer patterning in the production of integrated circuits.

In addition, EBL can be integrated into additive manufacturing processes, contributing to the creation of high-resolution patterns. This integration can be beneficial for producing complex structures with fine details, which is relevant in Industry 4.0 applications.

Current State-of-the-art of EBL:

Electron beam lithography is one of the few “top-down” methods in nanotechnology and it is becoming increasingly widespread in R&D and small volume production due to its flexibility and mask-less nature, very high (sub-10 nm) resolution and accuracy and in many cases, EBL is the only possible alternative.

The ultimate resolution of electron beam lithography is not set by the resolution of electron optical systems, which can approach 0.1 nm, but by the resolution of the resist and by the subsequent fabrication process [1], therefore superior resists are crucial for the application of e-beam lithography and their performance determines the final results of the structures patterning.

Achieving sub-100 nm structures using EBL is a very sensitive process determined by various factors, starting with the choice of polymer resist material, and ending with the development process.

There are many parameters affecting the EBL process in a complex, interactive fashion. The objective of manipulating these parameters is to achieve a high resolution, high quality, high throughput results with large process windows to maximize yield and reproducibility.

The requirements for better control, linearity, and uniformity of critical dimensions of structures for various nanodevices call for thinner, more etching durable, and more sensitive electron beam resists. Commonly used electron beam resists are polymer materials such as poly-methyl-methacrylate (PMMA) [2]. In the last decade, there has been significant interest in the usage of an alternative inorganic electron beam resist hydrogen silsesquioxane (HSQ) with the chemical formula $[\text{HSiO}_{3/2}]_n$ [3]. HSQ (Dow Corning) is a negative tone resist which cross-links to form an insoluble silica-like structure. HSQ is used as a high-resolution resist with resolution down below 10 nm when using very small spot sizes and acceleration voltages of 100 keV [4, 5, 6, 7, 8]. On the other hand, as inorganic resist material, it is attractive material as a masking layer in reactive ion etching (RIE) because selectivity in RIE is higher in comparison with polymer resists. High-contrast and high-resolution patterning in HSQ has numerous potential applications. For instance, quantum dots, large-area patterning of dot structures for the fabrication of high-density bit patterned media, novel superconducting single-photon detectors [9, 10].

A powerful alternative in the throughput improving is Variable Shaped Beam (VSB) writing principle which can achieve considerably higher throughput than Gaussian spot beam tools. Variable shaped beam mask writers are currently the most used tools. With VSB tools, EBL has made several advances in micro- and nanodevices possible. An example is VSB lithography system is ZBA23 tool (Vistec Electron Beam, GmbH) tool [11]. In this tool, the rectangular shape size can be varied from 50 nm up to 3000 nm in steps of 50 nm. Accelerating voltage is optional: 20 keV or 40 keV. The writing field, which is defined by the maximum deflection range of the electromagnetic deflection system, is $3 \times 3 \text{ mm}^2$, divided into $0.2 \times 0.2 \text{ mm}^2$ sub-fields by the fast electrostatic deflection system.

The global approach in semiconductor industry is the multiple electron beam lithography program developed by IMS-Nanofabrication (Vienna, Austria). The main strength of PML2 lies in the fact that pattern transfer is realized using an array of several hundreds of thousands individually addressable electron beams,

thereby pushing the potential throughput from hours per wafer into the wafers per hour regime. PML2 is a multi-generational concept with resolution limits below 10 nm. The world's first multi-beam mask writer for 6-inch photomasks, the MBMW Alpha tool, was realized in February 2014 [12]. As of 2016, IMS has been serving the mask industry with MBMW-101 mask writer production tools for use with the 7-nanometer technology node. The fully developed Multi-Beam Mask Writer (MBMW) offers both precision and exceptionally-high productivity for mask technology nodes from 28 to 5 nanometers (nm).

Some examples of nanostructures prepared by electron beam lithography are demonstrated in Figure 1. Pillars in the negative electron beam resist HSQ XR-1541 (Dow co.) on the 350 nm thin TiO_2 layer are shown in Figure 1a. The diameter of the pillars is 40 nm, the thickness of the resist - 150 nm, exposure was done using a Gaussian beam at voltage of 30 kV using a nanolithography control system Elphy Quantum (Raith co.). Pillars were used as a mask in the etching of the TiO_2 thin film for the development of the gas sensor [13].

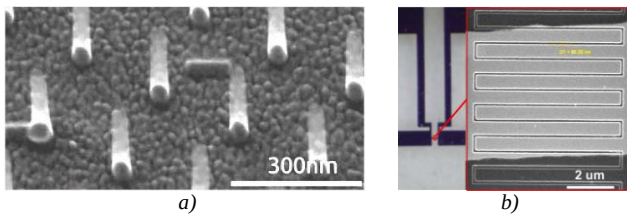


Fig. 1 a) Pillars in the negative e-beam resist HSQ XR-1541 on the TiO_2 layer with the diameter/height of 40/150 nm. (courtesy of Ivan Kostic, Inst. of Informatics SAS, Bratislava), b) 85 nm thick meander structure of gas sensor in Pt layer (courtesy of P. Durina, Comenius Univ. Bratislava).

Detail of gas sensor prototype fabricated by UV optical lithography, EBL and ion etching of a 20 nm platinum layer [14] is shown in Figure 1b. The meander structure was exposed using EBL VEGAII SBH (Tescan co.) in PMMA resist which served as a masking layer in Pt etching. The resulting linewidth was 85 nm. VEGAII SBH is equipped with a thermionic electron source (tungsten filament) with maximal voltage of 30 kV.

2. Results and discussion

2.1. Experiments

We present a study on the positive e-beam lithography resist PMMA for 30 keV electron energy. This work is focused on the dependence of PMMA resist profile and proximity effect on electron beam lithography process parameters. Experiments on a 600 nm thick layer of polymethyl-methacrylate (PMMA) [15] electron beam resist were carried out using EBL control system Elphy Quantum (Raith) installed on a scanning electron microscope Inspect F50 (FEI) with a field-emission cathode and Gaussian intensity distribution [16]. The exposures were performed at electron energy of 30 keV. PMMA was coated on silicon (Si) substrate. All exposure tests were immersed in the developer MIBK:IPA (1:3) for 60 seconds. A high-resolution scanning electron microscope Quanta 3D (FEI) was used for dimension measurements of PMMA resist profiles. A more detailed description of experiments was published in [17].

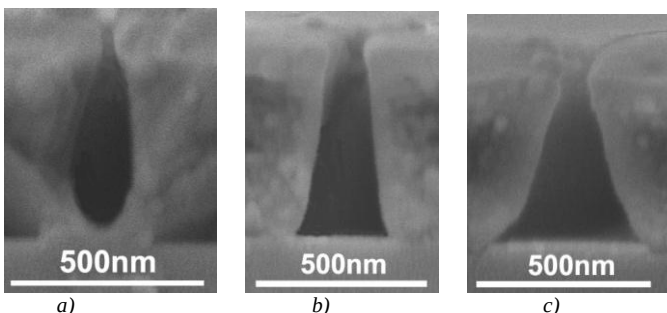


Fig. 2 Developed resist profiles at various exposure line doses for 600 nm

thick PMMA resist and 30 keV electron energy: a) $D = 1.78 \text{ nC/cm}$, b) $D = 17.70 \text{ nC/cm}$, and c) $D = 28.69 \text{ nC/cm}$.

The influence of various exposure doses on the profiles for 600 nm thick PMMA resist is demonstrated in Figure 2. The exposure dose is increased from left to right. Because of a single pixel line mode, the exposure line dose unit is expressed in nC/cm.

In case of 600 nm PMMA resist thickness and 30 keV (Figure 2), the linewidth at the top of PMMA resist is increased by a small value from 37.23 nm through 69.15 nm up to 85.11 nm for exposure doses of 1.78, 17.70, and 28.69 nC/cm, respectively. However, the linewidth at the bottom of PMMA resist is increased on remarkable value from nearly zero through 287.23 nm up to 437.10 nm, respectively. The dose of 1.78 nC/cm is the minimal value where the resist is developed down to the substrate.

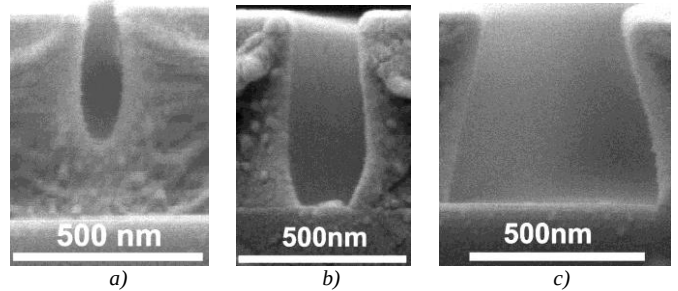


Fig. 3 Developed resist profiles at various exposure line doses D for 600 nm thick PMMA resist and 10 keV electron energy:

a) $D = 0.23 \text{ nC/cm}$, b) $D = 0.37 \text{ nC/cm}$, and c) $D = 1.14 \text{ nC/cm}$.

However, the sidewall shape is not linear but rounded. At higher dose, the sidewall shape becomes nearly linear in the main middle part of the resist depth, but the angle of side wall slope is increased with the increase of the exposure dose.

Similar observations are made for electron energy of 10 keV as seen in Figure 3 for various exposure line doses: $D = 0.23 \text{ nC/cm}$, 0.37 nC/cm , and 1.14 nC/cm .

2.2. Modeling and simulations

Figure 4 presents experimental contrast curves for: (1) a 1800-nm thick PMMA resist on a Si substrate for 30 keV electron energy; (2) a 1300-nm-thick PMMA resist on a Si substrate for 30 keV electron energy; (3) a 600-nm-thick PMMA resist on a Si substrate for 30 keV electron energy; (4) a 1800-nm-thick PMMA resist on a Si substrate for 10 keV electron energy; (5) a 1300-nm-thick PMMA resist on a Si substrate for 10 keV electron energy; (6) a 600-nm-thick PMMA resist on a Si substrate for 10 keV electron energy.

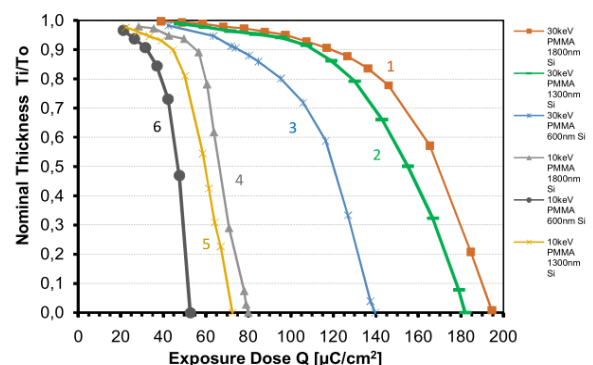


Fig. 4 Contrast curves for 600 nm and 1300 nm thick PMMA resist at various exposure doses, MIBK:IPA 1:3 developer, development time 60 s.

As seen, the PMMA resist shows a nonlinear development behaviour. Based on the residual resist thickness as a function of the development time, we calculated the solubility rates for MIBK:IPA 1:3 developer at different resist thicknesses (600 nm, 1300 nm, 1800 nm) when the exposure dose varied from $21.07 \mu\text{C/cm}^2$ to $80.0 \mu\text{C/cm}^2$ for electron energy of 10 keV, and when the exposure dose varied from $38.9 \mu\text{C/cm}^2$ to $194.6 \mu\text{C/cm}^2$ for 30 keV energy –

Figure 5. A low dissolution rate at low doses of e-beam exposure and a sharp increase of the resist removal at higher doses in the studied range has been observed.

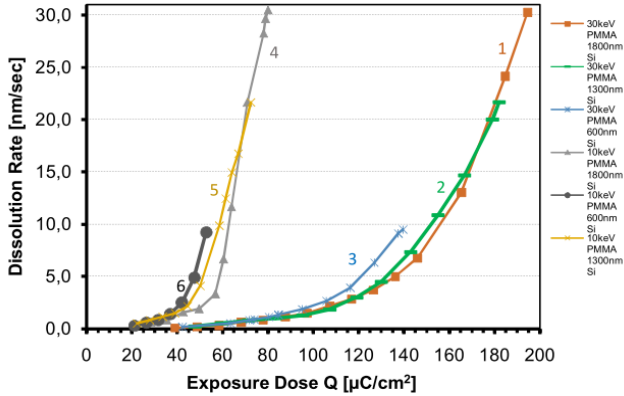


Fig. 5 Solubility rates for 600 and 1300 nm thick PMMA resist at various exposure doses for MIBK:IPA 1:3 developer, development time 60 s.

The proximity effect parameters are important for evaluation the electron scattering in the resist layer and substrate. Due to the large lateral scattering of the electrons, precise evaluation of the energy deposition function (EDF) in the resist layer is required for achieving high EBL resolution. By applying our Monte Carlo simulation tool and the methodology for approximation of EDF discrete data by analytical functions (a sum of two Gaussians) [18] the proximity effect parameters (β_f , β_b , η_E) have been calculated. Values of the characteristic widths of the forward (β_f) and the backward (β_b) scattering particles as well as the ratio of the energy depth dissipation of the backward scattering particles to that of the forward scattering particles (η_E) are determined and shown in Table 1. The proximity effect parameters' values are calculated at two characteristic depths in PMMA resist – at the resist surface and at the resist/substrate interface for the studied resist thicknesses (600 nm and 1300 nm PMMA) for 10 keV and 30 keV beam energy. The obtained results show that the higher e-beam energy reduces the backscattering from the substrate and the proximity effect is lower in regions near to the point of e-beam incidence as it is also seen in Figures 2, 3.

Table 1. Proximity effect parameters values for 10 keV and 30 keV.

E, keV	PMMA thickness, nm	Depth in the resist, nm	β_f μm	β_b μm	η_E
10	600	20	0.0089	0.607	0.908
		600	0.1486	5.536	0.089
30	600	20	0.0426	2.642	0.212
		600	0.0631	2.833	0.497

Based on performed experiments and measurements of the linewidth's sidewall and slope angles along the PMMA profile depth, regression models have been estimated [19]. Simulations for predicting and optimizing the profile shapes of the developed images in the resist for different EBL conditions (resist thicknesses and exposure doses) have been performed.

Figure 6 presents the calculated values of the sidewall slope angles (contour plots) of the developed images in PMMA in the range of 65 - 90 degrees. Based on the obtained results, suitable doses of exposure can be selected in order to obtain developed profiles with near to 90-degree sidewall slope angles (nearly vertical walls). The results show that at lower exposure doses and for thicker PMMA layers nearly vertical side walls of the image should be expected.

In Figure 7, contour plots of the half linewidths for 1800 nm PMMA resist thickness depending on the line exposure dose (for dose regions, where the expected slope angles are in the range of 69 - 90 degrees) are shown. Predicted developed profile in PMMA for the line doses of 40 nC/cm (Figure 7), is also presented and the

linewidth at the PMMA resist/substrate interface (bottom) is 245.96 nm and at the top is 47.76 nm (Figure 7).

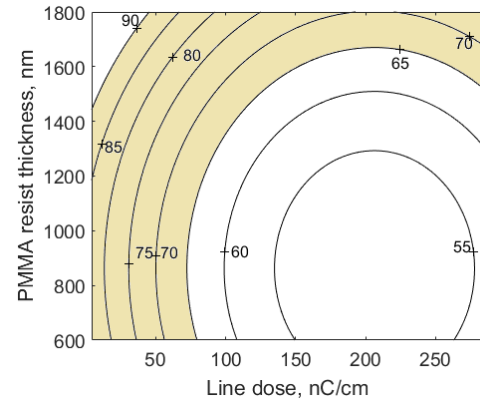


Fig. 6 Contour plots of the sidewall slope angle of the developed images in PMMA vs. the dose of exposure and PMMA thickness, 30 keV beam energy.

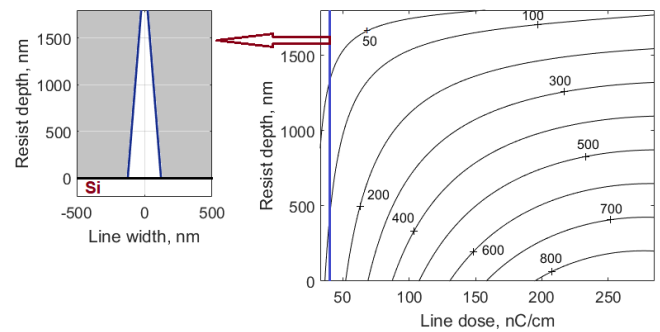


Fig. 7 Contour plots of the half linewidths for 1800 nm PMMA thickness as a function of the line dose and the resist depth and the corresponding developed profile for the line dose of 40 nC/cm.

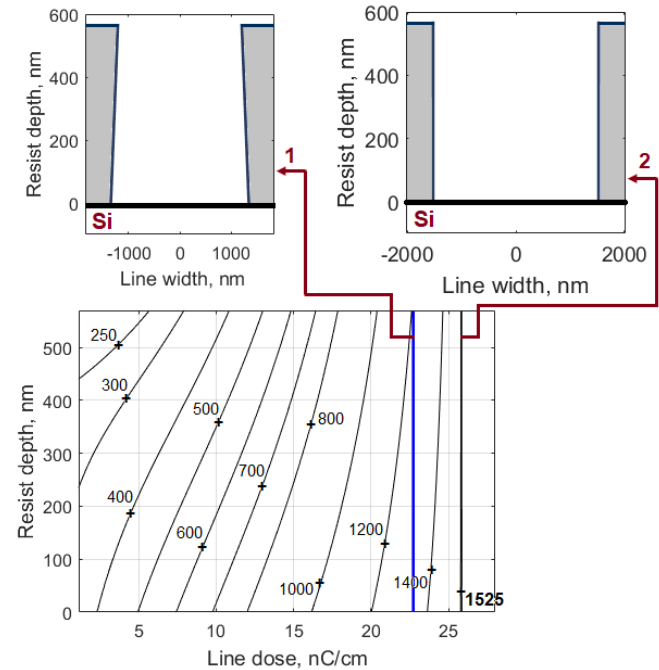


Fig. 8 Contour plots of the half linewidths for 600 nm PMMA thickness as a function of the line dose and the resist depth and the corresponding developed profiles for line doses of: 1 - 22.72 nC/cm, 2 - 25.84 nC/cm.

In Figure 8, contour plots of the half linewidths for 600 nm PMMA thickness and accelerating voltage of 10 keV as a function of the line dose and the resist depth are presented. The corresponding developed profiles for the line doses of 22.72 nC/cm and 25.84 nC/cm are also simulated and presented in these Figure.

It can be seen that at higher doses the profiles have near to vertical sidewalls and the line dose of 25.85 nC/cm is the optimal one for obtaining vertical sidewalls (Figure 8, profile 2).

3. Conclusions

In this paper, the critical role of EBL was introduced as one of advanced microfabrication techniques important for the realization of Industry 4.0 goals. Future developments and collaborations between EBL and other emerging technologies are important in the industrial landscape.

EBL boundaries are constantly shifting in terms of feature dimensions down to the range of nanometer units due to researchers' efforts to overcome various limiting factors in achieving maximum resolution such as electron beam cross-section, electron scattering, electron beam resist material, etc.

In semiconductor manufacturing, EBL is very slow for production, nevertheless, in last years, multiple electron beam lithography is developed as an alternative method for some limited applications. However, for photomasks fabrication, EBL is still the main technique. In the research, electron beam lithography is still a work horse of micro- and nanostructures fabrication despite of novel techniques are developed for the application in micro- and nanotechnology.

As an example of EBL research, we present a study on the positive e-beam lithography resist PMMA for 30 keV and 10 keV electron energy. The influences of exposure dose and resist thickness on the shape of the developed profiles in thick PMMA resist layers are studied experimentally and theoretically in order to achieve high-aspect-ratio of structures. Models for prediction and optimization of the geometry of the developed resist profiles in the PMMA resist are estimated. The results presented contribute to the knowledge on electron scattering in resist/substrate system in EBL for the case of field emission cathode and Gaussian intensity distribution and to development and approval of models and simulation tools for prediction and precise control of the obtained developed profiles in PMMA positive resist for Lift-off nanopatterning.

4. Acknowledgments

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<https://doi.org/10.1063/5.0067068>

Application of Blockchain for Hydrogen-Related Data from Internet of Thing Devices Equipped with Hydrogen Sensors

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 Institute of electronics, Bulgarian Academy of Science, Sofia, Bulgaria²
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Abstract: The Internet of Things (IoT) has seamlessly integrated more than a billion intelligent, interconnected devices into our world today, and is expected to accommodate soon hundreds of billions more such devices. This imminent proliferation heralds a profound transformation that stands to influence the electronics industry and many other sectors. Furthermore, integrating blockchain technology into IoT can impart genuine trust in the collected data. Hence, our research endeavors to harness this potential by applying it to hydrogen-related data, which are expected to be critical in realizing a carbon-neutral society.

Specifically, our attention is directed toward utilizing an initial blockchain system to securely store data obtained from IoT devices equipped with hydrogen sensors that can communicate through Sigfox technology.

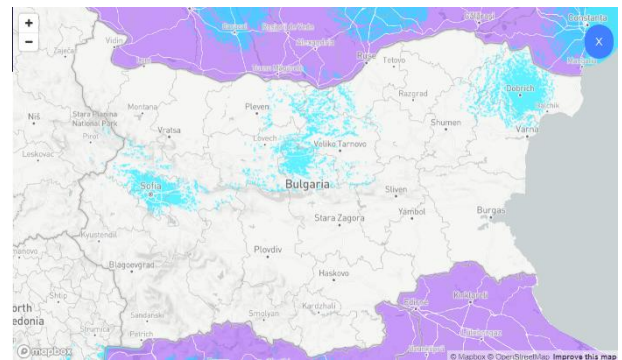
Keywords: HYDROGEN SENSOR, INTERNET OF THING, BLOCKCHAIN, SIGFOX, HASH FUNCTION

1. Introduction

Sigfox 0G technology is a Low-Power Wide-Area networking protocol owned by UnaBiz. It is designed to connect sensors and devices securely at low cost in the most energy-efficient way to enable Massive IoT (Fig. 1–3).

Since its inception in 2010, 0G technology has been adopted by 70+ national 0G network operators globally. The 0G operators own and commercialize the global 0G network in the respective countries that they operate in (Fig. 2).

Today, UnaBiz, the 0G operators, and over 800+ ecosystems of IoT players (chip manufacturers, device makers, solution providers, and system integrators) collaborate to provide the global 0G network as well as Massive IoT solutions and services to over 1,500+ B2B customers by connecting over 11 million devices.



(b)

Fig. 2 Europe (a) and Bulgaria (b) with 0G network coverage [2]

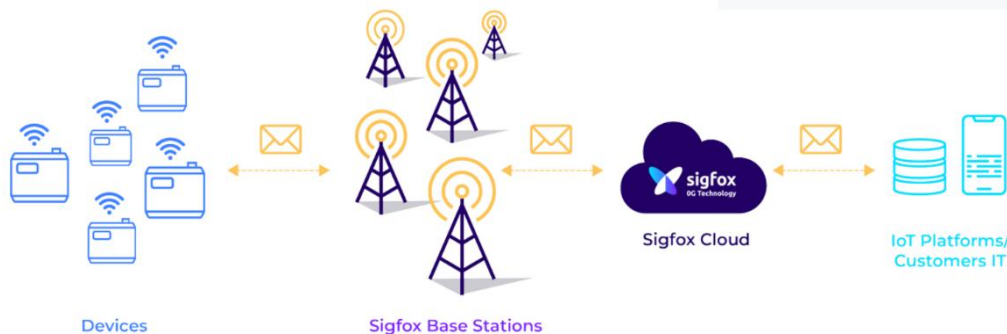
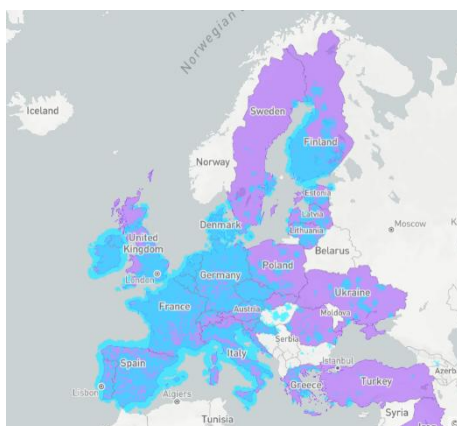


Fig. 1 Overview of Sigfox system [1]



(a)

THE 0G TECHNOLOGY



Autonomy

Extremely low-energy consumption, allowing years of battery life.



Simplicity

No configuration, connection request or signaling. Your device is up and running in minutes!



Cost efficiency

From the hardware to the network, every step is optimised to be as cost-effective as possible.



Small messages

No large assets or media allowed on the network, only small notifications: up to 12 bytes.



Complementarity

Sigfox oG technology can be used together with any other type of network, e.g.: Wi-Fi, Bluetooth, GPRS, NB-IoT, LoraWAN.

Fig. 3 Outline of the 0G technology [3]

The IoT has seamlessly woven together more than a billion intelligent, interconnected devices today, anticipating accommodating hundreds of billions more in the near future. This impending proliferation heralds a profound transformation that stands to influence not only the electronics industry but also a multitude of other sectors. Furthermore, the incorporation of blockchain technology into IoT has the potential to instill genuine trust in the data collected.

Hence, our research endeavors to harness this potential by applying it to hydrogen-related data, which are expected to be critical in realizing a carbon-neutral society.

In particular, we focus on using a preliminary blockchain system to securely store data derived from IoT devices equipped with hydrogen sensors capable of communicating via Sigfox technology.

2. Sigfox network

Sigfox provides an affordable, reliable, and energy-efficient solution for linking sensors and devices.

Through our dedicated radio-based network, we are committed to enable the efficient functioning of IoT. The Sigfox protocol emphasizes:

- **Energy Efficiency:** Minimal power consumption for extended battery life.
- **User-Friendly:** No complex setup or lengthy connection procedures—your device is operational within minutes.
- **Cost Optimization:** We streamline hardware and network operations for maximum cost-effectiveness.
- **Small Data:** Only small notifications, up to 12 bytes, are permitted on the network.
- **Versatility:** Sigfox can also serve as a complementary solution alongside other networks, such as Wi-Fi, Bluetooth, or GPRS, thanks to its affordability and ease of configuration.

3. Hydrogen gas sensor and measurement of its concentration

The MQ-8 gas sensor ((Fig. 4), which is manufactured by Zhengzhou Winsen Electronics Technology Co., Ltd, Zhengzhou, China utilizes SnO_2 as its sensitive material, exhibiting low conductivity in a clean-air environment. This sensor can measure hydrogen (H_2) gas in the concentration range of 100–1000 ppm. Users can transform the conductivity variations into a relevant output signal indicating gas concentration by employing a straightforward circuit. Our choice of the MQ-8 hydrogen sensor in this study is supported by these features.



Fig. 4 Photos of the hydrogen sensor (MQ-8) [4]

Basic Circuit

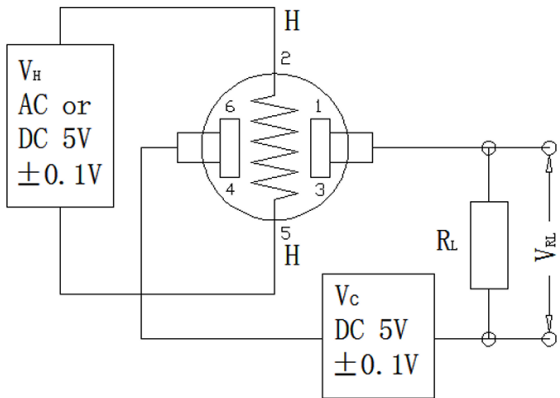


Fig. 5 MQ-8 test circuit [4]

Using the circuit in Fig. 5, we measured V_{RL} in the circuit to obtain the hydrogen concentration in the environment. The value of V_{RL} is used to calculate the sensor resistance. The graph's vertical axis represents the sensor's resistance ratio (R_s/R_0), whereas the horizontal axis indicates gas concentration. R_s denotes the resistance in various gas concentrations, and R_0 signifies the sensor's resistance in a clean-air environment. The resistance ratio of the sensor (R_s/R_0) can be corrected by considering concentration dependence (Fig. 6), temperature dependence (Fig. 7), and humidity dependence (Fig. 7). Therefore, it has been shown that the hydrogen concentration in the environment can be calculated using temperature, humidity, atmospheric pressure, voltage applied to the sensor, and hydrogen sensor voltage.

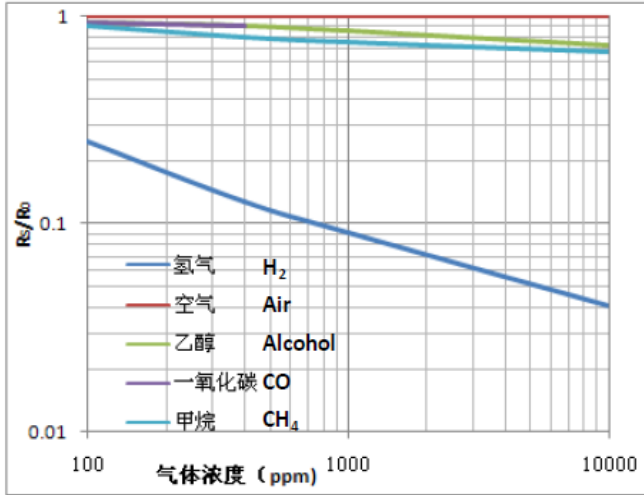


Fig. 6 Typical sensitive curve of MQ-8 [4]

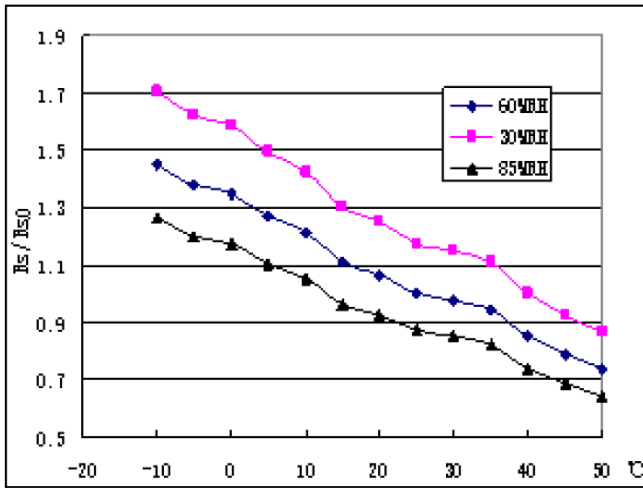


Fig. 7 Typical temperature humidity characteristics.

4. Data format and transfer method using Sigfox

Data from Sigfox IoT devices is a maximum of 12 bytes, and the data structure is as follows:

- Temperature integer: 2 bytes, four digits in hexadecimal
- Humidity integer: 2 bytes, four lines in hexadecimal
- Atmospheric pressure integer: 2 bytes, four digits in hexadecimal
- Sensor applied voltage: integer, 2 bytes, four digits in hexadecimal
- Hydrogen sensor voltage: integer, 2 bytes, four digits in hexadecimal.

In the remaining 2 bytes, the four digits of the hexadecimal hash SHA-256 are entered. These digits usually indicate the temperature, humidity, barometric pressure, sensor applied voltage, and hydrogen sensor voltage. Data on these same parameters are also transmitted in little-endian format. The sent data are displayed after decoding in Fig. 8.

Device 77200D - Messages

Time	Delay (s)	Seq Num	Data / Decoding
2023-10-29 17:11:45	< 1	415	20001400f8038813a2020000

Fig. 8 Message from the Sigfox device.

5. Data decoding and display

Device type UNABIZ_DevKit_80 - Callback edition

Callbacks

Type:

Channel:

Custom payload config: temp::int:16:little-endian humid::int:16:little-endian

URL syntax: http://host/path?id={device}&time={time}&key1={v1}

Available variables: device, time, station, data, rssi, seqNumber,

Custom variables: customData#temp, customData#humid, cust

Url pattern: https://api.thingspeak.com/update?api_key=UHV:

Use HTTP Method:

Fig. 9 Callback of the Sigfox device.

Using the Custom payload config of “temp::int:16: little-endian humid::int:16:little-endian press::int:16:little-endian x::int:16:little-endian y::int:16:little-endian z::int:16:little-endian” in the callback of the Sigfox device (Fig. 9), the parameters of temperature, humidity, atmospheric pressure, sensor applied voltage, and hydrogen sensor voltage were calculated. The H_2 concentration is estimated from the sensor resistance ratio (R_s/R_0) by considering concentration dependence (Fig. 6), temperature dependence (Fig. 7), and humidity dependence (Fig. 7). The results are shown in Fig. 10.

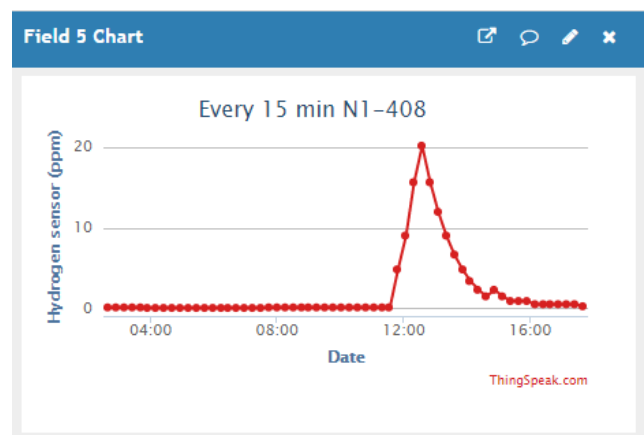


Fig. 10 Hydrogen concentration (ppm) estimated by the Sigfox device.

6. Blockchain

The Sigfox data comprised 10 bytes this time, and the maximum data size is 12 bytes, but there are still 2 bytes to spare.

Hence, when data are expressed in 24 hexadecimal digits, the parameters of temperature, humidity, atmospheric pressure, sensor voltage, and hydrogen voltage are properly indicated. Here, each set of 4-digit hexadecimal digits is used so that it can be used for other purposes. A hash of the transferred data was taken simultaneously with these four digits and appended to the end of the data (Fig. 11).

References

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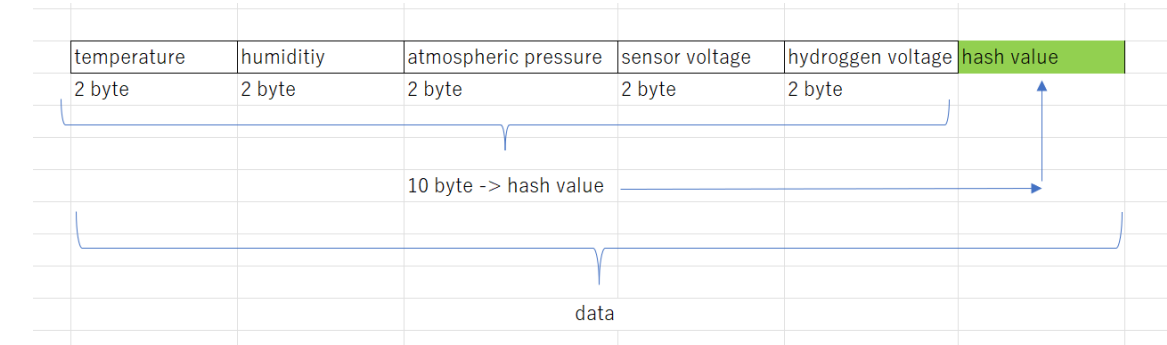


Fig. 11 Structure of data using Sigfox.

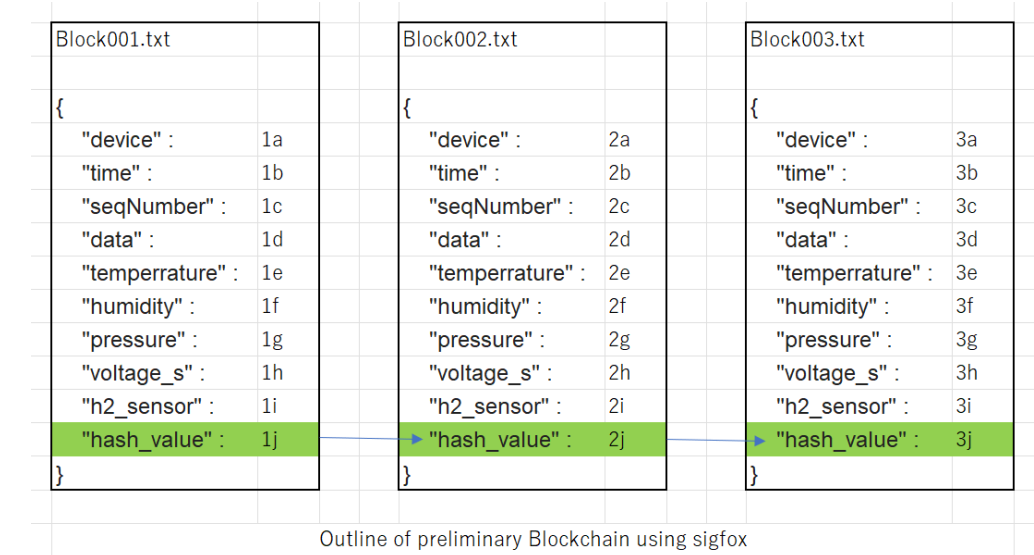


Fig. 12 Hashing performed using a general blockchain

Part of the transmitted data can now be hashed (Fig. 11). We performed hashing using a general blockchain (Fig. 12).

Thus, these values suggest that data reliability during data transmission could be significantly improved by using double hash values for data and files.

7. Summary

The IoT has seamlessly woven together more than a billion intelligent, interconnected devices today, anticipating accommodating hundreds of billions more in the near future. This imminent proliferation heralds a profound transformation that stands to influence the electronics industry and many other sectors.

Furthermore, integrating blockchain technology with IoT promises to instill genuine trust in the data collected. Hence, our research is dedicated to harnessing this potential, specifically in the context of hydrogen-related data, which play a pivotal role in realizing a carbon-neutral society. One suggestion for enhancing data reliability involves using double hash values for data and files during data transmission.

Application of perfect binary lattices for signal generation in multi-channel communication systems

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Abstract: In multichannel data transmission systems noise-like signals, generated on the basis of derivatives of the Walsh function are used. The article examines the correlation properties of derivatives of Walsh functions with generating functions in the form of perfect binary lattices, which make it possible to provide the necessary data synchronization when receiving signals. Also, it was justified the advantage of using these signals in the development of CDMA systems in order to reduce the interference level of multiple access and to protect against unauthorized access.

Keywords: CDMA SYSTEMS, NOISE-LIKE SIGNAL, PERFECT BINARY LATTICE, WALSH FUNCTION DERIVATIVE, GENERATING FUNCTION.

1. Introduction

The main method of communication and navigation in the modern world is wireless information transmission. At the same time, the number of users of various communication networks is steadily growing, which requires the creation of a large number of independent channels within one communication system. In this regard, it is necessary to use the best methods of organizing communication with limited frequency resources and growing demands on the quality and quantity of transmitted information. Under these conditions, the most efficient systems are Code Division Multiple Access (CDMA) [1, 2, 3, 5, 6].

One of the quality indicators of transmitted signals is its noise immunity. The signal energy is the main parameter for its noise immunity, that is, the greater this value, the lower the signal-to-noise ratio is needed for reception with acceptable number of errors. Consequently, noise-resistant reception is possible when the required energy of the useful signal is provided in the optimal receiver by:

- increasing signal processing time;
- increasing the amplitude of the signal (the magnitude of its spectral components);
- expansion of the signal spectrum.

The first method leads to a decrease in the resulting data transfer rate, and the second requires an increase in transmitter power, which are not acceptable in mobile communications. The third method involves the use of signals with wide bands of occupied frequencies, much larger than the band of the information signal. Such properties have noise-like signals (NLS). This explains the high noise immunity and secrecy of CDMA communication systems compared to other standards (FDMA, TDMA, FDMA/TDMA, etc.).

The signal energy in a CDMA receiver is brought to the required level not by increasing the power of base station transmitters, but by summing up a huge number of low-power spectral components of the received signal. This makes such a signal not only difficult to decode, but also difficult to detect.

It should be noted that the information itself can be introduced into the wideband signal in several ways. For example, a narrowband signal is multiplied by a pseudo-random sequence (PRS) with period T, consisting of N bits of each duration τ_0 . In this case, the NLS base is numerically equal to the number of PRS elements. [1, 2, 5, 6].

2. Theoretical preconditions

The reception of the NLS, as, indeed, of any other signals, is carried out using optimal receivers that minimize the probability of error. It is known that the structure of the optimal receiver depends on the type of modulation, as well as on how many signal parameters are known at the receiving point (coherent or non-coherent reception, etc.). However, in any case, the optimal receiver includes a correlator or a matched filter and a solver.

The receiver compares the received code sequence with its exact copy stored in memory. When it detects a correlation between them, it switches to the information receiving mode, establishes synchronization, and starts the operation of decoding useful information. Any partial correlations can lead to false triggering and disruption of the receiver, that's why the code sequence must have good correlation properties.

The dominant role in choosing the type of PRS for the formation of NLS in data transmission systems is played, first of all, by the mutual and autocorrelation characteristics of the signal ensemble, its volume, and the ease of implementation of devices for generating and "compressing" (convolution) signals in the receiver [1, 3, 4 - 6, 11].

It is known that for the correct processing of input signals, the receiving and transmitting devices must work synchronously and in phase. Synchronization of the receiving device is carried out using a correlator that calculates the ACF (auto-correlation function) of the input signal, which for discrete signals is calculated by the formula:

$$R_u(n) = \sum_{j=-\infty}^{\infty} u_j u_{j-n} \quad (1)$$

where n is an integer, positive, negative or zero.

There are periodic (PACF) and aperiodic (AACF) auto-correlation characteristics of signals.

Discrete signals with the best ACF structure include Barker signals (codes), M-sequences [1, 4, 6].

Recently, in the native and foreign literature, much attention has been paid to the application of perfect binary lattices (PBL) [2, 8, 9] in various radio engineering problems, for example:

- for antenna aperture synthesis;
- to build perfect time-frequency codes;
- to obtain noise-like signals for data transmission systems.

A perfect binary lattice is a two-dimensional matrix sequence:

$$H(N) = \left\| h_{i,j} \right\|, i, j = \overline{0, N-1}, h_{i,j} \in \{-1, 1\}, \quad (2)$$

which has an ideal two-dimensional periodic auto-correlation function, the elements of which are equal to:

$$R(m, n) = PACF(m, n) = \sum_{i=0}^{N-1} \sum_{j=0}^{N-1} h_{i,j} h_{i+m, j+n} = \begin{cases} N^2, & \text{at } m = n = 0 \\ 0, & \text{with other } m \text{ and } n \end{cases} \quad (3)$$

where $m, n = \overline{0, N-1}$.

In accordance with the rules for the formation of perfect binary lattices, which are set out in [2], a perfect binary lattice of order $N = 8$ with a dimension of eight symbols, shown in Fig.1, is constructed.

$$C = \begin{bmatrix} C_1 = + & - & - & - & + & + & - & + \\ C_2 = - & - & - & - & - & + & - & + \\ C_3 = + & - & + & + & + & + & + & - \\ C_4 = - & + & + & + & - & - & + & - \\ C_5 = + & - & - & - & + & + & - & + \\ C_6 = + & + & + & + & + & - & + & - \\ C_7 = + & - & + & + & + & + & + & - \\ C_8 = + & - & - & - & + & + & - & + \end{bmatrix}$$

Fig. 1 Ensemble of perfect binary lattices

Fig.1 shows that the sequences C_1 , C_5 and C_8 coincide with each other, as well as the sequences C_3 and C_7 . And the sequences C_1 and C_4 , C_2 and C_6 , C_4 and C_5 , C_4 and C_8 are inverse to each other, i.e., they have the same correlation characteristics.

3. Experimental data

Consider the correlation characteristics of some of the sequences of perfect binary lattices that are presented in Fig.1.

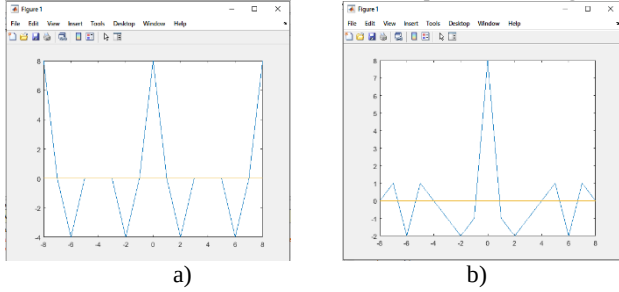


Fig. 2 PACF (a) and AACF (b) sequences C_1 , C_4 , C_5 and C_8 of perfect binary lattices

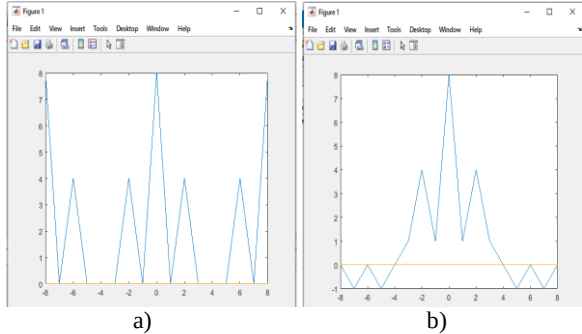


Fig. 3 PACF (a) and AACF (b) sequences C_1 , C_4 , C_5 and C_8 of perfect binary lattices

From Fig.2 and Fig.3 it follows that the correlation characteristics of the sequences C_1 , C_2 , C_4 , C_6 , C_8 have correlation characteristics somewhat worse than those of the Barker codes and M sequences - the suppression coefficient (the ratio of the amplitude of the main ACF lobe to the maximum amplitude of the side lobes) is equal to only 2 for all sequences.

However, the power of binary perfect lattices is much greater than that of Barker codes and M-sequences, and such a suppression coefficient makes it possible to reliably distinguish such signals on the background of noise.

In data transmission systems with division of channels (signals) according to the waveform, all subscribers can work simultaneously in the same frequency band, i.e., signal spectra overlap. In order for the signals (channels) not to influence each other, they must be orthogonal. In this case, the cross - correlation function (CCF) of two discrete signals, equal to their scalar product, is equal to zero:

$$R_{uv}(n) = \sum_{j=-\infty}^{\infty} u_j v_{j-n} = 0. \quad (4)$$

However, based on the generalized Rayleigh formula, the scalar product of two signals in the time domain, up to a factor of $1/2\pi$, is equal to the scalar product of their spectral densities:

$$(u, v) = R_{uv}(n) = \frac{1}{2\pi} (U(\omega), V(\omega)) = 0. \quad (5)$$

The zero CCF means that two signals are orthogonal for any τ only if their spectra do not overlap. However, in multi-channel code division systems, this cannot be achieved, since all subscribers operate in the same band. The consequence of this is the occurrence of multiple access interference, i.e., non-zero response of the receiver of the k -th user to the signals of other subscribers, and the level of this interference depends on the number of subscribers simultaneously working at the moment [6].

Therefore, it is necessary to choose such code sequences for which the CCF is minimal. Moreover, to solve the reception problem, only the correlation properties of the signal are important, and not their shape.

Walsh functions [7] can be attributed to discrete signals with the best structure of the cross-correlation function. The number of distinct functions in the Walsh system is $N = 2^m$, where m is an integer. Walsh functions take only two values: +1 and -1, which is a useful property when building circuits on binary digital elements.

The orthogonal system, which is most often used in multichannel code division systems, is the Walsh-Hadamard system (matrix) of order $N = 2^k$, k is an integer, which is determined by the recursive rule:

$$W_{2N} = \begin{bmatrix} W_N & W_N \\ W_N & -W_N \end{bmatrix}, \quad (6)$$

where W_N is the Walsh-Hadamard matrix of order N , assuming $W_1 = 1$, or in the signed form $W_1 = +$.

Should be noted, that a feature of orthogonal codes - the orthogonality property of these codes is satisfied only at the "point", i.e., in the absence of time shifts. In real conditions, this property of orthogonality is violated, which in turn leads to an increase in the level of multiple access interference and the appearance of errors in the processing of input data. Therefore, various methods are used to eliminate these shortcomings.

In order to improve the correlation properties (ACF and CCF) of Walsh functions, the so-called derivative systems of signals are often built [2, 6, 11].

A derivative signal is a signal that is obtained as a result of element-by-element (symbol-by-symbol) multiplication of two signals - the original and generating one. A system composed of derivative signals is called a derivative.

As a generating signal, such a signal is chosen so that the derivative system has good correlation properties. As a rule, this is a signal with a good ACF. Let us consider the correlation properties of derivatives of Walsh functions, if we take a matrix of **perfect binary lattices** (Fig. 1) as **generating functions**, which is multiplied row by row by the corresponding Walsh matrix (Fig. 4).

$$W_{\text{deriv}} = \begin{bmatrix} + & - & - & - & + & + & - & + \\ - & + & - & + & - & - & - & - \\ + & - & - & - & + & + & - & + \\ - & - & - & + & - & + & - & - \\ + & - & - & - & - & - & + & - \\ + & - & + & - & - & - & - & - \\ + & - & + & - & - & - & - & - \\ + & + & + & - & - & + & - & - \end{bmatrix}$$

Fig. 4 Derivative matrix of Walsh functions with perfect binary lattices as generating functions

The correlation characteristics of some sequences from the derivative matrix of Walsh functions (for example, 1st and 4th) were investigated in the Matlab environment. The results of the analysis of aperiodic (AACF) and periodic (PACF) autocorrelation

functions of the selected derivatives of the Walsh functions with perfect binary lattices as generating functions are presented in Fig.5 and Fig.6, respectively.

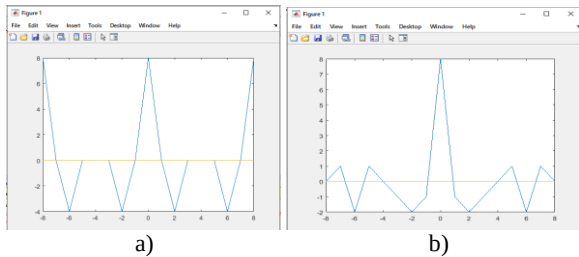


Fig. 5 PACF (a) and AACF (b) of the 1st derivative of the Walsh function with perfect binary lattices as generating functions

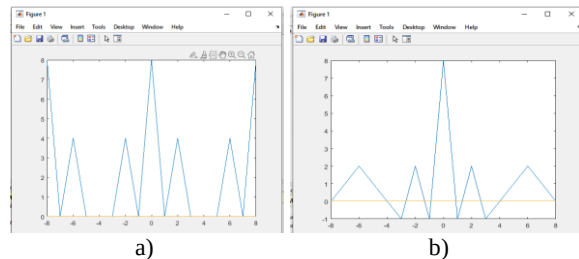


Fig. 6 PACF (a) and AACF (b) of the 4th derivative of the Walsh function with perfect binary lattices as generating functions

From Fig.5 and Fig.6 it follows that the characteristics of the autocorrelation functions of the derivatives of the Walsh functions are similar to the autocorrelation characteristics of **perfect binary lattices** and coincide with the conclusions made above.

As noted above, for multichannel systems with channel division by waveform, to reduce the interference of multiple access, the signals used in such systems must have certain cross-correlation characteristics.

Let us consider the cross-correlation characteristic of the 1st and 4th derivatives of the Walsh function, which were studied above (Fig. 7).

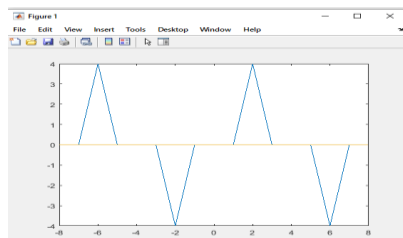


Fig. 7 CCF of the 1st and 4th derivatives of the Walsh functions with perfect binary lattices as generating functions

As can be seen from the CCF plot (Fig. 7), the considered derivatives of the Walsh function have satisfactory mutual correlation properties - the characteristic is more or less uniform with the same level of outliers (± 4). The considered derivatives of the Walsh function with **perfect binary lattices** as generating functions can be used in code division systems with the use of decision devices that do not respond to CCF emissions within the specified limits.

4. Conclusion

An analysis of the correlation properties of the studied broadband signals based on the derivatives of the Walsh functions with generating functions in the form of **perfect binary lattices** allows us to draw the following conclusions:

1. The correlation characteristics of Walsh functions that are orthonormal have good cross-correlation functions - the cross-correlation function between two different Walsh functions is zero. However, these functions have such properties only at a

point (at zero shift). In real conditions, especially with multipath propagation, orthogonality is violated and the cross-correlation function of these functions is nonzero. This leads to an increase in the level of interference of multiple access and to errors in the separation of signals (channels).

2. The correlation properties of derivative Walsh functions with generating functions in the form of **perfect binary lattices** have much better correlation characteristics than the original Walsh functions.
3. The derivatives of the Walsh function ($L = 8$ bits) have a large amplitude of the central peak of the ACF, equal to the length of the sequence, but the amplitude of the side lobes slightly increases. However, the suppression factor is equal to 2 for all sequences. This makes it possible to reliably distinguish such signals on the background of interference and ensure reliable synchronization of receiving devices.
4. The large length of the spreading code based on the derivative of the Walsh functions allows:
 - spreading the signal energy over the spectrum,
 - increasing the noise immunity of the system,
 - providing good protection against unauthorized access,
 - improving electromagnetic compatibility with neighboring radio systems.
5. When using the derivatives of the Walsh functions, it is necessary to take into account the increase in the level of the side lobes of the ACF and emissions of the VCF, i.e., take special measures to improve reception synchronization and eliminate the impact on channel separation when the level of multiple access interference increases.

The obtained results can be used in the development of broadband communication systems and information transmission systems with protection from unauthorized access.

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Overview of Generative AI Models in the Software Industry

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Abstract: Generative AI models have started to transform the software industry, driving innovation, and automating tasks previously deemed complex. This overview delves into the evolution, applications, and potential of these models, highlighting their capability to create novel content, enhance software development processes, and forecast industry trends. As these models continue to mature, the software industry stands on the cusp of a redefined future where human-machine collaboration will shape ground-breaking advancements.

Keywords: ARTIFICIAL INTELLIGENCE, GENERATIVE AI, LARGE LANGUAGE MODELS, SOFTWARE INDUSTRY INNOVATION, AI APPLICATIONS IN SOFTWARE INDUSTRY, SOFTWARE ENGINEERING, CHATGPT, GITHUB COPILOT

1. Introduction

AI is about to completely change how you use computers and upend the software industry
Bill Gates [1]

The arrival of Generative Artificial Intelligence (GenAI) has started a new phase in the software industry, changing the way technology is created and used. This type of AI, which can generate everything from code to digital art, does more than just automate simple tasks. It represents a major change in both the creative and analytical sides of software development.

Recent advances in GenAI have led to the creation of tools capable of devising innovative solutions to challenging problems, tasks traditionally handled by human intellect. These models, which learn and copy patterns from large datasets and open-source code repositories, can now do coding tasks, create complex algorithms, and more, greatly assisting developers in their day-to-day work.

This overview aims to provide an insight into GenAI's role in the software industry. We'll look at its development over time, its various uses in the software industry, and the major achievements it has brought to the field. In-depth case studies will provide examples of GenAI at work by evaluating the two most popular solutions nowadays: ChatGPT [2] and GitHub Copilot [3]. We'll also discuss the challenges and ethical issues it raises, along with predictions about its future impact.

This introduction is the beginning of a journey into GenAI, highlighting its significant influence on software development and the new paths it's paving for collaboration of developers and AI.

2. Evolution of Generative AI

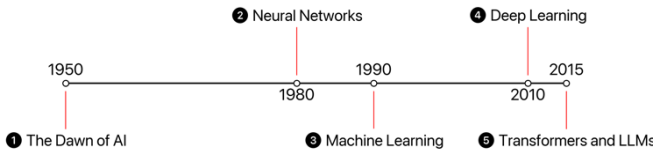


Fig. 1 Generative AI timeline

2.1. The Dawn of AI (1950-1980)

The history of GenAI can be traced back to the 1950s, with the development of Hidden Markov Models (HMMs) and Gaussian Mixture Models (GMMs). These early systems used rule-based reasoning to solve specific problems for generating sequential data like speech and time series. However, the lack of computing power needed by the algorithms and limited data sets available for training imposed significant constraints on their effectiveness and scope, slowing the progress in the field during its early years [4].

2.2. Neural Networks (1980-1990)

In this period, rule-based and expert systems got better, with advancements in how they represented knowledge and made inferences. At the same time, neural networks, modeled after the human brain, became popular in the 1980s. Key researchers like Geoffrey Hinton and Yann LeCun made important contributions to these networks, which are now a crucial part of GenAI [5].

2.3. Machine Learning (1990-2010)

Machine learning methods such as decision trees, support vector machines, and Bayesian networks gained prominence, forming the foundation for GenAI. These techniques enhanced abilities in pattern recognition and predictive analysis.

2.4. Deep Learning (2010-2015)

The emergence of deep learning marked a significant advancement in the field, leading to a paradigm shift towards deep neural networks. The creative power of GenAI is thanks to a specific type of neural network developed by Ian Goodfellow and his colleagues in 2014 and called a Generative Adversarial Network (GAN). GANs introduced a new paradigm for training models by using a two-network adversarial framework - a generator and a discriminator - which compete to improve the quality of the generated data.

2.5. Transformers and LLMs (2015-now)

Transformers, first presented in the influential 2017 paper "Attention Is All You Need" by Vaswani and colleagues [6], have evolved into a fundamental component for numerous advanced GenAI models. They changed how machines process text, making them understand and interpret it more accurately. Transformers use self-attention mechanisms to focus on important words in a sentence, improving context and meaning understanding. They're crucial in Large Language Models (LLMs) like GPT-4, handling huge datasets to produce text that's coherent and relevant.

ChatGPT, a renowned member of the GPT model family, achieved a remarkable milestone by reaching 100 million users in just two months, 4.5 times faster than TikTok [5].

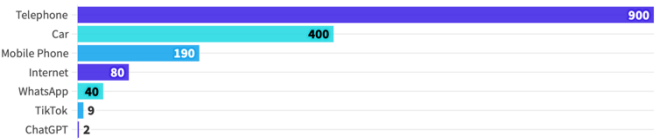


Fig. 2 Time to reach 100 million users for different technologies (in months)

The field of generative AI continues to evolve rapidly, with ongoing research and development leading to more sophisticated and diverse applications, including more ethically and socially aware AI instruments.

3. Applications of Generative AI in the Software Industry

GenAI has the potential to significantly improve software productivity by automating tasks, enhancing creativity, improving accuracy and efficiency, and streamlining development processes [7].

Developers no longer use big offline libraries like MSDN; instead, searching online on sites like StackOverflow or Google is now a part of their daily job. This approach has moved away from the old mindset of wanting to create everything from scratch. Nowadays, when developers are unsure about coding, they quickly look for answers on the internet.

ChatGPT and GitHub Copilot have taken this trend to new heights. Now, AI can assist you during coding sessions in a manner akin to real-life pair programming.

Empirical research involving over 40 McKinsey developers across the United States and Asia, engaging in tasks like code generation, refactoring, and documentation shows that software developers were able to complete tasks up to twice as fast when using AI-powered tools [8].

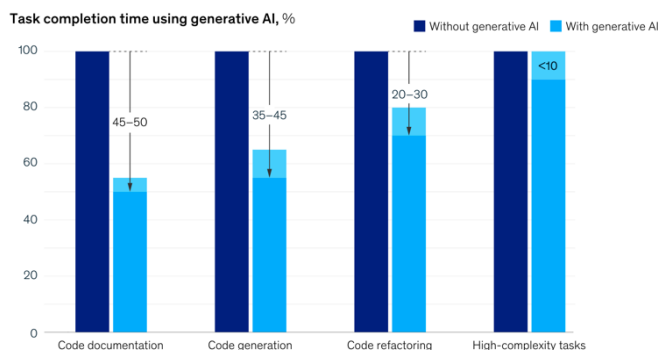


Fig. 3 Task completion time with and without GenAI

This research underscores the transformative potential of GenAI in software development while highlighting the need for a balanced approach that leverages both technological tools and human expertise.

4. In-Depth Case Studies

To understand how GenAI is changing software development, let's examine two key implementations: ChatGPT and GitHub Copilot. These tools show the power and potential of AI in helping developers write code, solve problems, and learn. By exploring ChatGPT and GitHub Copilot, we can see how AI is not just a futuristic concept but a practical tool in today's software engineering. Let's dive into each of these cases to see how they work and what they offer to the world of coding [9]–[12].

4.1. ChatGPT

Overview:

- **Developer:** OpenAI
- **Release Date:** November 2022
- **Purpose:** ChatGPT is designed as a conversational agent, utilizing advanced natural language processing and generation capabilities.

Technology:

- **Foundation:** Based on the GPT (Generative Pre-trained Transformer) architecture.
- **Working Principle:** It employs deep learning techniques, specifically transformer models, to understand and generate human-like text.

- **Key Features:** Autoregressive language model, meaning it generates text by predicting the next word in a sequence given all the previous words.

Applications in Software Development:

- **Code Writing and Assistance:** Provides suggestions and writes code snippets.
- **Debugging:** Helps in identifying and suggesting fixes for programming errors.
- **Documentation:** Assists in generating documentation for code.

Limitations:

- **Accuracy:** Sometimes generates incorrect or misleading information.
- **Context Understanding:** Limited in understanding complex software development contexts.

4.2. GitHub Copilot

Overview:

- **Developer:** GitHub in collaboration with OpenAI
- **Release Date:** June 2021
- **Purpose:** GitHub Copilot is an AI pair programming tool that helps in writing code and learns from the user's coding style.

Technology:

- **Foundation:** Built on the Codex model, a descendant of GPT-3, specifically trained on publicly available code.
- **Working Principle:** Analyzes existing code and comments to suggest individual lines or whole functions.
- **Key Features:** Ability to understand code in a broader context, supports multiple programming languages.

Applications in Software Development:

- **Automated Code Generation:** Suggests code completions and snippets.
- **Refactoring Assistance:** Helps in optimizing and restructuring existing code.
- **Learning Tool:** Adapts to user's coding style, providing personalized code suggestions.

Limitations:

- **Code Quality:** Suggestions may not always align with best practices or be the most efficient.
- **Dependency:** Can lead to over-reliance on automated tools, potentially reducing learning and problem-solving skills.

In comparison, **ChatGPT** focuses more on general language processing, including code, while **GitHub Copilot** is tailored specifically for coding tasks. Both are groundbreaking in their respective domains, pushing the boundaries of how AI can assist in software development. Nevertheless, it's crucial to view them as augmentative tools that enhance development processes, rather than substitution for the developer.

5. Challenges, Ethical Considerations, and Future Trends

Correctness: Relying on AI tools for tasks where you cannot determine the correct answer or how to verify it can lead to complications and pitfalls. For software development, it means that human supervision and intervention is necessary, such as reviews. Creativity and the capability to detect defects are the most important characteristics that distinguish you and your code from AI [7], [13].

Transparency and Explainability: GenAI models often work like a "black box" - it's not clear how they make decisions. This is a problem in situations where mistakes can be very costly, like in

healthcare or finance software. It's important to create AI models that are easier to understand, systems that can explain their decisions in a way that people can easily follow, ensuring they are reliable and trustworthy.

Copyright: GenAI presents challenges for intellectual property and copyright. The legal aspects of content created by GenAI, which is based on works from original creators, are not yet well-defined. This includes concerns about copyright violations, using unlicensed content in training data, and determining who owns the generated content. Since these issues are new, legislators are currently working on setting clear rules for how existing intellectual property laws apply to GenAI.

Economy: In a world of GenAI and low code, it's hard to imagine a future where software engineers are as highly paid as today. Jobs like programming will change. Developers will need to learn new things, like making AI-made software better, helping machines learn, and figuring out AI actions that don't make sense [14].

Dependency and Skill Degradation: Over-reliance on AI tools can lead to a degradation of human skills. As AI systems take over more tasks, there's a risk that human workers may lose the ability to perform these tasks themselves, which could be problematic in situations where AI assistance is unavailable or fails.

6. Conclusion and Research Directions

This paper provided an overview of GenAI models in the software industry, highlighting their evolution, capabilities, and the transformative impact they have had on various aspects of software development. From automating routine coding tasks to enhancing creative processes, models like ChatGPT and GitHub Copilot have demonstrated significant potential.

We also addressed the ethical considerations and challenges, such as correctness of generated code and the need for responsible AI practices, which are critical to ensure that these technologies contribute positively to the industry.

Future research directions:

- **Personalization:** Improve how AI models adapt to individual developer style and project needs.
- **Trustworthy and Reliability:** Focus on developing models that offer transparent and understandable explanations for their decisions, thereby boosting their reliability and trustworthiness for software developers.
- **Technology Integration:** Explore how GenAI can work with emerging technologies like quantum computing and blockchain.
- **Security Enhancements:** Focus on stronger security to prevent vulnerabilities in AI-generated code.
- **Economic and Organizational Impact:** Study how AI affects costs, workforce dynamics, and productivity in the software industry.
- **Sustainability:** Research the long-term environmental and resource implications of using GenAI.

By addressing these research directions, we can harness the full potential of GenAI models while mitigating risks and ensuring their beneficial integration into the software industry.

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Application of open ai and cognitive digital twins in Industry 5.0

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Abstract: Industry 5.0 is the production model based on the concept of how people and machines can work together. Modern industry is focusing on collaboration between people, robots, and intelligent machines with the help of AI. The design and implementation of solutions, based on Industry 5.0 brings a new level with the latest achievements in Artificial Intelligence and especially the Generative AI, realized on top of the Open AI.

This paper focuses on implementing modern automation with the help of Open AI as a new concept to use AI as a SaaS, integrated with smart machines and robots, helping them to work in a human-like way. The research overviews the use cases and proposes a framework to build a smart solution based on Generative AI and cognitive robots, where integration between SaaS AI and smart machines is based on Cognitive Digital Twins. Research results also include prototypes of cognitive digital twins and its integration with intelligent machines.

Keywords: OPENAI, CHATGPT, GENERATIVE AI, COGNITIVE DIGITAL TWIN, IOT, INDUSTRY 5.0, AI IOT

1. Introduction

ChatGPT (Chat Generative Pre-Trained Transformer) is one of the trending technologies in modern Artificial Intelligence (AI), and experts in this area expect to have a very high impact on the industry shortly.

The latest version of ChatGPT – GPT-4 has improved in many areas, providing a better understanding of the context and a more accurate analysis. Generative AI and ChatGPT have applications in different areas to generate human-like content quickly in various business domains in the modern industry.

This research gives an overview of the application of Generative AI, particularly ChatGPT, in modern, human-friendly manufacturing as one of the leading technologies to implement Industry 5.0-compliant solutions.

The paper analyzes options to use Generative AI together with another essential for modern analysis technology – Digital Twins in two different aspects:

1. To design and build Industry 5.0 systems for manufacturing
2. To implement Cognitive intelligent machines (smart robots) based on Generative AI and Cognitive Digital Twins,

Industry 5.0 brings a new focus to industrial solutions around better and easier communication between humans and intelligent machines. "Industry 5.0 advancements and is, by definition, comprised of nine critical "pillars."

- Additive manufacturing
- Augmented reality
- Autonomous robots
- Big Data and analytics
- Cloud connectivity
- Cybersecurity
- Horizontal and vertical system integration
- The Internet of Things (IoT)
- Simulation and digital twins[1].

This article considers the role of Generative AI, particularly OpenAI services, in creating self-learning intelligent machines. The proposed concept is based on Digital Twins (TD) as an integration layer that makes applying AI and analytics more formally possible.

The main goal of the research is to propose a concept for industrial solutions with self-learning intelligent machines based on Generative AI and Digital Twins. There are several technologies related to most of the solutions for predictive analytics that are considered in the current research:

- Internet of Things
- Digital Twins
- Generative AI (with a focus on OpenAI using GPT models)

The paper is focuses on analyzing options to use the latest GPT models offered by OpenAI and ChatGPT together with Digital Twins to generate easy to communicate and self-learning machines for the manufacturing.

Industry 5.0 brings several challenges:

- How can propose a human friendly interaction between humans and machines?
- How can make self-improved (cognitive) intelligent machines (robots)
- How to manage the security for AI related solutions
- To design and implement such solutions on a reasonable price!

The interaction between people and machines reach a new, higher level with the support of the Generative AI and particularly OpenAI services.

Digital Twin has gained significant impact "as a breakthrough technological development that has the potential to transform the landscape of manufacturing today and tomorrow." [2]

"One of the primary reasons digital twin technology is rapidly being adopted is there are multiple use cases across the industrial enterprise: engineering, manufacturing and operations, and maintenance and service. Digital twins are made possible (and improved) by a multitude of Industry 4.0 technologies – IoT, AR, CAD, PLM, AI, edge computing, to name a few – to create a powerful tool that's driving business value." [6].

The Digital Twin concept offers several different types of models related to the goals of usage of this technology:

- Digital Twin Prototype (DTP).
- Digital Twin Instance (DTI)
- Digital Twins Aggregate (DTA)

This paper uses Digital Twins in the context of both: DTP and DTI. Digital Twin Instance (DTI) is the most often considered option to monitor and maintain a specific existing instance of the original system, but the experimental setup also uses the concept of Digital Twins Prototype to design the sample models.

Digital Twins can be used to implement message routing in the replica in a way analytics services and other back-end modules Fig.1

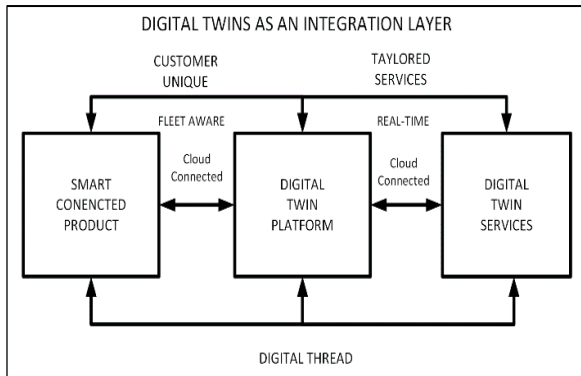


Fig. 1. Digital Twins as a part of the integration layer

The key question underlying self-learning machines is whether or whether self-learning digital twins can be built in order to learn from past experiences, enhance their models, and simplify suggested updates to configurations. This method will enable the model's prototype to be implemented more quickly, and it will also enable the model to be improved based on real data and simulations during the system maintenance timeline, as well as simulations during the design stage. Digital twins of this type that offer self-learning (or self-improving improving) capabilities are also known as Cognitive Digital Twins (CDT).

When writing new logic specifically for each new instance that arises from the basic rules combined with DT, CDT greatly increases the adaptivity of Digital Twins while reducing the labor required. When the initial rules coupled with DT required the requirement to develop specific new logic for new circumstances; CDT allows the adaptivity of Digital Twins to be considerably boosted and the effort to be decreased. Generative Artificial Intelligence (generative AI) is a specific kind of AI capable of generating different types of text, images, and other media types as a response to prompts, created automatically or in interactive mode.

The paper is focused on options to build Cognitive Digital Twins, based on DT and Generative AI, and to apply these rules in Industry 5.0 compliant solutions.

This research focuses on implementing CDT with Generative pre-trained transformers (GPT) models.

"Generative pre-trained transformers (GPT) are a type of large language model (LLM) and a prominent framework for generative artificial intelligence. The first GPT was introduced in 2018 by OpenAI." [3]. This concept uses Neural Networks and Reinforcement Learning, but deep-level details are never unveiled from OpenAI. Demonstration of the high-level design of the original GPT model is explained in [3].

"The most notable GPT foundation models have been from OpenAI's GPT-n series. The most recent is GPT-4 (OpenAI is working currently on GPT-5), for which OpenAI declined to publish the size or training details. "The competitive landscape and the safety implications of large-scale models." [2]

Table 1 exposes high-level information about the GPT foundations models.

Table 1. OpenAI Foundation GPT models [3]

Model	Architecture	Parameter count	Training data	Release date	Training cost
GPT-1	12-level, 12-headed Transformer decoder (no encoder), followed by linear-softmax.	117 million	BookCorpus 4.5 GB of text from 7000 unpublished books of various genres.	June 11, 2018	1.7e19 FLOP.
GPT-2	GPT-1, but with modified normalization	1.5 billion	Web Text: 40 GB of text, 8 million documents, from 45 million web pages upvoted on Reddit.	February 14, 2019 (initial/limited version) November 5, 2019 (full version)	1.5e21 FLOP.
GPT-3	GPT-2, but with modification to allow larger scaling	175 billion	499 Billion tokens consisting of Common-Crawl (570 GB), Web Text, English Wikipedia, and two books corpora (Books1 and Books2).	May 28, 2020	3.1e23 FLOP.
GPT-3.5	Undisclosed	175 billion	Undisclosed	March 15, 2022	Undisclosed
GPT-4	Also trained with both text prediction and RLHF; accepts both text and images as input. Further details are not public.	Undisclosed	Undisclosed	March 14, 2023	Undisclosed. Estimated 2.1e25 FLOP.

2. Prerequisites and means for solving the problem

A relatively recent area of artificial intelligence is called "Generative AI," in which specific AI models may create new data with comparable structures and attributes in response to specific requests after learning patterns and structures from training data. The new proposed data structure can be completely new, and it is unnecessary to have already created the same data in the past.

The current research focuses on applying Generative AI and GPT models, exposed via OpenAI API. OpenAI is a quite new artificial intelligence research laboratory and company. It was founded in 2015 by several tech visionaries, including Elon Musk and Sam Altman. Open AI provides research in different areas of Artificial Intelligence, including natural language processing (NLP), computer vision, reinforcement learning, and robotics. The current research covers the following areas:

- Options for the implementation of analysis based on Digital Twins and OpenAI
- Design and implementation of Cognitive Digital Twins using OpenAI
- Decomposition of complex solutions and cases using Digital Twins and Generative AI
- Implementation of intelligent machines, powered by Cognitive Digital Twins.

2.1 Implementation of Analysis based on Digital Twins and OpenAI/ChatGPT

Implementation of a smart Digital Twin requires:

- Digital Twin Implementation
- Available OpenAI API

- Coordination Service is needed to transform data from the DT model into appropriate questions to train the model in the service.

The coordination service has a very important role in supporting and generating the list of questions needed to clarify the exact search and allow the OpenAI service to provide a correct solution.

One high-level schema of the solution is presented in Fig. 2

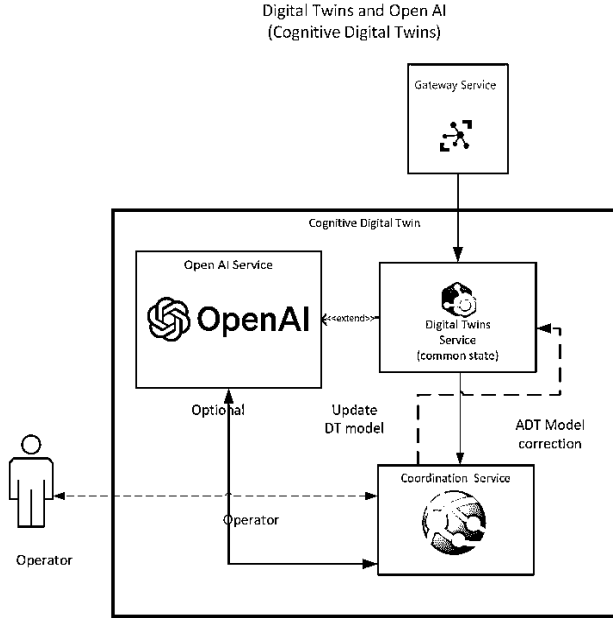


Fig 2. Sample Solution for Self-learning Digital Twins

2.2 Design and Implementation of Cognitive Digital Twins

Creating self-learning Digital Twins Models, also known as Cognitive Digital Twins, has been a focus of technology experts for the last several years. There are different concepts, but most of them are focused on combining Artificial Intelligence (AI) and Digital Twins. This research considers the Cognitive Digital Twins (CDT) mainly based on the usage of GPT models to create self-learning digital twin instances.

Cognitive Digital Twins have the feature to adapt the model better and faster based on the historical data in Digital Twins under the impact of different influences.

2.3 Decomposition of the case using conversation AI

One important goal when solving complex problems with Generative AI is to find a good solution to implement decomposition approaches. This case can be solved using multiple agents (chatbot agents or agent communication with AI) for complex tasks instead of one agent. The theoretical background is described in very detail in [7].

To demonstrate the idea of separating concerns, consider the sample, exposed in Fig. 3. A robot, or smart machine, has to gather fruits from a field according to predetermined guidelines. The objective is to gather every fruit as soon as you can. In Reinforced Learning, one agent's goal is to maximize the return, G_t , which is the expected discounted sum of rewards:

$$G_t = R_t + 1 + \gamma R_{t+1} + \gamma^2 R_{t+2} + \gamma^3 R_{t+3} + \gamma^4 R_{t+4} + \dots \quad (1)$$

By giving the agent a reward of +1 only if all the elements with anomalies are repaired, and by using a $\gamma < 1$, the optimal policy is guaranteed to use the minimal number of maintenance steps (respectively overall cost) to repair all elements. For a construction of 100 elements and n potential failures, if we need to check every element, the state space is $100 \times 100n = 102n+2$.

The codebase of the framework used to implement SoC with multiple agents is reused from (Pearce, Tim, et al.) [8]

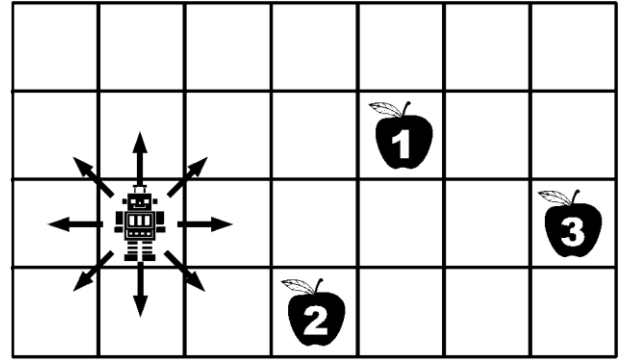


Fig. 3. Fruit collection example. A robot has to collect the fruits as quickly as possible (in any order) [7]

The decomposition of cases can be implemented using a cognitive approach where sub-cases were determined after several steps based on interaction with AI-powered chatbot agents.

It is possible to consider the options proposed in "Decomposing tasks like humans: Scaling reinforcement learning by separation of concerns" [5]

The main concept is using two agents (chatbot agents) and the Separation of Concerns (SoC) model.

The proposed model is a generalization of the traditional hierarchical decomposition. With a hierarchical decomposition, there is only one agent in control at any moment in time. By contrast, with our SoC model, multiple agents can act in parallel. This allows for more flexible task decompositions. One high-level schema of the proposed model for decomposition is explained in Fig 4.

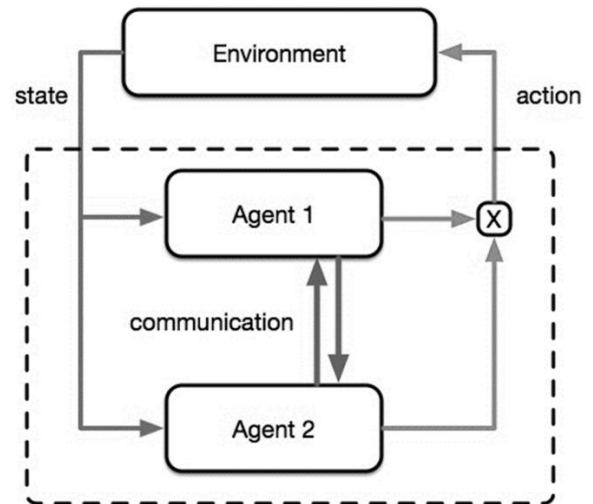


Fig.4 Decomposition by communicating agents [5]

Both agents: the low-level agent and the high-level agent, were trained using the deep Reinforcement Learning method of Deep Q-Network.

3. Solution of the examined problem

3.1 • Implementation of intelligent machines, powered by Cognitive Digital Twins.

The main focus is on how to solve similar cases using GPT models. Generative AI needs a very well-described case to generate a valuable answer. In the experimental solutions, the overall construction model with effects from manufacturing activities is represented with a digital twin (Azure Digital Twins service). A dedicated service is subscribed to specific properties and telemetry data and, based on the context, is creating requests against OpenAI API using very descriptive data. Generative AI is able to answer simple sub-cases providing a "prediction" if any anomaly is available. A robot, connected to the back-end communicates with CDT and accept configuration from the Digital Twin. CDT is based on DT, empowered by Open AI and based on the proposed concept can make continuous improvement of the model, represented via DT. Fig.5 demonstrates the high-level design of the anomaly detection solution, based on ADT, OpenAI (using both GPT-3.5 and GPT-4 modes), and implementing SoC to optimize the overall maintenance cost.

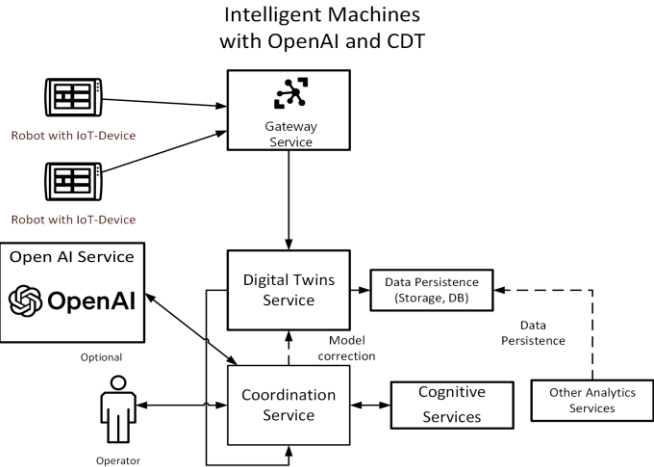


Fig.5. Experimental Setup: Cognitive Digital Twins based on Microsoft Azure and OpenAI

4. Results and discussion

In this paper, there are added metrics related to the experimental project PoC, realized using Microsoft Azure, Cognitive Services, Azure Digital Twins, and OpenAI service (using ChatGPT-3.5 and ChatGPT-4 models): CTD is connected to experimental small vehicle, using Raspberry Pi 4 Model B – Fig.5

The vehicle should “collect” fruits (to go through specific locations in defined area 10m*10m. Every next tour there are added new elements, that restricts some of the routes.

The experiment is measuring the success rate of the adaptation of the “smart vehicle” after each route changes.

Table 2. Experimental results for accuracy of the simulated cases in the production process using Anomaly Detector and OpenAI GPT-3.5 and GPT-4 models.

	#items	#success rate	#success rate 1 change	#success rate 2 change	#success rate 3 change	#success rate 4 change
Open AI with GPT-3.5 models	100	97%	74%	79%	84%	87%
Open AI with GPT-4 models	100	98%	76%	81%	87%	92%

5. Conclusions

Modern automation solutions can effectively solve complex cases and implement self-improving digital twins based on cases/models' decomposition and the use of OpenAI GPT models combined with other analytics technologies. The approach is domain-agnostic and can be used in different business domains.

The opportunity to use services for general analysis in systems with custom logic from a specific business domain is based on integration via Digital Twins. Digital Twins allows analysis domain agnostic and exposes via a digital replica only data that is taken off from the context of the system.

Behaviour optimization in the case of complex solutions with several components for intelligent machines is an important new area, where powered from OpenAI solutions can optimize the maintenance cost for the structures

6.Future work:

Research will be extended, based on more complex cases and improved Digital Twins modes. The major focus will be solving the real life cases about prediction and maintenance, related to manufacturing systems.

7.Abbreviations

- 1. DT Digital Twins
- 2. ADT Azure Digital Twins
- 3. IoT Internet of Things
- 4. CDT Cognitive Digital Twins
- 5. ChatGPT Generative pre-trained transformers
- 6. SoC Separation of Concerns

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Робастна многокритериална оптимизация при процеса кополимеризация чрез присъединяване

Robust multicriteria optimization for grafting copolymerization process

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Абстракт: В тази статия е представено приложението на методология, наречена обобщена робастна оптимизация, за параметрична оптимизация при робастно инженерно проектиране с използване на обобщена функция на желателност. Този подход се основава на оценени модели за средните стойности и дисперсиите на изследваните качествени характеристики на синтезиран водоразтворим кополимер с флокулантни свойства от царевично нишесте. Този кополимер е получен посредством индуцирано чрез облъчване в електронен ускорител процес на присъединяване на акриламид. Свойствата на получения кополимер – коефициент на превръщане на мономер, остатъчна концентрация на мономер и вътрешен вискозитет – са оптимизирани. Изследването включва изучаване на влиянието на различни параметри като тегловното съотношение на акриламид/нишесте, дозата на електронното облъчване и скоростта на дозата на облъчване на линеен електронен ускорител със средна енергия 6.25 MeV. Представена е многокритериална оптимизация, съобразена с изискванията за средните стойности и дисперсиите на качествени характеристики, чрез различни модификации на обобщения подход за робастна оптимизация. Тези модификации включват определянето на различни тегла за индивидуалните и общите функции на желателност за средните стойности и дисперсиите. Предложеният метод взема предвид точността на оценените модели, измерена с техните коефициенти на детерминация.

КЛЮЧОВИ ДУМИ: ВОДОРАЗТВОРИМИ КОПОЛИМЕРИ, ЕЛЕКТРОННО ЛЪЧЕВО ОБЛЪЧВАНЕ, КОПОЛИМЕРИЗАЦИЯ ЧРЕЗ ПРИСЪЕДИНЯВАНЕ, МОДЕЛИ ЗА СРЕДНИТЕ СТОЙНОСТИ И ДИСПЕРСИИТЕ, ФУНКЦИЯ НА ЖЕЛАТЕЛНОСТ.

1. Въведение

Процесът електроннолъчевото индуцирано присъединяване на кополимери се осъществява когато радикалите, образувани в и върху полимерен субстрат се превърнат в място за започване на мономерна полимеризация. Крайният резултат е, че два различни полимери са ковалентно свързани и образуват нов материал: кополимер. Синтезираните кополимери са получени чрез разтваряне на царевично нишесте в дестилирана вода, добавяне на акриламид в различни количества и съотношения. За да протече химичната реакция се облъчват с помощта на линейни електронни ускорители със средна енергия от 6.25 MeV, като процеса протича при стайна температура и атмосферно налягане [1].

Робастно (нечувствително към шумове и грешки) инженерно проектиране се прилага в случаите, когато вариацията на изходната характеристика не е хомогенна, а зависи от стойностите на параметрите на процеса във факторното пространство, както и от шумовите фактори [2, 3]. Наблюденията в този случай се наричат хетероскедастични (дисперсията на изходната величина варира с изменение на нивата на факторите).

В тази статия се прилага робастно инженерно проектиране и се оценяват модели, описващи зависимостите на средните стойности и разсейванията на изследваните характеристики за качество. Представена е подход за многокритериална оптимизация, базиран на обобщена робастна оптимизация и приложение на функция на желателност, който обединява изискванията за икономическа ефективност, гаранция за ниска токсичност, ефективност на кополимера във флокулантни процеси и устойчив на вариацията на показателите на качеството (робастност).

2. Робастно инженерно проектиране

Построяването на регресионни модели на средното и дисперсията е възможно чрез повторни наблюдения в точките на експерименталния план [2]. Трябва да се отбележи, че в този случай всъщност се изследва само нехомогенността на показателите на качеството, а грешките в задаването на факторите са едни и същи при всички повторни образци и следователно не могат да се вземат предвид. В случай, че е проведен експеримент с n повторни опити, като е изпълнен

план на експеримента в N различни точки и във всяка от тях са направени по p повторни наблюдения. Общият брой на наблюденията е $N \times p$. Като се използват повторните наблюдения, могат да се изчислят средните и дисперсиите във всяка точка на плана както следва:

$$(1) \quad \bar{y}_u = \frac{1}{n} \sum_{j=1}^n y_{uj}$$

$$(2) \quad s_u^2 = \frac{1}{n-1} \sum_{j=1}^n (y_{uj} - \bar{y}_j)^2$$

където $u = 1, 2, \dots, N$, а стойностите на $\bar{y}_i$ и s_u^2 , $u = 1, 2, \dots, N$ могат да се разглеждат като две изходни величини и с тяхна помощ да се построят два регресионни модела с помощта на метода на най-малките квадрати [2]:

- Модел на средната стойност:

$$(3) \quad \tilde{y} = \sum_{i=1}^{K_y} \hat{\theta}_{yi} f_{yi}$$

- Модел на дисперсията:

$$(4) \quad \log(s^2) = \sum_{i=1}^{K_\sigma} \hat{\theta}_{si} f_{si}$$

където $\hat{\theta}_{yi}$ и $\hat{\theta}_{si}$ са оценки на регресионните коефициенти в оценяваните полиномни модели, а f_{yi} и f_{si} са известни функции на факторите (параметрите на процеса).

3. Описание на експеримента

Направено е експериментално изследване, при което царевично нишесте е облъчено в електронен линеен ускорител със средна енергия 6.25 MeV.

Процесът се извършва на два етапа [1]:

1. Получаване на разтвори, съдържащи нишесте и мономер – водни разтвори на нишесте се получават чрез разтваряне на царевично нишесте в дестилирана вода. След това се прибавя акриламид, при вариране на съотношение акриламид-нишесте.

2. Облъчване на разтвора с електронен лъч – Хомогенните водни разтвори се подлагат на облъчване с електронен лъч. Облъчванията са проведени при стайна температура и атмосферно налягане с помощта на два линейни електронни ускорители със средна енергия 6.25 MeV и с различни дози на облъчване и скорости на дозите.

Характеризирането на синтезираните кополимери е извършено чрез следните показатели:

- остатъчна концентрация на мономера - $\tilde{y}_1$;
- коефициент на преобразуване на мономера - $\tilde{y}_2$;
- вътрешен вискозитет - $\tilde{y}_3$;

За определянето на средните стойности и дисперсиите на показателите на качество са проведени 30 серии опита, всяка с по 3 повторни наблюдения.

Факторите, които варират по време на експеримента, както и нивата им на вариране са показани в Таблица 1.

Таблица 1: Диапазони на изменение на параметрите на процеса.

Фактори	Означение	Мин. $z_{i\min}$	Макс. $z_{i\max}$	Основно ниво, z_{i0}
Доза на облъчване [kGy]	z_1	0.65	5.50	3.075
Скорост на дозата [kGy/min]	z_2	0.41	1.50	0.955
Тегловното съотношение AMD/St*	z_3	2.00	11.00	6.50

*AMD/St – акриламид/нишесте

4. Модели за средната стойност и дисперсията на характеристиките за качество

Моделите за средната стойност и дисперсията на характеристиките за качество са оценени и представени в Таблица 2 и 3 [4], заедно с коефициентите им на детерминация – R^2 . Входните параметри в моделите са кодирани в диапазона $[-1 \div 1]$ чрез следното уравнение (5):

$$(5) \quad x_i = (2z_i - z_{i,\max} - z_{i,\min}) / (z_{i,\max} - z_{i,\min}),$$

където x_i и z_i са съответно кодираният и натуралната стойност на съответния фактор, $z_{i,\min}$ и $z_{i,\max}$ са долната и горната им граница на изменение (Таблица 1).

Таблица 2: Модели на средната стойност на показателите за качество.

Парм.	Модел	R^2	ω'
$\tilde{y}_1$	$-4.3456957x_1 + 5.3915161x_1^2 - 1.5283048x_2^2 - 1.3886159x_1x_2 - 5.0568769x_1x_3$	0.7944	0.3396
$\tilde{y}_2$	$86.89582 + 34.751905x_1 - 7.1056848x_2 - 34.141859x_1^2 + 34.945289x_3^2 + 33.500225x_1x_3$	0.8276	0.3537
$\tilde{y}_3$	$1.8341046 - 1.4972781x_1 + 1.5368173x_1^2 + 1.401751x_3^2 - 1.3446153x_1x_2 + 1.1090262x_2x_3 - 3.1125045x_1x_3$	0.7174	0.3067

Таблица 3: Модели на дисперсията на показателите за качество.

Дисп.	Модел	R^2	ω'
$\ln(\tilde{s}_1^2)$	$-8.1907995 - 2.4376459x_1 - 2.0808965x_2 + 1.2422924x_3 + 3.3800892x_1^2 + 3.0435881x_3^2 - 3.064369x_1x_2$	0.7259	0.3747
$\ln(\tilde{s}_2^2)$	$-2.0505708x_2 + 1.1227946x_3 + 1.3503166x_1x_2^2 + 2.2543255x_2x_3^2 - 2.8020033x_1x_3^2$	0.7517	0.3880
$\ln(\tilde{s}_3^2)$	$-5.3591952 + 1.6879963x_1^2 + 1.7422987x_3^2 - 2.1837351x_1^3 - 1.6195118x_1x_3 + 2.7501263x_1x_2^2$	0.4597	0.2373

5. Обобщена робастна функция на желателност – Обобщена робастна оптимизация

Многокритериалната оптимизация в случая на робастно инженерно проектиране трябва да е насочено към търсенето на решение, което едновременно да взема под внимание заданията за средните стойности и заданията за дисперсиите на всички качествени характеристики. За целта може да се използва комбинирана (обобщена – Overall) функция на желателност, дефинирана чрез обобщена функция на показателите на качество. Обобщената робастна функция на желателност има следния вид [5]:

$$(6) \quad D_{\text{overall}}(x) = D_{\text{opt}}(x)^{\omega_{\text{opt}}} \times D_{\text{Rob}}(x)^{\omega_{\text{Rob}}},$$

където $D_{\text{opt}}(x)$ е обобщената функция на желателност за средните стойности на показателите на качество и може да се изчисли по формулата:

$$(7) \quad D_{\text{opt}}(x) = d_{o1}(x)^{\omega_{1\mu}} \times d_{o2}(x)^{\omega_{2\mu}} \times \dots \times d_{or}(x)^{\omega_{r\mu}},$$

а $D_{\text{Rob}}(x)$ е обобщената функция на желателност на робастните модели за дисперсиите на показателите на качество:

$$(8) \quad D_{\text{Rob}}(x) = d_{R1}(x)^{\omega_{1\sigma}} \times d_{R2}(x)^{\omega_{2\sigma}} \times \dots \times d_{Rr}(x)^{\omega_{r\sigma}}$$

Във формулите (7) и (8) $\omega_{j\mu}$ и $\omega_{j\sigma}$ са съответно тегловните коефициенти на j -тия модел на средните стойности и j -тия модел на дисперсиите на показателите на качество. А индивидуалните функции на желателност $d_{or}(x)$ и $d_{Rr}(x)$ могат да се определят по три начина [6].

- Когато е дефинирана целева стойност:

$$(9) \quad d_j(\vec{x}) = \begin{cases} \frac{\tilde{y}_j(\vec{x}) - lb_j}{\tau_j - lb_j}; & lb_j \leq \tilde{y}_j(\vec{x}) \leq \tau_j \\ \frac{\tilde{y}_j(\vec{x}) - ub_j}{\tau_j - ub_j}; & \tau_j < \tilde{y}_j(\vec{x}) \leq ub_j \\ 0; & \tilde{y}_j(\vec{x}) < lb_j \text{ or } \tilde{y}_j(\vec{x}) > ub_j \end{cases}$$

- Когато се търси максимум („по-голямо, по-добре“):

$$(10) \quad d_j(\vec{x}) = \begin{cases} 0; & \tilde{y}_j(\vec{x}) \leq lb_j \\ \frac{\tilde{y}_j(\vec{x}) - lb_j}{ub_j - lb_j}; & lb_j < \tilde{y}_j(\vec{x}) \leq ub_j \\ 1; & \tilde{y}_j(\vec{x}) \geq ub_j \end{cases}$$

- Когато се търси минимум („по-малко, по-добре“):

$$(11) \quad d_j(\vec{x}) = \begin{cases} 1; & \tilde{y}_j(\vec{x}) \leq lb_j \\ \frac{ub_j - \tilde{y}_j(\vec{x})}{ub_j - lb_j}; & lb_j < \tilde{y}_j(\vec{x}) < ub_j \\ 0; & \tilde{y}_j(\vec{x}) \geq ub_j \end{cases}$$

Където с lb_j и ub_j се бележат съответно долната и горната граница на j -тия оптимизационен критерий (y_j), който в случаите на робастно инженерно проектиране може да бъде както средна стойност, така и дисперсия.

Тегловните коефициенти ω_{opt} и ω_{Rob} използвани във формула (6), служат, за да се придаде повече значение на една от двете обобщени функции на желателност – тази за средните стойности на показателите на качество (D_{opt}) и тази на дисперсиите им (D_{Rob}), съставляващи обобщената функция на робастна желателност $D_{\text{overall}}(x)$ (формула (6)) като се спазва правилото: $\omega_{\text{opt}} + \omega_{\text{Rob}} = 1$. Придавайки по-голяма тежест на едната от двете половини, тя се приоритизира.

Тегловният коефициент ω_j може да бъде изчислен на базата на коефициента на детерминация R^2 . По този начин по-голямата стойност на R^2 ще доведе до по-голяма тежест. Това става по формула (12):

$$(12) \quad \omega_j' = \frac{R_j^2}{\sum_{j=1}^m R_j^2},$$

където m е общия брой на участващите в D_{Opt} и D_{Rob} модели.

6. Резултати и дискусии

Обобщената робастна функция на желателност за електронно лъчевото (ЕЛ) индуцирано получаване на кополимера е изчислена по формула (6) и има следния вид:

$$(13) \quad D_{Overall}(\vec{x}) = [d_{01}(\vec{x})^{\omega_{1\mu}} \times d_{02}(\vec{x})^{\omega_{2\mu}} \times d_{03}(\vec{x})^{\omega_{3\mu}}]^{\omega_{Opt}} \times [d_{r1}(\vec{x})^{\omega_{1\sigma}} \times d_{r2}(\vec{x})^{\omega_{2\sigma}} \times d_{r3}(\vec{x})^{\omega_{3\sigma}}]^{\omega_{Rob}}$$

В Таблица 4 са дадени приемливите региони на изменение за средните стойности и дисперсиите, заедно с типа на функцията на желателност („по-малко, по-добре” – за минимум и „по-голямо, по-добре” – за максимум).

Таблица 4: Специфични региони и целеви стойности за средните стойности и дисперсиите на показателите на качество.

Граници	$\tilde{y}_1(\vec{x})$	$\tilde{y}_2(\vec{x})$	$\tilde{y}_3(\vec{x})$	$\tilde{s}_1^2(\vec{x})$	$\tilde{s}_2^2(\vec{x})$	$\tilde{s}_3^2(\vec{x})$
lb (долна)	0	90	3	0	0	0
ub (горна)	5	100	20	0.7	4.2	0.5
τ (цел)	Мин.	Макс.	Макс.	Мин.	Мин.	Мин.

Тежестите ω_j' са изчислени и представени в Таблица 2 за средните и в Таблица 3 за моделите за дисперсиите на качествените характеристики.

Обобщената робастна функция на желателност е формулирана за няколко случая:

Случай 1: Тегловните коефициенти ω_j определят средните геометрични стойности на компонентите от индивидуалните функции на желателност за средните стойности, определящи обобщената функция на желателност (D_{Opt}) за показателите на качеството. По същия начин се определят и теглата на индивидуалните функции на желателност в обобщената функция на желателност за дисперсиите (D_{Rob}). Те не са свързани с точността на изведените модели:

$$\omega_{10} = \omega_{20} = \omega_{30} = 1/3 \text{ и } \omega_{r1} = \omega_{r2} = \omega_{r3} = 1/3.$$

За формулиране на обобщената робастна функция на желателност се определя средногеометричното на двете обобщени функции: D_{Opt} и D_{Rob} :

$$\text{т. е. } \omega_{Opt} = \omega_{Rob} = 1/2.$$

Случай 2: Тегловните коефициенти са изчислени по формула (12) и са показани в Таблице 2 и 3.

Разгледани са следните 3 подслучая на определяне на тегловните коефициенти на двете обобщени функции: D_{Opt} и D_{Rob} :

$$\text{Случай 2.1: } \omega_{Opt} = \omega_{Rob} = 1/2;$$

$$\text{Случай 2.2: } \omega_{Opt} = 0.8 \text{ и } \omega_{Rob} = 0.2;$$

$$\text{Случай 2.3: } \omega_{Opt} = 0.2 \text{ и } \omega_{Rob} = 0.8.$$

Случай 3: Тегловните коефициенти не зависят от точността на моделите и тежестта е разпределена по равно между тях, без да се дава приоритет на никой от показателите на качество или дисперсиите:

$$\omega_{10} = \omega_{20} = \omega_{30} = \omega_{r1} = \omega_{r2} = \omega_{r3} = 1/6.$$

Случай 4: Без да се взима предвид моделите, тежестите са равни помежду си:

$$\omega_{10} = \omega_{20} = \omega_{30} = \omega_{r1} = \omega_{r2} = \omega_{r3} = 1,$$

$$\text{т. е. } \omega_{Opt} = \omega_{Rob} = 1.$$

Таблица 5: Оптимални входни параметъра за четирите случая.

Случай	z_1	z_2	z_3
1	2.7355	1.5000	10.6850
2.1	3.7298	0.5408	2
2.2	3.9480	0.4263	2
2.3	3.5358	0.6661	2.1800
3	2.7355	1.5000	10.6850
4	2.7355	1.5000	10.6850

В Таблица 5 са представени получените оптимални параметри на процеса (доза на облъчване – z_1 ; скорост на дозата – z_2 ; тегловно съотношение AMD/St – z_3) при четирите случая. В Таблица 6 - са дадени индивидуалните и обобщените робастни стойности на функциите на желателност, а в Таблица 7 са представени оптималните стойности за средните стойности и дисперсиите на показателите на качество, получени за четирите случая.

Таблица 6: Оптимални претеглени индивидуални стойност и Overall на функциите на желателност.

Сл.	d_{10}	d_{20}	d_{30}	d_{1r}	d_{2r}	d_{3r}	$D_{Overall}$
1	0.9974	1	0.4826	0.9709	0.8381	0.8994	0.5935
2.1	1	1	0.5109	0.9435	0.9617	0.8376	0.6231
2.2	0.9999	1	0.5597	0.9110	0.9627	0.7257	0.5742
2.3	0.9999	1	0.4395	0.9649	0.9550	0.8890	0.7233
3	0.9987	1	0.6947	0.9853	0.9155	0.9484	0.5935
4	0.9923	1	0.1124	0.9152	0.5886	0.7276	0.0437

Таблица 7: Оптимални средни стойности и дисперсии на показателите на качество.

Сл.	$\tilde{y}_1(\vec{x})$	$\tilde{y}_2(\vec{x})$	$\tilde{y}_3(\vec{x})$	$\tilde{s}_1^2(\vec{x})$	$\tilde{s}_2^2(\vec{x})$	$\tilde{s}_3^2(\vec{x})$
1	0.0386	100	4.9111	0.0594	1.7277	0.1362
2.1	0	100	4.9028	0.1007	0.4018	0.2631
2.2	0.0017	100	5.5618	0.1541	0.3922	0.3706
2.3	0.0019	100	4.1644	0.0637	0.4698	0.1954
3	0.0386	100	4.9111	0.0594	1.7277	0.1362
4	0.0386	100	4.9111	0.0594	1.7277	0.1362

От Таблица 7 се вижда, че има разлика само в стойностите на функциите на желателност, докато получените оптимални параметри на процеса са еднакви в случаи 1, 3 и 4. Вижда се още, че случай 2.2, при който теглата зависят от точността на моделите, предлага най-добри стойности за средните стойности на показателите на качество, а дисперсиите им са достатъчно малки.

6. Заключение

Разгледан е подход за многокритериална оптимизация, базиран на обобщена робастна функция на желателност, който отчита робастността, както и оптимизирането на параметрите на процеса при производствени условия. Обобщената робастна функция се изчислява чрез оценка на индивидуалните функции на желателност на средните стойности и дисперсиите на характеристиките на качеството на продукта. Приложеният подход дава възможност за използване на тегла за коригиране на значимостта на индивидуалните функции на желателност според точността на оценените регресионни модели и в полза

на обобщената функция на средните стойности на показателите на качеството или на техните дисперсии.

Изследван е процеса на електронно индуцираното присъединяване на кополимери, използвано за синтез на водоразтворими кополимери с флокулантни свойства. Оптимизацията на параметрите се извършва с цел да се удовлетворят едновременно изискванията за икономическа ефективност, гаранция за ниска токсичност ефективност на кополимера във флокулантни процеси, като в същото време получените показатели на качеството да останат нечувствителен към външните шумове и смущения.

Благодарности

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Design a tracking system for optimum solar energy

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Abstract: Environmental and economic problems caused by over dependence on fossil fuels have increased the demand and request for green energy produced by alternative renewable sources. Solar energy systems have emerged as a viable source of renewable energy over the past two or three decades, and are now widely used for a variety of industrial and domestic applications. Such systems are based on a solar collector, designed to collect the sun's energy and to convert it into either electrical power or thermal energy. Solar energy is predictable to play a great role in the infrastructure as a distributed source, due to the fact that it is an easily available renewable source of energy. In Jordan, natural conditions for solar are excellent, with an intensity of direct solar radiation with 5 to 7 kWh/m². The main purpose of the present study to estimate the performance of a solar tracking photovoltaic (PV) panel of dual axis type, through designing, construction and testing of a solar tracking system which automatically searches the optimum PV panel position with respect to the sun by means of a DC motors controlled by Arduino Mega board that receives input signals from dedicated Light Dependent Resistor (LDR), and compare the results with fixed PV panel. The results showed that the use of the Dual-Axis Tracking System can produce about 37.37% gain of power output, compared with a fixed system inclined at 30° to the horizon.

KEYWORDS: SOLAR ENERGY, PV, TRACKING SYSTEM, FIXED SYSTEM, DUAL AXIS. OPTIMUM SOLAR ENERGY

Background: In this technologically based world, electric power plays the sole role of providing energy for the operations of machines, either commercial based or industrial based. However, the generation of electricity often leads to environmental destruction. It is related with aspects as deforestation control, protection of ozone layer, reduction of CO₂ emissions and others. The environmental issues are now being regarded as the most crucial problem. Therefore, the goal of obtaining good energy supplies of electric power is to be emphasized [1]. According to that goal and considering additionally the exhaustion of the energy reserves and the global heating of the planet to promote and improve systems sourced with renewable energies is a must. A good energy source prospect for industrial continuous processes needs to be: more or less constant energy throughout the year; highly reliable and needs little maintenance; low cost to build and operate; virtually no environmental impact; modular and thus flexible in terms of size and applications; landscape friendly. A solar electric system-also known as photovoltaic (PV) systems—fulfils this entire characteristic [2]. Photovoltaic power generation is achieved using solar panels which are composed of a number of solar cells made up of a photovoltaic material. Materials currently used for photovoltaic include amorphous silicon, copper indium gallium selenide/supplied, cadmium telluride, mono-crystalline silicon, and polycrystalline silicon. Due to the continuous increase in demand for renewable energy sources, the manufacturing of Solar Cells and Photo-Voltaic Arrays has considerably advanced over the past few years [3]. The output of a Photo-Voltaic panel is non-linear in nature as well as the output greatly varies with environmental changes like temperature, solar insolation, etc. [4]. This poses a huge threat during its use. The entire Photovoltaic array does not receive equal amount of radiations at all times. Sometimes parts of the array is under shading due to clouds, tree, towers, dust, etc. This results in occurrence of multiple peaks in the Power v/s Voltage characteristics of the array which hinders the proper functioning on maximum power point tracker [5]. Considerable power loss will be experienced if local maximum power point is tracked and not the global maximum. Hence it is pertinent to track the optimal operating voltage of the Photovoltaic array for better efficiency PV generators. The Photovoltaic array for better efficiency of PV generators. The PV array gives different output at different time of day for different orientations depending upon the amount of sunlight falling on the module and on the angle at which rays fall on it [6]. Thus the angle at which the module is placed with respect to the ground can be optimized so as to obtain maximum output from the module at all time. Radiation with 5 to 7 kWh/m, [14]. fossil fuels [7]. With extensive growth of population, in Jordan, natural conditions for solar are excellent, with an intensity of direct solar.

Statement of the problem: Design, Construction and testing a tracking system for optimum photovoltaic (PV) will be the main part of this work. The topic proposed in this paper refers to the design of a dual axis solar tracker system that automatically

searches the optimum PV panel position with respect to the sun by means of DC motors controlled by an intelligent drive unit that receives input signals from a light intensity sensor. Also design a fixed PV system for comparison purpose. For many years, several energy companies and research institutions have been performing solar tracking for improving the efficiency of solar energy production. A variety of techniques of solar energy production used have proven that up to 30% more solar energy can be collected with a solar tracker than with a fixed PV system [15].

Motivation of the Study: Jordan is a non-oil-producing country and imports 96% of the energy used. As a consequence, energy imports accounts for roughly 22% of the GDP (Gross domestic product). The population's growth rate is high; about 2.3% per year. This causes the demand on energy sources, mainly oil products to increase rapidly. Implementation of renewable energy resources such as solar and wind energy, will lead to economic, social and environmental benefits [16].

Objectives of the Study: The main objective of this work is to estimate the performance of a solar tracking PV panel of dual axis type. While the sub-objectives are:

- Increases solar panel output
- Maximum efficiency of the panel
- Maximum power per unit area
- Able to grab the energy throughout the day
- Compare results obtained from the tracking system with the fixed system.

Research Methodology: In order to achieve the overall objectives of the research, it is always important to have a systematic approach for the framework of research implementation. Thus, the following approach is adopted in the current research. Literature review: The understanding and evaluation of the current state of the research is one of the most fundamental and important step in any research activity. Development of conceptual design of proposed system. Experimental study and measurements. Comparison between tracking PV and fixed PV systems results.

Solar Tracking Technologies: Solar tracking is the act of making a solar collection surface change its orientation with the movement of the sun in the sky. There are two significant relative motions in the earth-sun system. The first is the diurnal movement due to the earth's rotation about its axis, causing day and night. This is responsible for the hourly variation of incident solar radiation on a surface [3]. The second is the much slower movement due to the earth's elliptical voyage round the sun. Two factors in this motion combine to affect incident radiation. First, the actual sun-earth distance affects the extra-terrestrial radiation in accordance with an inverse square law [4]. Secondly, the angle between the earth's equatorial plane and its orbit causes an apparent seasonal north-south range of travel of the sun in the upper celestial hemisphere [5]. Full control of solar harvest surface orientation is therefore a 2-degree of freedom problem. In practice, control is achieved by manipulating rotations about 2 of any 3 orthogonal axes. Commonly used axes are: West-East; North-South in the horizontal

plane and the vertical Nadir-Zenith, [6-13] among others – report the following pairs to constrain the rotation as to keep the surface facing the sun all day long.

- W-E and S-N
- S-N and Nadir – Zenith
- Nadir – Zenith and W-E

Rotation about these axes affects the surface slope β and its azimuth ψ . Tracking manipulates these angles to vary with the sun angles: The elevation and the solar azimuth ψ_{ss} . These are dependent on the time and day of year. Hence, from a tracking point of view, they are independent variables, see figures- 1 and 2.

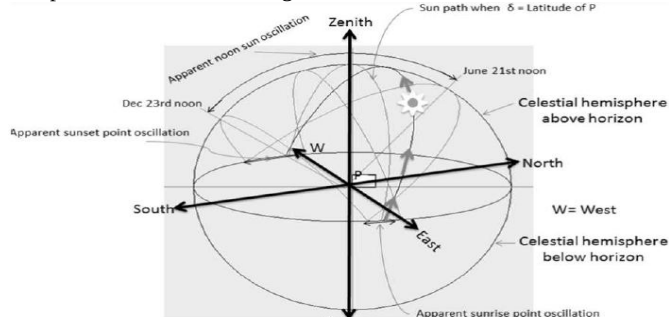


Figure-1: Apparent sun motion on the 'inside' surface of an inverted celestial hemisphere for a place 'P' within the tropics [14]

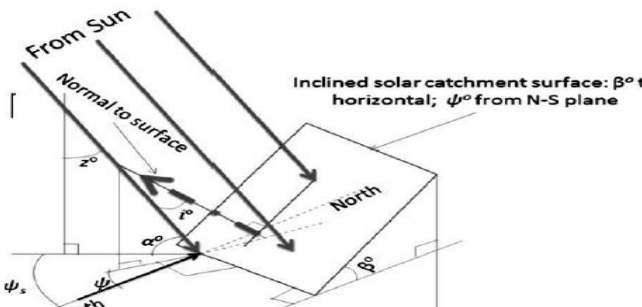


Figure-2: Important angles for a solar tracking surface: 'i' is the incidence angle to be minimized [14]

Broadly, the angles β and ψ track α and ψ_s using mechanisms classified according to two criteria [15, 16].

- Passive or Active tracking
- One axis or Two axes tracking

When the radiation catchment plane or aperture is adjusted without use of electrical power, the tracking is said to be passive.

Solar Tracker System Design and Calculations:

1- Annual motion of the sun

There are many motions for the sun during a year, the first one is motion in winter and the second one in summer as shown in the figure-3. So in winter the sun doesn't rise as high as in summer. Hence the sun rising hours in summer are more than in winter so the quantity of radiation absorbed in summer is more than in winter.

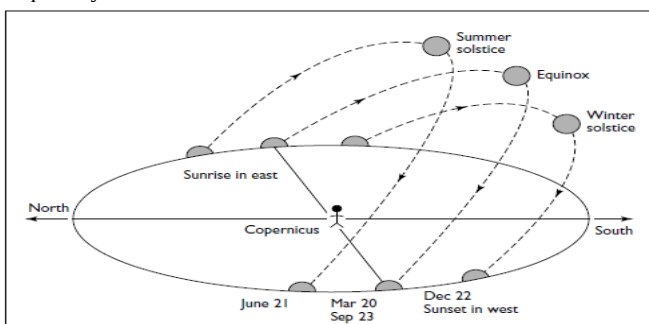


Figure-3: Annual motion of the sun [17]

Sun- earth angles: The energy flux of beam radiation on the surface with arbitrary orientation can be obtained from the knowledge either on the surface perpendicular to the sun rays or in the horizontal surface. Consider the flux incidence on the plane surface is $(I \cos \theta)$, where θ is the angle between surface and incident beam, and I is the incident beam [18]. Latitude angle (Φ): defined as the location where the angle made by the radial line joining the given location to the center of the earth, the latitude angle is positive for the northern and negative for the southern hemisphere. Declination (δ): defined as the angle between joining center of the sun and the earth, and its projection on the equatorial plane. Slope (β): is the angle between the plane surface and the horizontal [19, 20]. It is positive for surfaces sloping toward the south and negative for surfaces sloping toward the north. Angle of incidence (θ_z), is the angle between beam radiation on the surface and normal to that surface.

2- Solar tracker system design and its components: The system consists of many components which are:

(a) Battery: A solar battery is a rechargeable that integrates a solar cell with battery power storage. In this project, sealed acid rechargeable battery is used for solar system (12 V ,7 Ah). The number of battery needed, as follows:

Estimated Watt demand =

$$\text{DC Amps} \times \text{System Voltage} \dots\dots\dots (2)$$

$$= 1.76 \text{ A} \times 12 \text{ V} = 21.12 \text{ Watt}$$

$$\text{Watt-Hours per day} = \text{Watts} \times \text{Hours} \dots\dots\dots (3)$$

$$= 21.12 \text{ Watt} \times 3 \text{ hours/day} = 63.36 \text{ Wh/day}$$

$$(\text{Total Amp}) / \text{day} =$$

$$\frac{\text{Watt-Hours per day} \times \text{battery loss factor}}{\text{system voltage}} \dots\dots\dots (4)$$

$$= \frac{63.36 \times 1.2}{12} = 6.336 \text{ Ah /day}$$

$$\text{So, the number of battery needed} = \frac{\text{total Amp /day}}{\text{battery Amp rating}} \dots\dots\dots$$

$$(5) \quad \frac{6.336}{7} = 0.905 \approx 1.0$$

(b) Solar panel: The type of solar panel used is polycrystalline module, the panel produces peak power values at an irradiance level of 30 Watt. Those are for solar radiation of 1000 W/m² at 25°C.

$$P_{\text{max}} = 30 \text{ W}$$

$$V_{\text{oc}} = 21.6 \text{ V}$$

$$I_{\text{sc}} = 1.83 \text{ A}$$

$$V_{\text{mp}} = 18.00 \text{ V}$$

$$I_{\text{mp}} = 1.67 \text{ A}$$

$$\text{The number of panel needed: Sun hours per day} = 4.5 \text{ hours}$$

$$\text{Total Amp} = \frac{\text{total Amp /day}}{\text{Sun hours per day}} \dots\dots\dots (6)$$

$$= \frac{6.336}{4.5} = 1.408 \text{ am}$$

$$\text{So the number of panels} = \frac{\text{total Amp}}{I_{\text{mp}}} \dots\dots\dots (7)$$

$$= \frac{1.408}{1.67} = 0.843 \approx 1.0$$

(c) Charge controller: A charge controller is a device used to control the rate at which electric current is added to or pulled from electric batteries. It prevents overcharging and may protect against overvoltage, which can reduce battery performance or lifetime, and may pose a safety risk. It may also prevent completely draining ("deep discharging") a battery, or perform controlled discharges, depending on the battery technology, to protect battery life

$$\text{The number of charge controller needed} = \frac{I_{\text{mp}}}{\text{Rated charge current}} \dots\dots\dots (8)$$

$$= \frac{1.67 \text{ A}}{10 \text{ A}} = 0.167$$

(d) Motors: In the solar tracker system two types of motor have been used

(1) DC motors: DC motors were the first type widely used, since they could be powered from existing direct-current lighting power distribution systems. A DC motor's speed can be controlled over a wide range, using either a variable supply voltage or by changing

the value of current in its field windings. The DC motor that used in this work is ASMO (873410.073) which have these specification:

Torque = 2 N.m

Voltage = 24 V

Current = 85 mA

Output speed = 1.8 r/min

(2) Actuator: An actuator is a compact of machine that is responsible for moving or controlling a mechanism or system. It is operated by a source of energy, typically electric current, hydraulic fluid pressure, or pneumatic pressure, and converts that energy into motion. An actuator is the mechanism by which a control system acts upon an environment. The control system can be simple, software-based, a human, or any other input. There are varieties of actuators and they are Mechanical actuators, Hydraulic actuators, Pneumatic actuators, Electro-mechanical, Linear motor etc. In our system we have used linear actuator because linear actuator creates motion in a straight line, in contrast to the circular motion of a conventional electric motor.

Torque needed to rotate the panel:

Panel weight = 3 kg

Dimensions of panel: 670 mm × 410 mm × 25 mm

$\text{torque} = T = r \times F$ (9)

$$T = \frac{mgr}{2} \dots\dots\dots (10)$$

$$g = 9.8 \text{ ms}^{-2}$$

$$r = \frac{\text{Width}}{4} = \frac{410}{4} = 102.5 \text{ mm} = 0.1025 \text{ m}$$

$$T = \frac{3 \times 9.8 \times 0.1025}{2}$$

$$= 1.771 \text{ N.m}$$

3- Control System: To control the motion of the panel in order to be faced to the sun. So, need a control system is required. This system contains:

(a) Arduino Mega Board

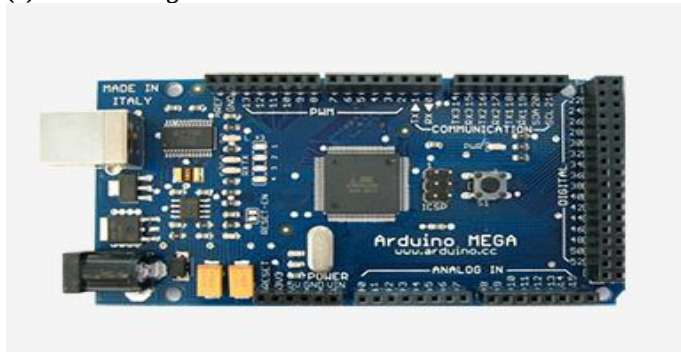


Figure -4: Arduino mega board

The Arduino Mega is a microcontroller board based on the ATmega1280. It has 54 digital input/output pins, 16 analog inputs, 4 UARTs (hardware serial ports), a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Mega is compatible with most shields designed for the Arduino Duemilanove or Diecimila. Figure-4, shows the Arduino mega board.

(b) Light Dependent Sensor



Figure- 5: Light Dependent Resistor

A Light Dependent Resistor (LDR) or a photo resistor is a device whose resistivity is a function of the incident electromagnetic radiation. Hence, they are light sensitive devices, as shown in figure-5. A light dependent resistor works on the principle of photo conductivity. Photo conductivity is an optical phenomenon in which the materials conductivity is increased when light is absorbed by the material. When light falls i.e. when the photons fall on the device, the electrons in the valence band of the semiconductor material are excited to the conduction band.

(c) Current Sensor

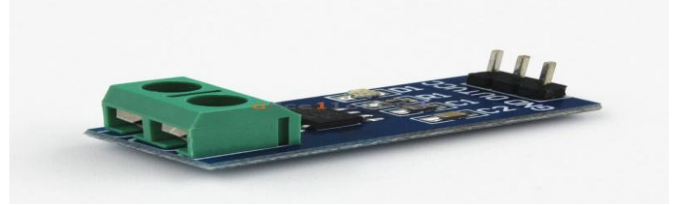


Figure-6: Current sensor

A current sensor as in figure-6, is a device that detects electric current (AC or DC) in a wire, and generates a signal proportional to it. The generated signal could be analog voltage or current or even digital output. It can be then utilized to display the measured current in an ammeter or can be stored for further analysis in a data acquisition system or can be utilized.

(d) Voltage Sensor (voltage divider): A voltage divider is a simple circuit which turns a large voltage into a smaller one. Using just two series resistors and an input voltage, we can create an output voltage that is a fraction of the input. Voltage dividers are one of the most fundamental circuits in electronics.

Figure-7, shows the voltage divider circuit.

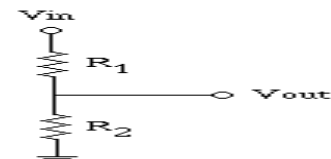


Figure-7: Voltage divider circuit

$$V_{out} = V_{in} \times \frac{R_2}{R_1 + R_2} \dots\dots\dots (11)$$

$$5 = 18.5 \times \frac{R_2}{R_2 + 10}$$

$$R_2 = 4.7 \text{ k}\Omega$$

(e) Motor Driver (H-bridge)

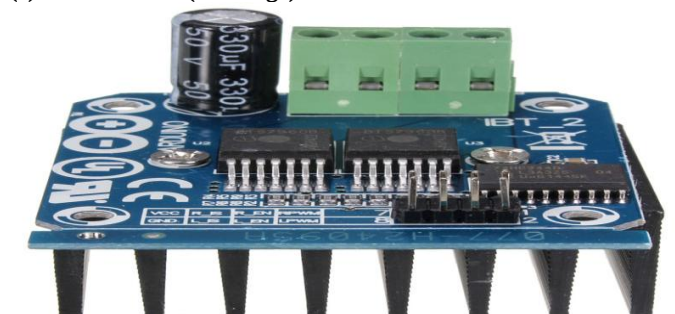


Figure-8: Motor Driver

Motor driver is a little current amplifier; the function of motor drivers is to take a low-current control signal and then turn it into a higher-current signal that can drive a motor. Shown in figure-8.

(f) SD Card Shield:



Figure-9: SD Card Shield

The Arduino SD Card Shield is a simple solution for transferring data to and from a standard SD card. The pin out is directly compatible with Arduino, but can also be used with other microcontrollers. It allows users to add mass storage and data logging to their project. SD Card Shield is shown in figure-9.

4- Installation and Programming

This section is dedicated to reflect how to used research and design to build prototype of the sun tracking system. After an intensive research on all the available techniques and components, to meet the requirement of the desired sun tracking system and to satisfy the prime objective of the project, suitable methods and components were selected and implemented through electrical circuits. In our system we have a control circuit controlled by the microcontroller in Arduino system with the following components:

a) **Electrical circuits:** Solar tracker system consists of many electrical circuits which are:

- **LDR circuit:** The LDR gives out an analog voltage when connected to Vcc (5V), which varies in magnitude in direct proportion to the input light intensity on it. That is, greater the intensity of light, greater will be the corresponding voltage from the LDR. Since the LDR gives out an analog voltage, it is connected to the analog input pin of the Arduino. The Arduino, with its inbuilt ADC (Analog to Digital Converter) then converts the analog voltage (from 0-5V) into a digital value in the range of (0-1023). Thus, when there is sufficient light in its environment or on its surface, the converted digital values read from the LDR through the Arduino will be in the range of 800-1023. LDR circuit shown in figure-10.

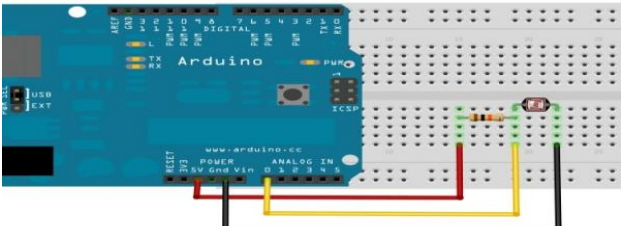


Figure-10: LDR Circuit

- **Current sensor circuit:** This circuit used for Read, Sense and Control current flow in the system. Figure-11, shows the current sensor circuit.

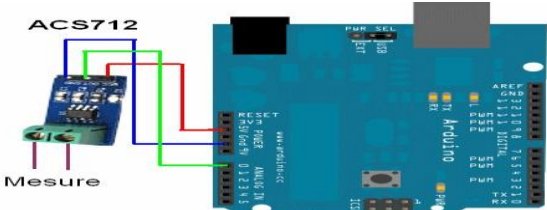


Figure-11: Current Sensor Circuit

- **Voltage Divider Circuit:** This circuit works as a voltmeter, which is measure the voltage between two points in the circuit and, with digital electronics, this is an analog range from zero to the level of the power supply (Vcc). Digital voltmeters work by converting the analog value to a digital value using an analog to digital converter (ADC). A typical Arduino has several of these converters on the board. Figure-12, shows the circuit.

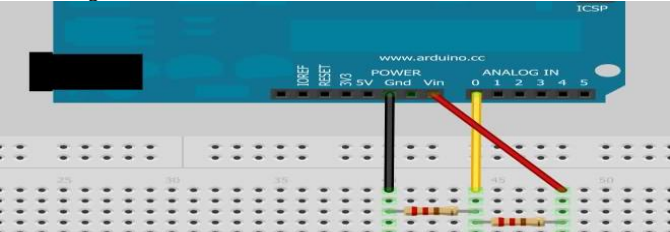


Figure-12: Voltage Divider Circuit

- **Motor Driver Circuit:** Figure-13 illustrates the wiring. B+ and B- at the top of the diagram represent the power supply for the motor. A 5 k or 10 k potentiometer is used to control the speed.

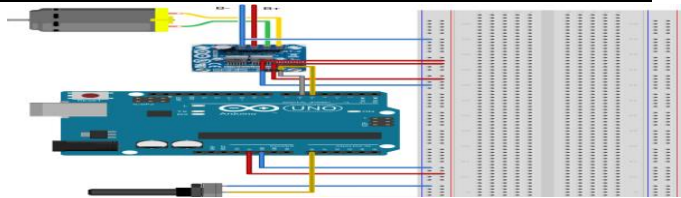


Figure-13: Motor driver circuit

-**SD Card Shield Circuit:** This circuit used to save the data collected from current and voltage sensors into SD card. Figure-14, shows the circuit.

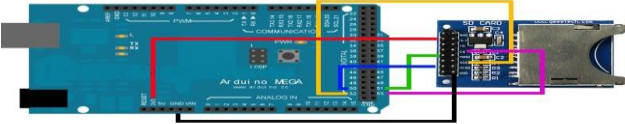


Figure-14: SD Card Shield Circuit

b) **Arduino programming**
In proposed system Arduino 1.6.9 version for

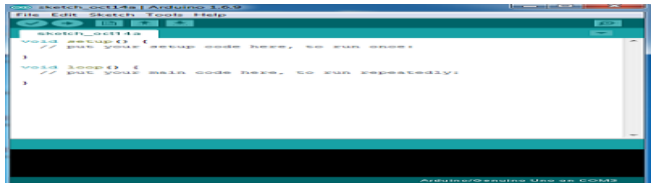


Figure-15: Empty sketch book of the Arduino

programming has been used, figure-15. That is an open project that allows writing and debugging codes efficiently which is also immensely supported by vast library files. The library files assisted us in designing algorithms from a sketch books and example's directory. Verification and compilation of error is smooth and easily accessible. By opening Arduino mega 2560 sketch book we can select specific board and upload programming codes. Solar tracker system operation and the flow chart are shown in figures-16 and 17. LDR detect the sun light and send signals to the Arduino which is send signals to the motor drivers to derive the motors that moves the solar panel toward the sun.

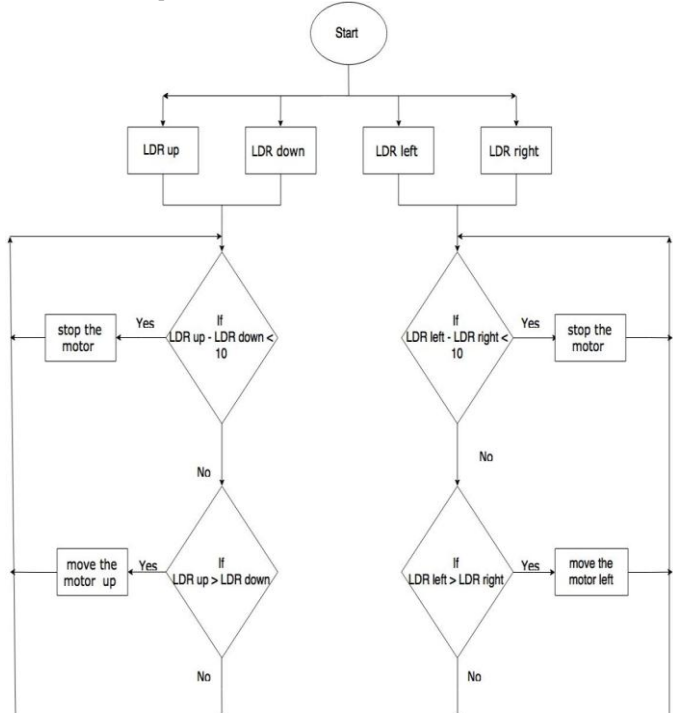


Figure-16: The block diagram of the operation of the whole proposed system

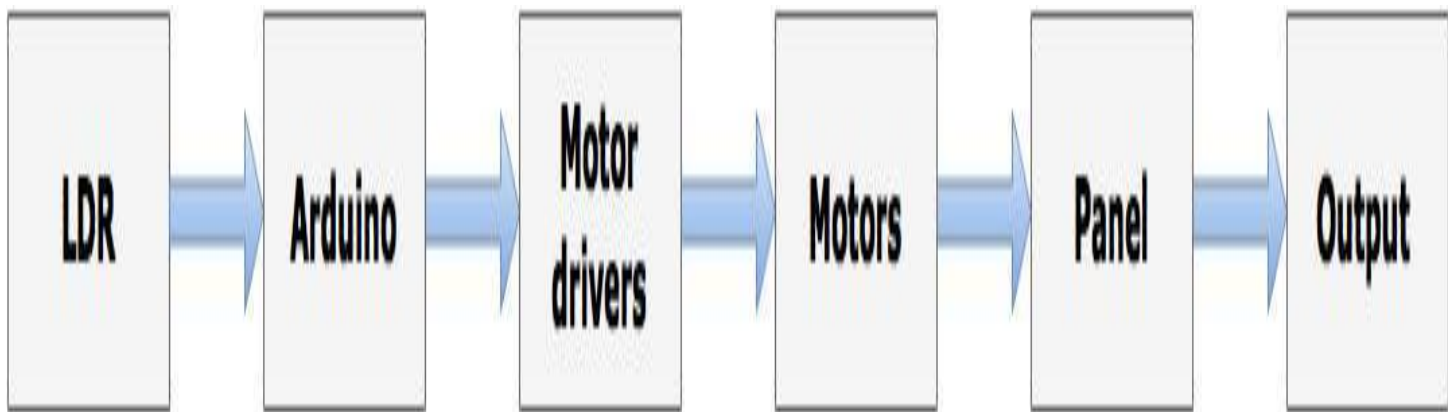


Figure-17 Shows The Flow Chart of Arduino Program

5-Final Solar Tracking System Components:

Figures – 18 to 21 show the final design of the solar tracking system of this work.

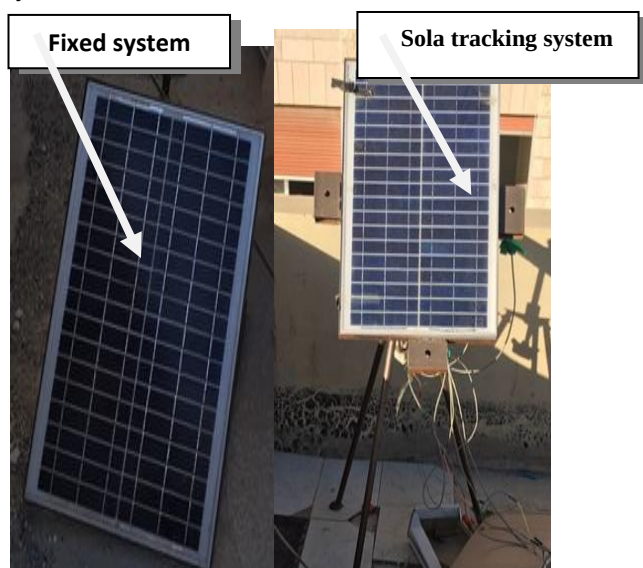


Figure-18: Solar Tracking PV System and Fixed PV System

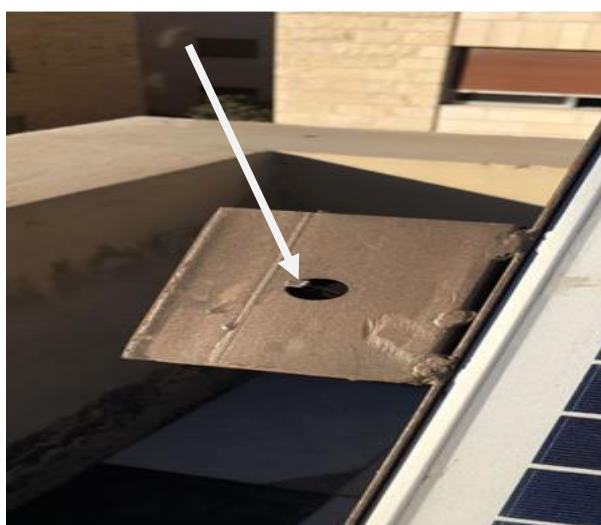


Figure-19: LDR That Used in The System

LDR

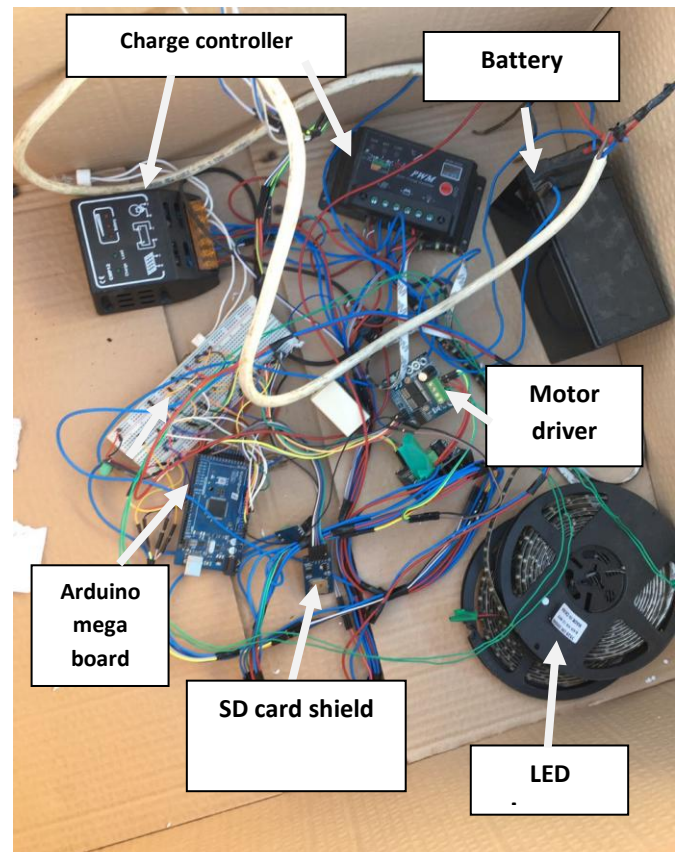


Figure-20: Electrical Circuits

Results and Data Analysis:

The experimental investigation was carried out in order to compare the performance of the solar tracking PV panel in comparison with a fixed PV panel of the same type. The two PV panels were subjected to the same solar irradiation conditions in the same time and the energy output of each panel was monitored and compared. The experimental measurements were carried out in different meteorological conditions with the purpose of comparing the supplementary output power obtained in case of a PV panel equipped with a solar tracking mechanism. The experimental study of the solar tracking prototype has used a modern Data Acquisition System (DAS) composed of a SD card module, that can read and write, and save the data that have been collected. The software interface for the management of the measurement system was developed using Arduino development platform since it is characterized by a high compatibility with many types of data acquisition boards. The recorded data can be saved in TXT files, that can be analyzed separately. Since the studied application could entail very long data acquisition

running time. The experiment was performed at different meteorological conditions. The system takes the measurement every 6 minutes. The data were setup to determine the percentage difference in power output between fixed position (30 degrees to the horizontal) and dual-axis tracker. Figures 22- 29 show the power output of two systems, fixed and dual-axis tracker at sunny, dusty, partially cloudy and cloudy days. The average power output was greater in favor of the dual-axis tracker than fixed one.

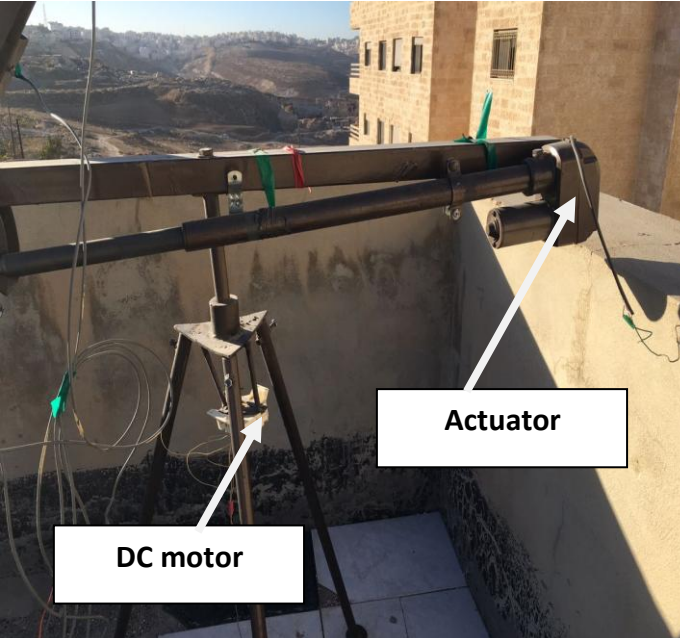


Figure-21: Motors That Used in The System

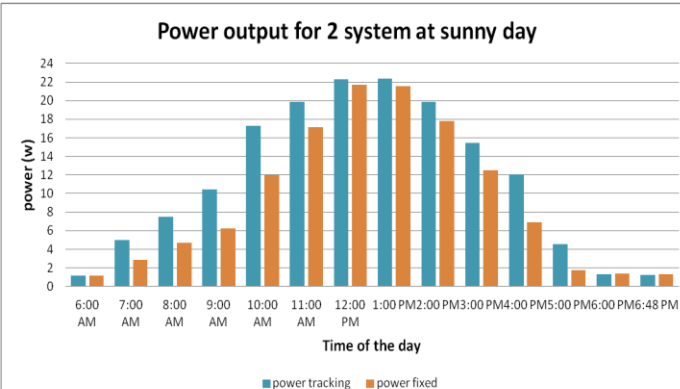


Figure-22: power output for 2 systems at sunny day

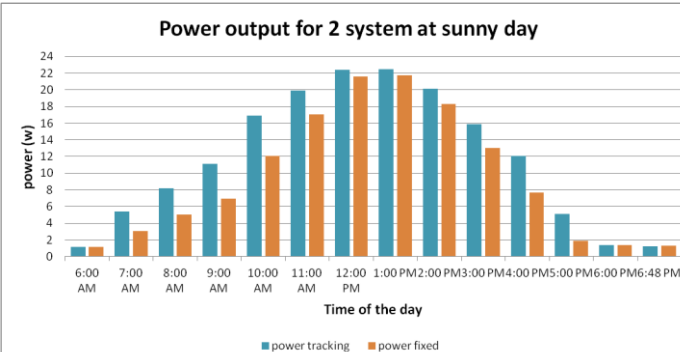


Figure-23: power output for 2 systems at sunny day

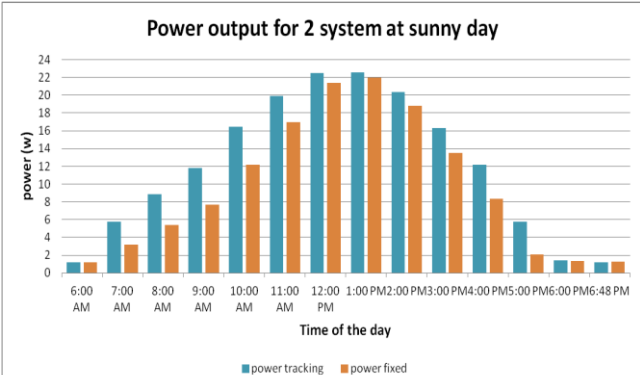


Figure-24: Power output for 2 systems at sunny day

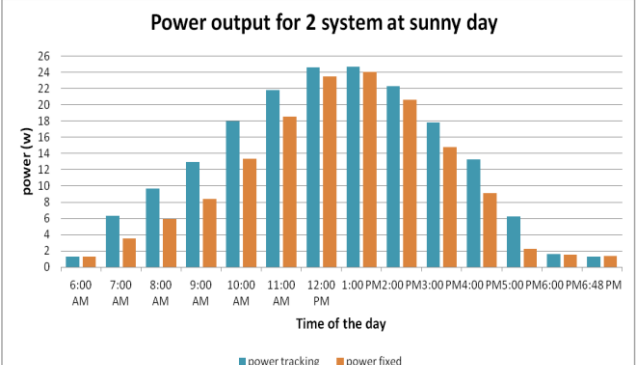


Figure-25: Power output for 2 systems at sunny day

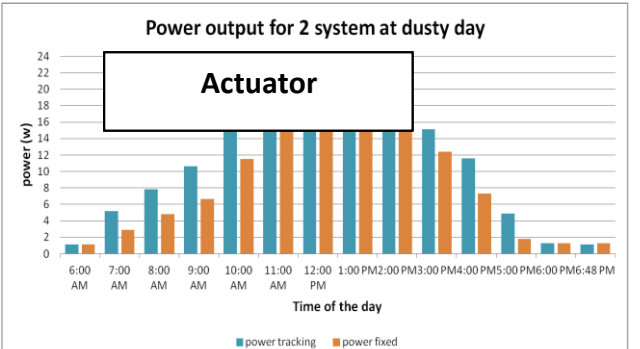


Figure-26: Power output for 2 systems at dusty day

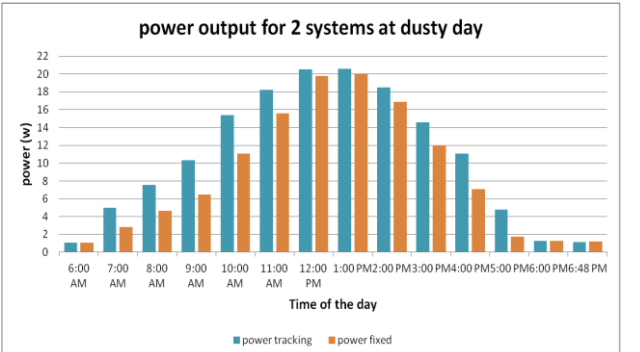


Figure-27: Power output for 2 systems at dusty day

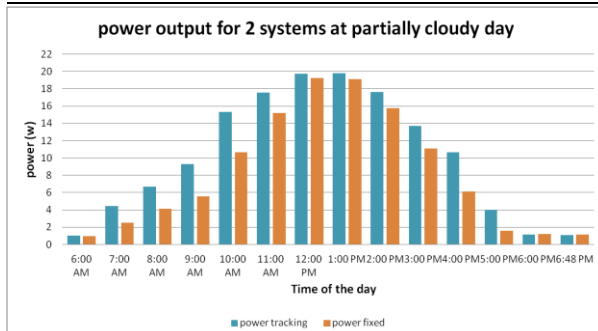


Figure-28: Power output for 2 system at partially cloudy day

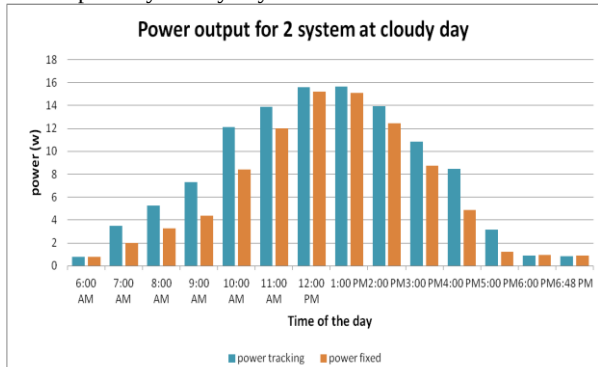


Figure-29: Power output for 2 systems at cloudy day

Within the day the power was nearly zero at sunrise and sun set for the two systems because there is no sun light. At noon the power generates by two systems was almost the same because the fixed PV panel is directly faced to the sun like the tracked PV panel. The power generated by the two systems affected by the metrological conditions like dust and clouds. Regardless the time periods of linear increasing and decreasing of power output, the monotonic power output region, the period of time chosen was between 6:00 and 19:00. By employing dual-axis tracker the average of increasing was calculated to be 39.8%, 35.4%, 36.91%, 36.4%, 36.95%, 36.86%, 37.63% and 37.628% over the fixed one due to 8 days.

Conclusions :

From the results of this work the following conclusions can be drawn:

- Analysis of data showed that a significant gain of the power output when using tracking system in comparison with the fixed axis. Also confirmed that the dual- axis tracking system oriented PV modules perpendicularly to the sun had a tremendous performance improvement on PV panel output.
- The amount of the collected global solar radiation and the produced electricity by the different systems depends on the system, the sky state conditions and the orientation parameters. Also the results revealed that the employment of the Dual-Axis Tracking System can produced 37.37% gain of power output, compared with a fixed System inclined at 30° to the horizontal

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ОБОСНОВАНИЕ ВЫБОРА РАЦИОНАЛЬНОГО ОБОРУДОВАНИЯ ДЛЯ КОНТЕЙНЕРНОГО ПОДЪЕМА НА ОТКРЫТЫХ ГОРНЫХ РАБОТАХ

JUSTIFICATION OF THE CHOICE OF RATIONAL EQUIPMENT FOR CONTAINER LIFTING IN OPEN-OPEN MINING

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Abstract: This paper proposes a new technology for delivering rocks in containers without constructing transport communications in the quarry and having technological and energy-saving advantages. These advantages are: transportation of rocks over the shortest distance and a low container tare ratio, which will reduce energy consumption and the cost of transporting rock mass. Quarry single-bucket excavators and cranes of various types were considered as equipment for lifting rock mass. The results of the calculations prove the technical feasibility of operating quarry lifting machines based on a dragline. The technological scheme using quarry lifting machines has sufficient reliability, flexibility and versatility. It allows you to gradually increase the lifting height, disperse complexes of lifting machines, distribute or combine cargo flows by type of rock mass.

Keywords: QUARRY, TRANSPORTATION OF ROCKS, BLADE, LIFTING MACHINE, CONTAINER, ROPE EXCAVATOR, CRANE.

1. Введение

Наиболее распространенным видом карьерного транспорта в настоящее время является автомобильный [1]. Автотранспорт широко применяется на нижних горизонтах глубоких карьеров, а также как основной вид транспорта, на мелких карьерах небольшой производительности. Он применяется в качестве сборочного, подъемного и доставочного оборудования в силу ряда его бесспорных достоинств: маневренности, автономности, универсальности и простоты организации его работы. В то же время, несмотря на очевидные преимущества автотранспорта, ему присущи и серьезные недостатки. С увеличением глубины крупных карьеров автотранспорт все меньше используется как сборочный и все больше выполняет работу по подъему горной массы по борту карьера [2-4].

Энергетически подъем горной массы по борту карьера автотранспортом на большую высоту нерационален из-за высокого коэффициента тары автосамосвалов. Исследования и опыт эксплуатации автотранспорта в карьерах [5-6] показывают, что расход топлива автомобилем и, соответственно, вредные выбросы в атмосферу возрастают в 4 раза при переходе автосамосвала с горизонтального перемещения горной массы на подъем его из карьера по траншее. Таким образом, наиболее распространенный в настоящее время вид карьерного транспорта - автотранспорт — не отличается энергоэкономичностью и экологичностью в необходимой степени [7].

Выполненный анализ существующих технологий открытых горных работ и современного состояния горного производства указывает на насущную потребность в разработке новой ресурсосберегающей и экологически безопасной технологии. Была предложена новая контейнерная технология транспортировки горной массы в контейнерах без строительства в карьере технологических и транспортных коммуникаций. Достоинствами, которой будут являться:

1. Одноразовая экскавация горной массы при погрузке ее в контейнер снижает энергозатраты.
2. Доставка горной массы транспортом сборочного звена от забоев к месту подъема выполняется на минимальные расстояния по горизонтальным автодорогам, что приводит к снижению потребного парка автотранспорта, удельного расхода топлива, шин и выбросов вредных газов в атмосферу.
3. Коэффициент тары контейнера (0,25-0,30) значительно меньше коэффициента тары автосамосвала (0,70-0,80) или железнодорожного состава (0,80- 0,82), поэтому удельные

затраты энергии на подъем горной массы в контейнере подъемной машиной сокращаются в 1,4 раза.

4. Комплекс подъемных машин обладает мобильностью, что позволяет перемещать его на новое место при производстве взрывных работ или в другой карьер при последовательной отработке группы карьеров. Повышаются возможности регулирования и соблюдения оптимального режима горных работ.

5. Исключается необходимость дополнительного энергоемкого дробления горной массы в отличие от технологических схем с применением конвейерных подъемников.

6. Контейнерная доставка вскрышных пород и использование карьерных подъемных машин при отвалообразовании позволит уменьшить необходимый земельный отвод и формировать компактный высокий отвал с минимальными затратами на подъем породы.

Главной особенностью предлагаемой технологии является, что все оборудование для контейнерной доставки просто в изготовлении и может быть изготовлено на самом горном предприятии. В качестве подъемной машины было рассмотрено использование карьерных и шагающих экскаваторов, а также деррик-кранов.

На многих карьерах ряда европейских стран (Италии, Испании, Франции, Греции и др.) доминирующее распространение получили деррик-краны грузоподъемностью до 50 тонн и длиной стрелы до 40 метров [8]. К их преимуществам можно отнести:

- возможность использования одного вида оборудования для двух совмещаемых процессов (выемки-погрузки и транспортирования блоков);
- простоту обслуживания;
- относительно низкую стоимость оборудования;
- возможность комплексной механизации процессов выемки-погрузки и транспортирования.

Применение деррик-крана возможно при размещении его опорных частей на бетонированном основании объемом 8-10 м³, что не всегда осуществимо в сложных горно-геологических условиях, так как вызывает трудности при перестановке в случаях значительной подвижки фронта горных работ. В ряде европейских стран крепление деррик-кранов осуществляется следующим образом: бурение шпура или скважины диаметром 75-105 мм на глубину 2-7 метров; размещение в скважине или шпуре металлического стержня с последующей его заливкой быстротвердеющими органическими смесями; болтовое или сварное соединение опоры или основания деррик-крана со стержнем [9-10].

Применение на разрабатываемом месторождении деррик-кранов нецелесообразно, так как они стационарны и затрудняют ведение горных работ при использовании БВР. Кроме того, их сложно устанавливать на уступе и необходимо проводить мероприятия для предотвращения деформации борта.

2. Методика проведения эксперимента

В наибольшей степени предложенным требованиям контейнерной технологии отвечает экскаватор ЭШ-10/70. Наиболее ответственным узлом экскаватора является стрела, которая должна выдержать нагрузку от веса груженного контейнера, кроме того при проектировании стрелы необходимо учитывать инерционные и ветровые нагрузки на рабочее оборудование. Экскаваторы ЭШ-10/70 оборудуются комбинированной стрелой, которая не выдерживает новой концевой нагрузки - 80 тонн. Поэтому была спроектирована новая трехгранная жесткая стрела, у которой были назначены диаметры труб, из которых планируется собрать стрелу: несущие трубы – диаметр 720 мм, толщина стенки 10 мм; распорки – диаметр 219 мм, толщина стенки 6 мм.

Расчет стрелы производится в программном комплексе ЛИРА 9.6. Программный комплекс ЛИРА (ПК ЛИРА) – это многофункциональный программный комплекс для расчета, исследования и проектирования конструкций различного назначения. В результате расчетов установлено, что стержни 60, 61, 84, 85 не обеспечивают достаточную прочность. По рекомендации программы необходимо применить трубы большего диаметра. По данным расчета прочность стрелы обеспечивается. Схема стрелы приводится на рисунке 1.

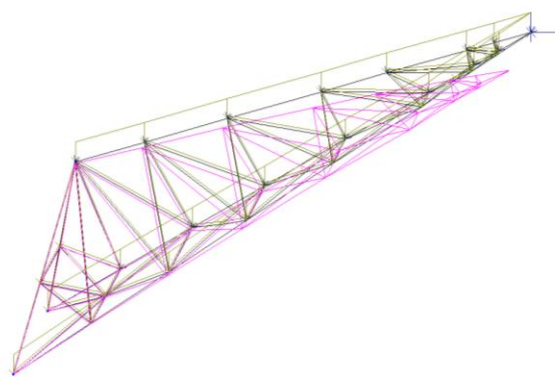


Рис. 1 Схема деформации стрелы

Для выявления работоспособности драглайна были проведен динамический расчет приводов экскаватора и выполнен статический расчет с проверкой машины на устойчивость и уравновешенность поворотной платформы. Все проведенные вычисления доказывают работоспособность предложенного варианта.

Для исследования работы подъемной машины с контейнером данной конструкции был изготовлен его макет и проведены испытания. Для проведения эксперимента действующая модель драглайна была переоборудована в подъемную машину. Был заменен ковш на контейнер и заменена запасовка тягового каната. Схема станда показана на рисунке 2. Щит приборов оборудован амперметром и вольтметром для измерения нагрузки на приводах подъема, тяги и поворота и секундомером для измерения времени цикла.



Рис.2 Модель подъемной машины

3. Обработка экспериментальных данных

На основании экспериментальных данных была построена зависимость времени цикла от грузоподъемности контейнера, которая приводится на рисунке 3.

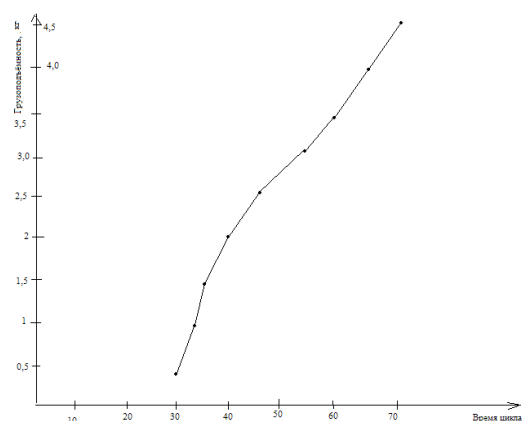


Рис. 3 Зависимость грузоподъемности контейнера от времени цикла подъемной машины

Зависимость массы концевой нагрузки от мощности главных приводов показана на рисунке 4.

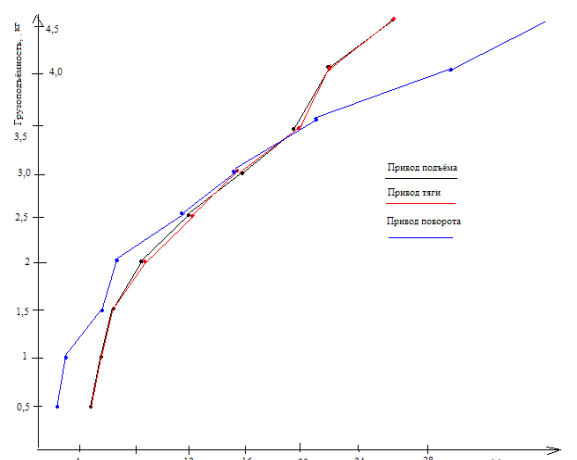


Рис. 4 Зависимость потребляемой мощности приводов подъемной машины от грузоподъемности контейнера

4. Выводы

Контейнерная технология позволяет повысить показатели открытых горных работ по экономии энергоресурсов и

сохранению окружающей среды на качественно новый уровень. С учетом опыта ее развития в других отраслях промышленности позволит на открытых горных работах снизить удельные энергозатраты, повысить экологическую безопасность и производительность труда. Снижение расхода энергии и разрушительного воздействия открытых горных работ на окружающую среду происходит за счет использования на всех этапах доставки горной массы оптимальных видов транспорта, а также за счет выполнения перегрузочных операций с высокой производительностью без дополнительной экскавации горной массы. Контейнерная технология позволяет решать весь комплекс задач по основным технологическим процессам открытых горных работ – от выемки пород в забое до укладки их в отвал. В качестве оборудования новой технологии, возможно, использовать существующие горные машины с небольшой доработкой, проводимой на самом горнодобывающем предприятии.

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Application and effectiveness of SMFC-based biosensors for real-time monitoring of water pollution with chromium, zink and nickel

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Abstract: Heavy metal pollution from various industries has received much attention worldwide due to their toxicity and persistence in the environment. Traditional water quality monitoring relies on sampling, preservation, transportation and subsequent laboratory analysis. All these procedures require considerable time and make it impossible to timely detect heavy metal contamination. To overcome the drawback, SMFC-based biosensors can be used for monitoring water pollution with heavy metals. The electrochemical characteristics of SMFCs are sensitive to heavy metal ions, therefore, when heavy metals enter them, the cell voltage immediately rises in proportion to their concentration. The change in voltage can be used to find the presence of heavy metals in the water and their concentration. In the present study, the possibilities for monitoring water contaminated with copper, zinc, nickel and chromium by means of SMFC-based biosensors were investigated. The constructed biosensors showed high sensitivity to the ions of the four investigated metals.

Keywords: SMFC-BASED BIOSENSORS, HEAVY METALS, WATER MONITORING

1. Introduction

Heavy metal pollution can be both natural and anthropogenic. Heavy metals from anthropogenic activity are more mobile and bioavailable than natural ones and pose a greater risk to human health and the environment. The level of heavy metal pollution has increased significantly with rapid industrialization. Heavy metals released from various industrial activities are distributed in the environment, mainly through running surface waters. [11]

Industrial wastewater usually contains heavy metals such as chromium, copper, lead and others, which in high concentrations can cause health problems and pollution of natural ecosystems. There are various chemical, physical and biological technologies for treating such waters that effectively remove heavy metals. However, after treatment, the water must be examined to see if it meets the discharge standards. If emissions of heavy metals exceed permissible concentrations, this can lead to serious environmental problems and damage to the environment. It is crucial that the concentrations of heavy metals in wastewater are strictly controlled in real time before they are released into the environment. [6] Most control methods include periodic monitoring, which implies a limitation in monitoring, as the samples reflect the current water quality. No contamination may be detected at the time of sampling or it may be minimal, but may have a significant impact on aquatic ecosystems over a long period of time. This disadvantage is much more serious in running surface water, where conditions can change at any time. [9] This problem is solved with the use of appropriate biosensors, through which water quality can be monitored and environmental pollutants can be detected on site and in real time. [1] Traditional methods of analysis have high selectivity and sensitivity, but are also expensive, have complex sampling and sample preparation, and cannot provide real-time and on-site data. [4] In recent years, a number of biosensors have been developed, which integrated devices are combining biological materials and transducers, for quantitative and semi-quantitative monitoring of various analytes, such as heavy metals, BOD and others. [12]

To overcome the shortcoming, it is possible to use sensors based on sediment microbial fuel cells to monitor heavy metal contaminants occurring in wetlands. [2] The main advantages of the sensor include the reduction of heavy metals on the cathode leading to an increase in voltage. [8] Sediment adsorbs much of the heavy metal, protecting electroactive microorganisms from being inhibited by heavy metal ions, so the sensor can operate normally after shock contamination. The sensor uses natural electroactive bacteria living in the sediment, generating base voltage, therefore the inoculation process can be avoided. Based on the above advantages, the sensor would be suitable for monitoring recurrent heavy metal contamination in water. [3]

The main advantages of sediment microbial fuel cells are low cost, simple construction and long-term output power. In this way, the system is applicable as a biosensor for long-term in situ

operation. [5] There are a number of data on the application of SMFC-based biosensors for real-time monitoring of environmental parameters such as temperature and dissolved oxygen. [7]

The purpose of this study is to investigate the possibilities for application of sediment microbial fuel cells, such as biosensors for monitoring recurrent water pollution with chromium, zink and nickel.

2. Materials and methods

Soil Sampling

For the purpose of the study, river sediment was taken from Ivanyanska river, Bulgaria (42°42'27.1"N 23°11'46.4"E), from a depth of 20-30 cm. After taking the river sediment, the larger pieces were removed by sieving through 2 mm. In order to carry out physicochemical analyses, part of the sieved soil was air-dried. Soil pH was measured by pH-meter HANNA HI-9021 determined at 1 : 2.5 (soil:water). Soil electrical conductivity (EC) was measured by WTW LF 197-S determined at 1 : 5 (soil:water). The main soil physicochemical properties were as follow pH 6.89, EC 142.31 $\mu\text{S cm}^{-1}$. The soil was classified as sandy clay loam, the Kjeldahl-N content were 0.214% and dissolved organic carbon 68.34 mg kg^{-1} .

Construction of SMFC biosensor

The sediment microbial fuel cell is a plastic container with a volume of 800 cm^3 . At the bottom of the vessel is a stainless steel electrode with an area of 32 cm^2 . The vessel was filled with river sediment with a volume of 550 cm^3 . The cell was then filled with pure water and a second 32 cm^2 stainless steel electrode was placed in the surface layer of the water. The physicochemical characteristics of water was pH 7.08, Eh 363 mV and EC 62 $\mu\text{S cm}^{-1}$ measured by Vernier LabQuest Mini. On Figure 1 is shown a scheme of the laboratory model of the SMFC-biosensor

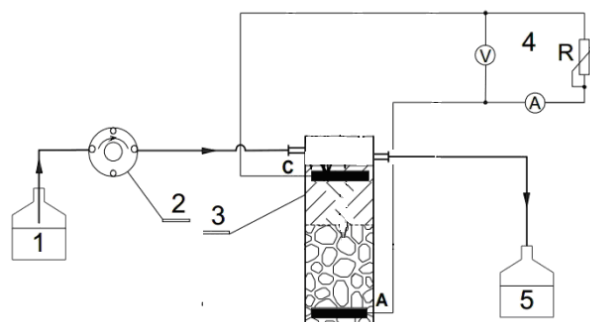


Fig. 1 The schematic diagram of the SMFC-based biosensor

1 – Inflow, 2 – Peristaltic pump, 3 – Sediment microbial fuel cell, 4 – Digital multimeter, 5 – Outflow, A – Anode C – Cathode

The test solutions pass through the cathode zone, where heavy metals ions play the role of an additional electron acceptor and increase the voltage of the cell by changing the electrochemical parameters. Three identical SMFC-based biosensors were made. The anode and cathode of each biosensors were connected with an external 1000 Ω resistor using copper wire. Then they had been acclimated, until the base voltage is reached and the electroactive microorganisms acclimatize.

Heavy metals pollution

For the purposes of the study, synthetic solutions containing chromium ($K_2Cr_2O_7$), zinc ($ZnSO_4 \cdot 7H_2O$) and nickel ($NiSO_4 \cdot 6H_2O$) with different concentrations were prepared. Solutions were prepared in seven concentrations – 0.5, 1, 2.5, 5, 10, 25, 50 mg/l.

Electrochemical analysis

To determine the response of voltage signals to Cu^{2+} shock, the biosensors' voltage was measured and recorded with Vernier LabQuest Mini and Logger Lite software.

3. Results and discussion

Based on the obtained electrical characteristics, the three SMFC-based biosensors were switched to operate with an external resistor of 1000 Ω for 14 days until the voltage reached a relatively stable plateau and acclimatize the electroactive microorganisms. The results of the study are presented in Figure 2.

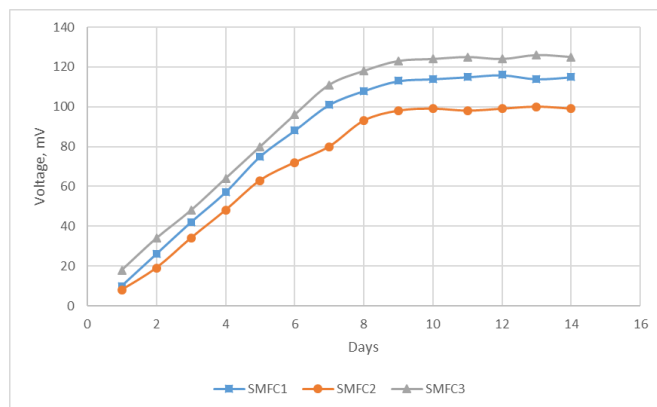


Fig. 2 Base voltage dynamic of SMFC-based biosensors

From the graph presented, it can be seen that after the ninth day, all three SMFC-based biosensors reach a base voltage of approximately 126 ± 2 mV, 117 ± 3 mV and 99 ± 2 mV.

After stabilizing the voltage, we moved on to the next part of the experiment. Synthetic heavy metals solutions with increasing concentration – 0.5, 1, 2.5, 5, 10, 25, 50 mg/l were successively fed to the three SMFC-based biosensors. The feed rate was 3 ml/s. The feed rate affect on speed of reaction of SMFC-based biosensor but not on the value of the voltage change. When feeding the individual solutions, the change in voltage after its stabilization was taken into account. Based on the change in voltage at different heavy metals concentrations, a standard curve is plotted.

Figure 3 shows the results for Cr^{6+}

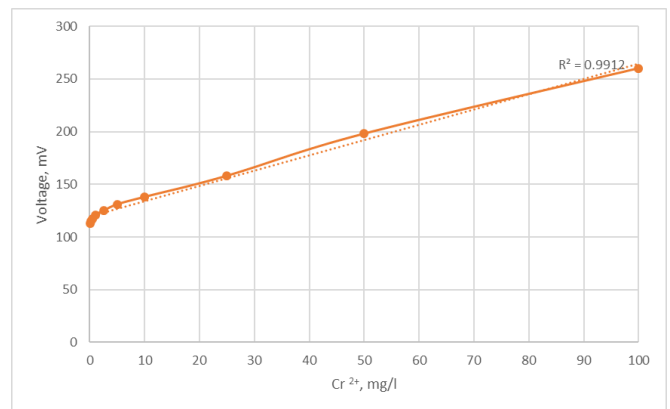


Fig. 3 SMFC-based biosensors standard curves Cr^{6+}

The graph shows a high coefficient of determination - $R^2 = 0.9912$, for Cr^{6+} . A slight deviation is also observed of the graph from the standard curves in the studied interval.

Figure 4 shows the results for Zn^{2+}

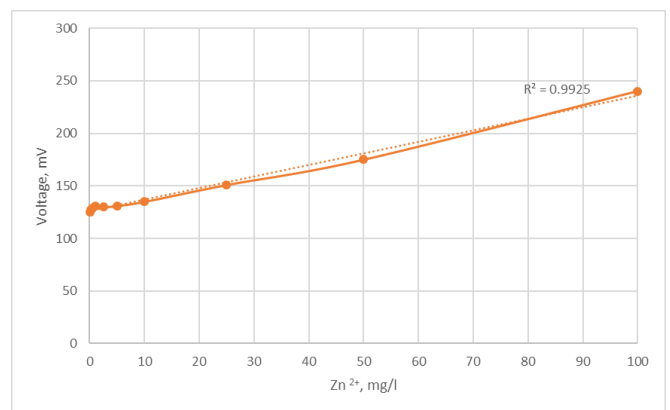


Fig. 4 SMFC-based biosensors standard curves Zn^{2+}

For Zn^{2+} coefficient of determination reach $R^2 = 0.9925$. It can be seen from the graph that the sensor exhibits good sensitivity to zinc ions and a strong correlation between its concentration and the rise of the sensor voltage

Figure 5 shows the results for Ni^{2+}

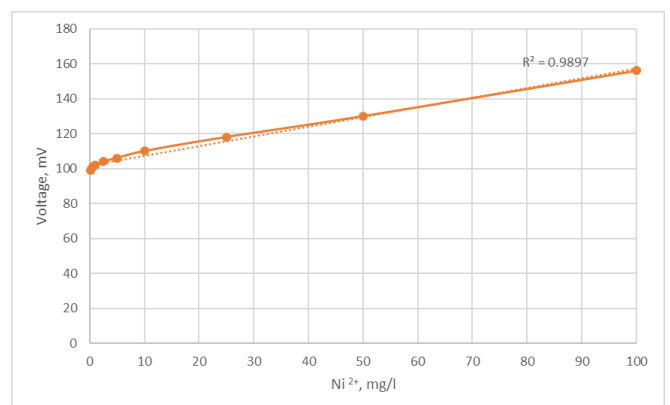


Fig. 4 SMFC-based biosensors standard curves Ni^{2+}

In the study with synthetic zinc solution, the biosensor also showed good performance. The coefficient of determination reach $R^2 = 0.9897$. Of the metals studied, zinc shows the weakest rise in voltage with increasing metal concentration.

4. Conclusion

In order to determine the possibilities for application of sediment microbial fuel cells as biosensors for monitoring of recurrent water pollution with chromium, zinc and nickel, two identical SMFC-biosensors were constructed. The influence of seven concentrations of chromium, zinc and nickel (0.5, 1, 2.5, 5, 10, 25, 50 mg/l) on the change of the electrochemical parameters of the cells was studied. The addition of heavy metals ions in the cathode region increases the electrochemical parameters of the cell, because in addition to dissolved oxygen, copper cations are also used as the ultimate acceptor of electrons.

When using SMFC, a correlation was found between the increase of the heavy metal ions concentration in the cathode region and the change in the electrochemical parameters of the cell, reaching a coefficient of determination of $R^2 = 0.9912$, 0.9925 , 0.9897 for Cr^{6+} , Zn^{2+} , and Ni^{2+} respectively. Research has shown that sediment microbial fuel cells can be used as biosensors for recurrent contamination with chromium, zinc and nickel, but further research is needed on their design, inertia in changing electrochemical parameters and detection range.

From the conducted studies, it was established that with all three resistances, the same sensitivity to copper ions and high efficiency of SMFC-based biosensors was observed in the studied interval. The results also have shown that the constructed SMFC-biosensor has wider detection interval and larger voltage change ΔV at the studied concentrations

Acknowledgements

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Energy evaluation of a three-cylinder steam turbine which operates in combined cycle power plant

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Abstract: This paper presents an energy analysis of a three-cylinder steam turbine from a combined cycle power plant. Observing all the cylinders from the analyzed turbine, it is found that the dominant mechanical power producer is Low Pressure Cylinder (LPC), followed by the Intermediate Pressure Cylinder (IPC), while High Pressure Cylinder (HPC) is the cylinder which produces the lowest mechanical power. Whole observed steam turbine develop 119.41 MW of useful mechanical power. Energy loss and energy efficiency of all cylinders are reverse proportional – higher energy efficiency will result with lower energy loss and vice versa. IPC is the cylinder which has the lowest energy loss (equal to 2.59 MW) and the highest energy efficiency of 93.32%. Whole observed steam turbine has energy loss equal to 23.43 MW, while its energy efficiency is equal to 83.60%, what falls in the expected range of such low power steam turbines. Steam mass flow rate through each cylinder is the main element which defines produced mechanical power and energy flows.

KEYWORDS: THREE-CYLINDER STEAM TURBINE, COMBINED CYCLE POWER PLANT, ENERGY FLOW STREAMS, ENERGY EVALUATION

1. Introduction

Considering energy systems worldwide, it can be concluded that in many of them exists heat turbines in various combinations [1, 2]. In conventional steam power plants and nuclear power plants, steam turbines are essential components [3-5]. Steam turbines can also be often found in various cogeneration power plants and systems which simultaneously produces and delivers two types of energy – heat and electrical [6, 7].

Power plants which have one of the highest overall efficiencies are combined cycle power plants [8]. Combined cycle power plants consist of at least one gas turbine and at least one steam turbine [9]. In such power plants, combustion gases after expansion in gas turbine are not released to the atmosphere – heat from combustion gases is utilized in Heat Recovery Steam Generator (HRSG) and used for superheated steam production [10, 11]. Steam from HRSG is delivered to steam turbine which produces an additional amount of useful mechanical power, dominantly used for electrical generator drive [12]. As HRSG in combined cycle power plant did not use additional fuel (or use a small amount of additional fuel), the entire steam mass flow rate is produced by using waste heat from gas turbine [13]. Heat utilization in combined cycle power plants results with notable fuel savings, which increases plant efficiency and have many economic benefits [14].

In combined cycle power plants can be used various types of steam turbines, what mostly depends on the HRSG composition and operation characteristics [15]. In this paper is analyzed (from the energy aspect) three-cylinder steam turbine, as well as its cylinders, which operate in the commercial combined cycle power plant. It is investigated which cylinder of this turbine shows the best performance, the characteristics and operation parameters of the whole steam turbine are also analyzed and the steam turbine dependence on HRSG is discussed. This analysis can and should be used as a baseline for further improvements of this and many similar steam turbines which operate in combined cycle power plants.

2. Description and operation characteristics of the analyzed turbine

Steam turbine analyzed in this paper operates in a steam part of complex combined cycle power plant [16]. The turbine is composed of three cylinders connected to the same shaft which drives an electric generator, Fig. 1.

The steam mass flow rate used in the steam turbine cylinders is produced in HRSG which uses combustion gases from a gas turbine to produce steam. If required, an additional amount of fuel can be used in a secondary burner before HRSG for the combustion gases temperature increase, but the dominant heating medium is combustion gases from gas turbine [17]. In such way, HRSG utilizes heat released from the gas turbine and produces superheated steam which will expand in the steam turbine cylinders. Due to the high heat utilization, combined cycle power plants have extremely

high efficiencies, one of the highest in the overall energy sector [18].

Observation of the steam turbine analyzed in this paper shows that superheated steam produced in HRSG is delivered firstly to High Pressure Cylinder (HPC), expands through it and is returned back to HRSG. Again, from HRSG steam is delivered to Intermediate Pressure Cylinder (IPC), expands through it and is again returned back to HRSG. The last cylinder which gets steam from HRSG is Low Pressure Cylinder (LPC). After expansion in LPC steam has a very low temperature and pressure, it cannot be used anywhere else in the power plant, so from the LPC outlet steam is delivered to steam condenser for condensation [19]. Condensate obtained in steam condenser will be returned back to HRSG and from that condensate will be produced superheated steam for the HPC again. This circulation is continuous during power plant operation.

From the general and simplified steam turbine scheme, Fig. 1, can be observed that neither one cylinder did not possess steam extraction, so the steam mass flow rate which enters in each cylinder will expand through entire cylinder until its outlet. HRSG in this power plant is a highly complex device, so in Fig. 1 are presented only some HRSG parts essential for the turbine operation.

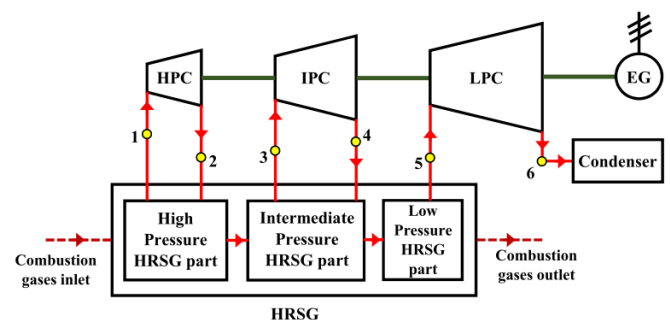


Fig. 1. General scheme of the observed three-cylinder steam turbine from combined cycle power plant along with operating points necessary for the energy analysis

Steam expansion processes (both ideal and real) through each cylinder of the observed steam turbine are presented in specific enthalpy-specific entropy (h - s) diagram in Fig. 2.

Real (polytropic) steam expansion process through each cylinder is marked in accordance to operating points from Fig. 1. From Fig. 2 is clear that real (polytropic) steam expansion process involves losses which occur during steam expansion due to increase in steam specific entropy.

In comparison to real (polytropic) steam expansion, ideal (isentropic) steam expansion process did not consider any losses which occur during expansion, therefore in an ideal process steam specific entropy remains always the same. The ideal steam expansion process is actually the process between the same pressures and with same mass flow rates as real process, but in ideal

process steam specific entropy remains unchanged from the inlet until the outlet of each cylinder. Due to losses neglecting, ideal (isentropic) steam expansion process will result with the highest theoretical power which can be developed by each cylinder and the whole turbine. Real expansion processes should have intention to be as close as possible to the ideal ones, but ideal processes cannot be achieved in real exploitation conditions. However, the ideal expansion process can be a proper guideline for losses decreasing in any cylinder and whole turbine. The operating points of the ideal (isentropic) steam expansion processes are numerated in a same manner as presented in Fig. 1, but with “is” as an addition along with the number.

In Fig. 2, ideal expansion process in HPC is marked with operating points 1 and 2is, in the IPC ideal process is marked with operating points 3 and 4is and in LPC ideal steam expansion process is the process between operating points 5 and 6is.

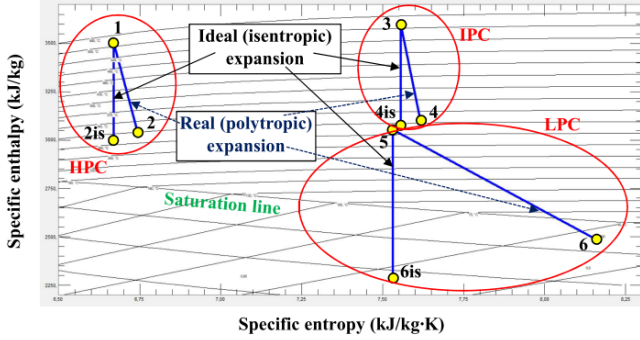


Fig. 2. Steam expansion process (ideal and real) in h - s diagram throughout all the cylinders of the analyzed three-cylinder steam turbine from combined cycle power plant

3. Equations required for the analysis

The first law of thermodynamics defines energy analysis. Such kind of analysis did not consider the parameters of the ambient inside which observed system or a component operates [20].

However, in the energy analysis exists a few overall equations and balances which should always be satisfied, in any operating conditions of the observed system or a component. These equations will be presented in the first part of this section, after which will be presented exact equations for the energy analysis of the observed three-cylinder steam turbine from a combined cycle power plant.

3.1. Overall energy analysis equations and balances

For any system or a component, always valid energy balance equation is [21]:

$$\dot{Q}_{IN} + P_{IN} + \sum \dot{E}n_{IN} = \dot{Q}_{OUT} + P_{OUT} + \sum \dot{E}n_{OUT} + \dot{E}n_L, \quad (1)$$

where $\dot{Q}$ is an energy transfer by heat, P is mechanical power, index IN is related to the inlet (input), index OUT is related to outlet (output) and index L is related to the loss (destruction). $\dot{E}n$ is a total energy flow of any fluid stream, which definition can be found in [22] and presented by an equation:

$$\dot{E}n = \dot{m} \cdot h, \quad (2)$$

where $\dot{m}$ is a fluid mass flow rate and h is fluid specific enthalpy. Standard fluid mass flow rate balance (for a system or component without leakages) is [23]:

$$\sum \dot{m}_{IN} = \sum \dot{m}_{OUT}. \quad (3)$$

The overall energy efficiency equation is [24]:

$$\eta_{EN} = \frac{\text{CUMULATIVE ENERGY OUTPUT}}{\text{CUMULATIVE ENERGY INPUT}}. \quad (4)$$

It should be highlighted that overall energy efficiency equation (Eq. 4) can significantly vary from the presented one, what depends on the observed system or component operation characteristics.

3.2. Equations for the energy analysis of whole three-cylinder steam turbine and its cylinders

Equations for the energy analysis of each cylinder and whole observed turbine (WT) are composed according to recommendations from the literature [25]. Markings in the equations are placed in accordance with operating points presented in Fig. 1 and Fig. 2 for both ideal and real expansion processes. Real (polytropic) mechanical power of each cylinder from the observed turbine is:

$$P_{RE,HPC} = \dot{m}_1 \cdot (h_1 - h_2), \quad (5)$$

$$P_{RE,IPC} = \dot{m}_3 \cdot (h_3 - h_4), \quad (6)$$

$$P_{RE,LPC} = \dot{m}_5 \cdot (h_5 - h_6). \quad (7)$$

Ideal (isentropic) mechanical power of each cylinder from the observed turbine (according to Fig. 2) is:

$$P_{ID,HPC} = \dot{m}_1 \cdot (h_1 - h_{2is}), \quad (8)$$

$$P_{ID,IPC} = \dot{m}_3 \cdot (h_3 - h_{4is}), \quad (9)$$

$$P_{ID,LPC} = \dot{m}_5 \cdot (h_5 - h_{6is}). \quad (10)$$

The energy loss of each cylinder from the observed turbine is:

$$\dot{E}n_{L,HPC} = P_{ID,HPC} - P_{RE,HPC}, \quad (11)$$

$$\dot{E}n_{L,IPC} = P_{ID,IPC} - P_{RE,IPC}, \quad (12)$$

$$\dot{E}n_{L,LPC} = P_{ID,LPC} - P_{RE,LPC}. \quad (13)$$

The energy efficiency of each cylinder is:

$$\eta_{EN,HPC} = \frac{P_{RE,HPC}}{P_{ID,HPC}}, \quad (14)$$

$$\eta_{EN,IPC} = \frac{P_{RE,IPC}}{P_{ID,IPC}}, \quad (15)$$

$$\eta_{EN,LPC} = \frac{P_{RE,LPC}}{P_{ID,LPC}}. \quad (16)$$

For the whole turbine, real (polytropic) mechanical power is:

$$P_{RE,WT} = P_{RE,HPC} + P_{RE,IPC} + P_{RE,LPC}, \quad (17)$$

ideal (isentropic) mechanical power is:

$$P_{ID,WT} = P_{ID,HPC} + P_{ID,IPC} + P_{ID,LPC}, \quad (18)$$

while energy loss and energy efficiency of the whole observed three-cylinder steam turbine are:

$$\dot{E}n_{L,WT} = P_{ID,WT} - P_{RE,WT}, \quad (19)$$

$$\eta_{EN,WT} = \frac{P_{RE,WT}}{P_{ID,WT}}. \quad (20)$$

4. Steam operating parameters necessary for the analysis

Essential steam operating parameters (steam pressure, temperature and mass flow rate) in each operating point of the real (polytropic) expansion process from Fig. 1 and Fig. 2 are found in [16] and presented in Table 1.

Table 1. Steam operating parameters at each cylinder inlet and outlet of the observed three-cylinder turbine – real expansion

O.P.*	Temperature (°C)	Pressure (bar)	Mass flow rate (kg/s)	Specific enthalpy (kJ/kg)	Specific entropy (kJ/kg·K)
1	560.6	124.00	65.21	3505.0	6.6695
2	313.2	23.16	65.21	3046.2	6.7423
3	560.6	22.00	72.43	3600.8	7.5554
4	317.2	4.10	72.43	3102.2	7.6168
5	293.0	4.10	94.58	3052.4	7.5307
6	32.9	0.05	94.58	2488.0	8.1563

* O.P. = Operating Point (in accordance to Fig. 1 and Fig. 2)

For the ideal (isentropic) steam expansion process, steam operating parameters are presented in Table 2 (ideal process is the process between the same pressures and with same mass flow rates as ideal one, but it assumes always the same steam specific entropy from each turbine cylinder inlet until the outlet).

Other steam operating parameters presented in Table 1 and Table 2 are calculated by using NIST-Refprop 9.0 software [26] from essential steam parameters.

Table 2. Steam operating parameters at each cylinder inlet and outlet of the observed three-cylinder turbine – ideal expansion

O.P.*	Pressure (bar)	Mass flow rate (kg/s)	Specific entropy (kJ/kg·K)	Isentropic specific enthalpy (kJ/kg)
1	124.00	65.21	6.6695	3505.0
2is	23.16	65.21	6.6695	3004.2
3	22.00	72.43	7.5554	3600.8
4is	4.10	72.43	7.5554	3066.5
5	4.10	94.58	7.5307	3052.4
6is	0.05	94.58	7.5307	2296.6

* O.P. = Operating Point (in accordance to Fig. 2)

5. Results and discussion

Ideal (isentropic) as well as real (polytropic) mechanical power of each cylinder and whole observed three-cylinder steam turbine from a combined cycle power plant are presented in Fig. 3.

Observing all the cylinders from the analyzed turbine, it can easily be seen that the dominant mechanical power producer (both ideal and real) is LPC. IPC produces approximately two times lower mechanical power than LPC in both ideal and real cases, while HPC is the cylinder which produces the lowest mechanical power.

Produced mechanical power in turbine cylinders is directly proportional to mass flow rate of steam which expands through each cylinder. From Table 1 and Table 2 can be seen that the complex arrangement of the HRSG results with an increase in the steam mass flow rate from the highest pressures up to the lowest pressures. A complex HRSG arrangement allows that all steam mass flow rates which exist in the steam part of combined cycle power plant (main and auxiliary steam mass flow rates) can be effectively used in the steam turbine. Therefore, through HPC expands the lowest steam mass flow rate what results with the lowest produced mechanical power of all cylinders, while through LPC expands the highest steam mass flow rate what results with the highest produced mechanical power of all cylinders.

Whole observed steam turbine from combined cycle power plant develop 119.41 MW of useful mechanical power in real process which involves all losses during the expansion, while in an ideal situation, whole turbine will be capable to develop 142.84 MW of mechanical power.

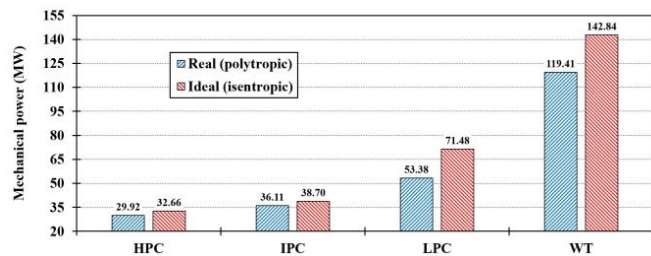


Fig. 3. Ideal (isentropic) and real (polytropic) mechanical power of each cylinder and whole observed three-cylinder steam turbine from combined cycle power plant

Energy loss and energy efficiency of each cylinder and whole observed three-cylinder steam turbine from a combined cycle power plant are presented in Fig. 4.

From Fig. 4 is clear that energy loss and energy efficiency of all cylinders are reverse proportional – higher energy efficiency will result with lower energy loss and vice versa. IPC is the cylinder which has the lowest energy loss (equal to 2.59 MW) and the highest energy efficiency of 93.32% in comparison to the other

cylinders. Such high energy efficiency and low energy loss of IPC can be explained with the fact that IPC avoids the dominant losses which occur in the turbine. In HPC can be expected increased losses due to its operation with a steam of the highest temperature and pressure, while in LPC can be expected increased losses due to its operation with the wet steam at least in last few LPC stages. As the IPC avoids all mentioned losses, its performance and operating conditions are almost optimal. From the energy aspect, wet steam losses are more influential than losses of steam which has high temperature and pressure, therefore, LPC has much higher energy loss (equal to 18.10 MW) and much lower energy efficiency (equal to 74.68%) in comparison to both HPC and IPC. It is interesting to note that HPC energy loss is only slightly higher and its energy efficiency is only slightly lower in comparison to IPC.

Whole observed steam turbine from a combined cycle power plant has energy loss equal to 23.43 MW, while its energy efficiency is equal to 83.60%. As the whole presented and analyzed turbine develops 119.41 MW of useful mechanical power (real expansion), this turbine can be considered as a low power steam turbine, so obtained energy loss and energy efficiency are in the expected range of such steam turbines [27].

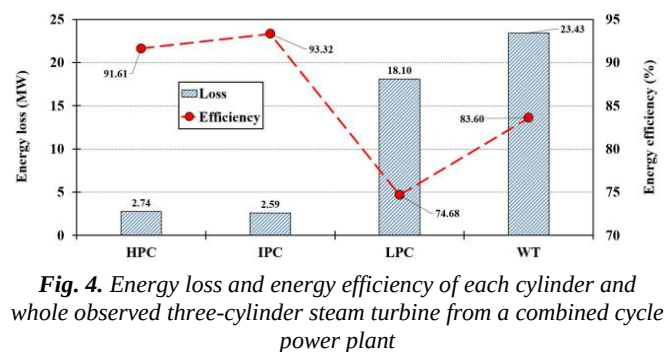


Fig. 4. Energy loss and energy efficiency of each cylinder and whole observed three-cylinder steam turbine from a combined cycle power plant

Total energy flows at each cylinder inlet and outlet (calculated by using Eq. 2) for the observed three-cylinder steam turbine are presented in Fig. 5 in relation to fluid (steam) mass flow rate.

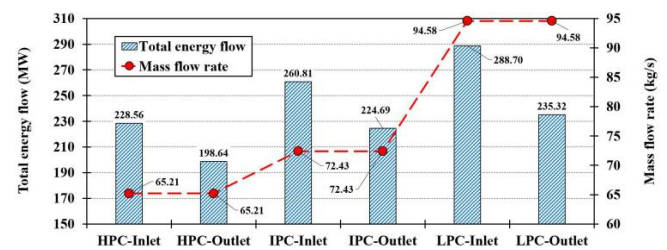


Fig. 5. Total energy flow in relation to steam mass flow rate at each cylinder inlet and outlet for the observed three-cylinder steam turbine from combined cycle power plant

From Fig. 5 can be clearly seen that increase in steam mass flow rate increases total energy flows at each cylinder inlet and outlet and vice versa. If comparing cylinders of the observed turbine, it can be concluded that total energy flows of LPC (at both LPC inlet and outlet) are higher in comparison to any total energy flow of the HPC. This fact can be explained with notably higher steam mass flow rate through LPC (equal to 94.58 kg/s) in comparison to steam mass flow rate through HPC (equal to 65.21 kg/s).

In the observed turbine, steam mass flow rate through each cylinder is the main element which defines produced mechanical power and energy flows, while it did not have an obvious and direct impact on cylinder energy efficiency and energy loss.

6. Conclusions

In this paper is presented an energy analysis of a three-cylinder steam turbine which operates in a combined cycle power plant. Using measured steam operating parameters during turbine exploitation, for each cylinder and whole turbine is calculated real and ideal mechanical power, energy loss and energy efficiency. At each cylinder inlet and outlet are calculated total energy flows and

their relation to steam mass flow rate through each cylinder is described. The most important conclusions of this paper are:

- Observing all the cylinders from the analyzed turbine, it is found that the dominant mechanical power producer is LPC, followed by the IPC, while HPC is the cylinder which produces the lowest mechanical power.
- Whole observed steam turbine from combined cycle power plant develop 119.41 MW of useful mechanical power.
- Energy loss and energy efficiency of all cylinders are reverse proportional – higher energy efficiency will result with lower energy loss and vice versa.
- IPC is the cylinder which has the lowest energy loss (equal to 2.59 MW) and the highest energy efficiency of 93.32%, while the highest energy loss (equal to 18.10 MW) and the lowest energy efficiency of 74.68% has LPC.
- Whole observed steam turbine from a combined cycle power plant has energy loss equal to 23.43 MW, while its energy efficiency is equal to 83.60%. The observed steam turbine can be considered as a low power steam turbine, so obtained energy loss and energy efficiency are in the expected range of such steam turbines.
- Steam mass flow rate through each cylinder is the main element which defines produced mechanical power and energy flows, while it did not have an obvious and direct impact on cylinder energy efficiency and energy loss.

7. Acknowledgment

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СРАВНИТЕЛЬНЫЙ АНАЛИЗ ЭВОЛЮЦИИ МИКРОСТРУКТУРЫ ПРИ ДЕФОРМИРОВАНИИ ЗАГОТОВОК В ТРАПЕЦИЕВИДНЫХ И ВЫПУКЛО-ВОГНУТЫХ БОЙКАХ

COMPARATIVE ANALYSIS OF THE MICROSTRUCTURE EVOLUTION DURING DEFORMATION IN TRAPEZOIDAL AND CONVEX-CONCAVE STRIKERS

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Abstract. This work is devoted to the study of the influence of the deformation process in trapezoidal and convex-concave strikers on the microstructure evolution of steel 40. Analysis of the results shows that the development of significant alternating deformations in the entire volume of the deformable body both in trapezoidal and convex-concave strikers allows intensive processing on the cast metal structure to obtain fine equiaxed grain throughout the volume of the deformed workpiece. At the same time, in both cases, there is a better processing of the initial structure when using strikers with a protrusion length equal to the length of the depression. The best result in the processing of the initial structure is observed when using trapezoidal strikers with a protrusion length equal to the length of the depression. At the same time, the smallest change in the size of the initial workpiece is observed when using strikers with a convex-concave surface with a protrusion-to-depression ratio $m/n < 1$.

Keywords: FORGE, STRIKERS, MICROSTRUCTURE, DEFORMATION.

1. Введение

При производстве металла улучшение его качества достигается не только при его выплавке, разливке и последующей термической обработке, но и в процессе обработки его давлением. Несмотря на интенсивное развитие металлургических процессов производства полуфабрикатов, направленных на совершенствование режимов выплавки, разливки и кристаллизации, существенное улучшение свойств литого металла, обеспечивающее его широкое применение в современном машиностроении, достигается путем горячей пластической деформации. Именно в процессе обработки металлов давлением в нем устраняют дефекты литья, измельчается структура металла, и повышаются его механические свойства до определенного уровня, соответствующему ковальному состоянию. То есть данный процесс можно рассматривать как некоторый «фазовый переход» из литого состояния в деформированное, наступление которого связано с выполнением определенного условия предельного нагружения.

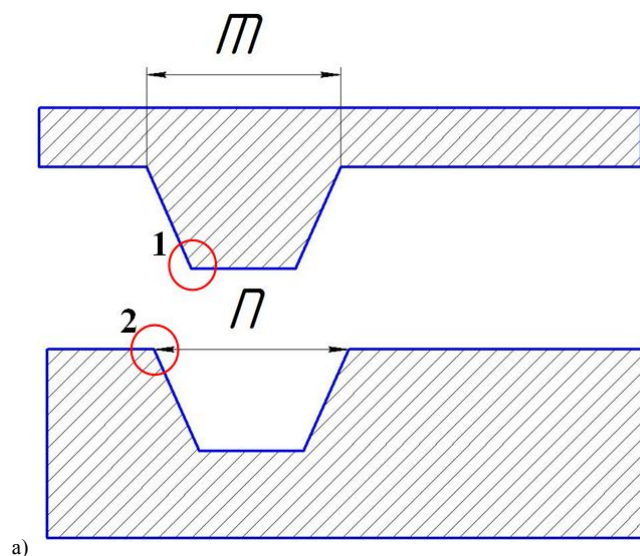
И именно поэтому уже не одно десятилетие во всем мире уделяется большое внимание целенаправленному применению высокопроизводительных и экономичных процессов обработки металлов давлением в металлургической и машиностроительных отраслях.

Одним из наиболее универсальных процессов обработки металлов давлением являетсяковка. Так как именно ковкой можно получить, как крупные многотонные деформированные изделия, так и поковки массой несколько десятков грамм со сложными формами.

Основным направлением улучшения качества изделий, получаемых ковкой, является создание в процессе деформирования сдвиговых или знакопеременных деформаций (интенсивной пластической деформации), что позволяет получать поковки с требуемыми физико-механическими свойствами при меньшем улове [1]. Реализовать сдвиговые или знакопеременные деформации в процессековки на практике, например, возможно путем совершенствования конструкции кузнечного инструмента.

В настоящее время уже разработан целый ряд новых технологийковки, позволяющих реализовывать в процессе деформирования дополнительные сдвиговые или знакопеременные деформации, и инструменты для их

реализации. Одной из такой технологий, например, является технологияковки прямоугольного поперечного сечения и пластин в трапециевидных бойках с отношением трапециевидного выступа к впадине равным $m/n=1$ и $m/n<1$ (где m - длина трапециевидного выступа, n -длина трапециевидной впадины (рис.1)) [1]. Данный способ деформирования при циклическом деформировании позволяет получать заготовки прямоугольного сечения с мелкозернистой структурой и повышенным уровнем механических свойств при незначительных энергозатратах. Но эта технология имеет один недостаток – это появление опасных концентраторов напряжений в точках 1 и 2 (рис.1), которые могут привести не к повышению качества металла за счет реализации значительных сдвиговых деформаций, а к браку в результате разрушения металла. Для устранения данного недостатка была усовершенствована данная технология, и дляковки поперечного сечения и пластин были предложены не трапециевидные бойки, а выпукло-вогнутые бойки, которые позволяют избежать появления опасных концентраторов напряжений.



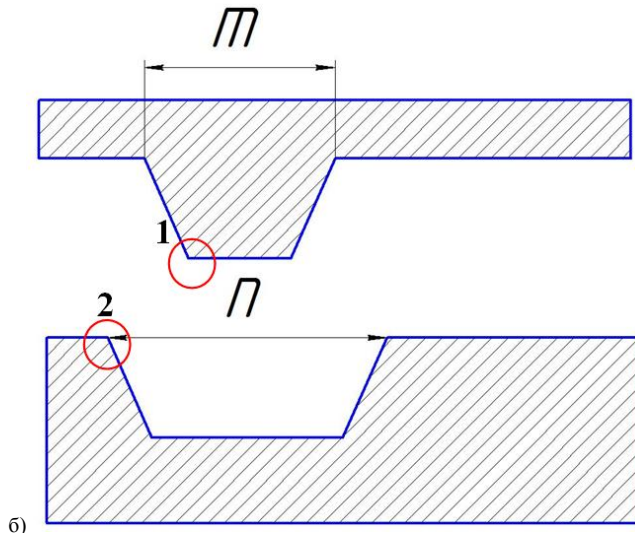


Рис. 1. Трапециевидные бойки с отношением трапециевидного выступа к впадине равным $m/n=1$ (а) и $m/n<1$ (б)

Поэтому были разработаны выпукло-вогнутые бойки (рис.2) [2, 3], так же с отношением выступа к впадине равным $m/n=1$ и $m/n<1$, назначением которых было повышение качества металла заготовки за счет локализации сдвиговых деформаций во всем объеме деформируемого тела и избежание появления микро- и макротрещин в металле. Технический результат при использовании предлагаемой конструкции бойков дляковки поковок и заготовок типа плит и пластин достигается тем, что инструмент для протяжки заготовок прямоугольного поперечного сечения имеет верхний боек со сферическим выступом, а нижний боек со сферической впадиной.

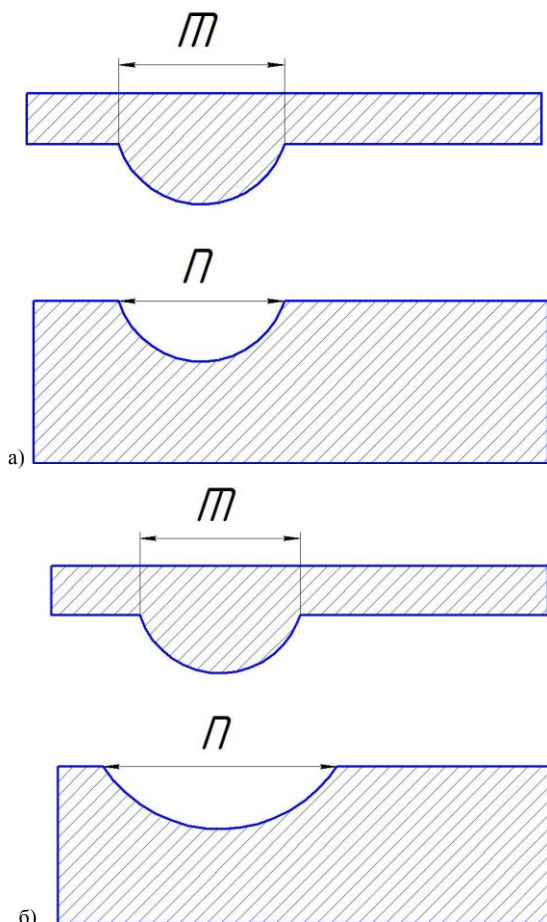


Рис. 2. Выпукло-вогнутые бойки с отношением выступа к впадине равным $m/n=1$ (а) и $m/n<1$ (б)

Проведенный в работе [4] сравнительный анализ результатов компьютерного моделирования процесса деформирования заготовок в трапециевидных и выпукло-вогнутых бойках, позволил сделать следующий вывод: при использовании выпукло-вогнутых бойков, несмотря на более низкий уровень проработки металла, реализуется более благоприятное напряженно-деформированное состояние для деформирования металла без разрушения. Кроме этого, дополнительным преимуществом ступенчато-клиновидных бойков является более широкая зона распределения деформации, меньшее изменение исходных размеров заготовки, а также меньшее значение развиваемого усилия деформирования.

Целью данной работы является проведение сравнительного анализа эволюции микроструктуры при деформировании заготовок в трапециевидных и выпукло-вогнутых бойках.

2. Экспериментальная часть

В соответствии с поставленной целью, для изучения влияния многоциклового деформирования в выпукло-вогнутых и трапециевидных бойках на эволюцию микроструктуры металла были изготовлены заготовки из стали 40 размерами $h \times b \times l = 30 \times 30 \times 200$ мм. Для восстановления исходной структуры заготовки были подвергнуты рекристаллизационному отжигу. Термообработку проводили при температуре 680°C . Время выдержки заготовок в печи 6 часов.



Рис. 3. Деформирование заготовок в выпукло-вогнутых бойках: а – в бойках с шириной выступа равной ширине впадины ($m=n$); б – в бойках с шириной выступа меньше ширины впадины ($m < n$)

Знакопеременное циклическое деформирование заготовок в выпукло-вогнутых (рис. 2) и трапециевидных бойках (рис. 1) с отношением $m/n=1$ и $m/n < 1$ (где m – длина выступа, n – длина впадины) и с углами наклона 35° осуществляли на

гидравлическом прессе с усилием 1.25 МН следующим образом. Заготовки нагревали до температуры началаковки 1200°C. Первую партию заготовок подавали в выпукло-вогнутые бойки с отношением $m/n = 1$ с углом наклона 35°, в которых осуществляли знакопеременное деформирование (рис. 3, а). Эти заготовки после знакопеременного деформирования кантовали на 180° и подвергали обжатию на плоском участке выпукло-вогнутых бойков. Таким образом, заготовки деформировали по всей длине с количеством циклов от 1 до 4. Вторую часть заготовок деформировали в аналогичных бойках, но уже с отношением $m/n < 1$ (рис. 3, б).

Аналогичным образом и с таким же количеством циклов производили знакопеременное деформирование заготовок в трапециевидных бойках с отношением $m/n = 1$ и $m/n < 1$ с углом наклона 35°.

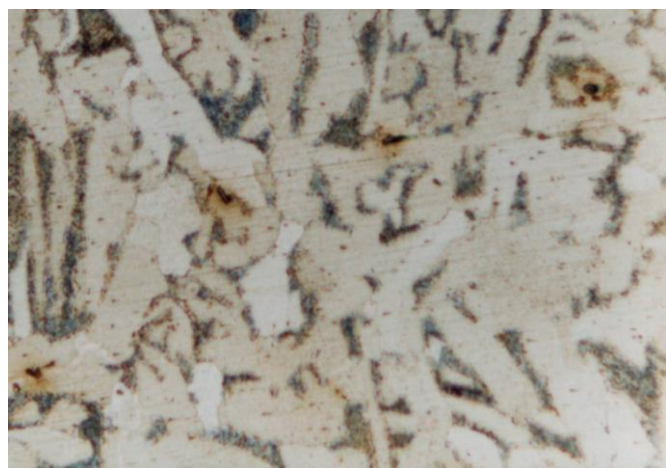
3. Результаты и обсуждение

Размеры заготовок после протяжки приведены в таблице 1. При этом после каждого цикла из заготовок были изготовлены темплеты для изучения микроструктуры.

Таблица 1. Размеры заготовок после протяжки

№ цикла	Выпукло-вогнутые бойки			
	$m/n = 1$		$m/n < 1$	
	h×b	Δh	h×b	Δh
1	28,5×30,21	1,5	29,0×30,15	1,0
2	27,6×30,24	2,4	28,1×30,20	1,9
3	26,7×30,31	3,3	27,4×30,24	2,6
4	25,4×30,35	4,6	26,6×30,29	3,4
№ цикла	Трапециевидные бойки			
	$m/n = 1$		$m/n < 1$	
	h×b	Δh	h×b	Δh
1	28,4×30,21	1,6	28,8×30,15	1,2
2	27,4×30,24	2,6	27,9×30,20	2,1
3	26,6×30,31	3,4	27,1×30,24	2,9
4	25,3×30,35	4,7	26,4×30,29	3,6

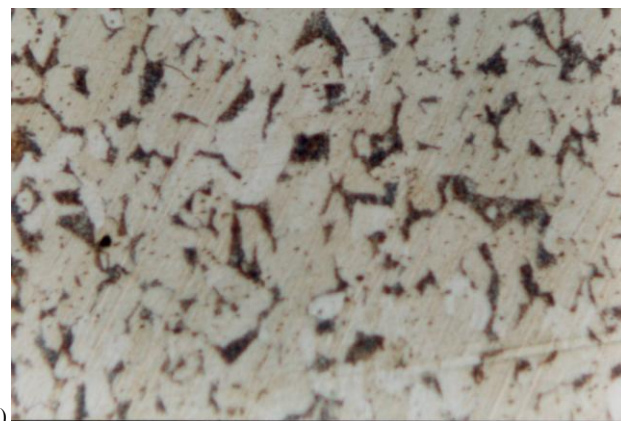
После протяжки заготовок в выпукло-вогнутых и трапециевидных бойках с количеством циклов от 1 до 4 производили металлографические исследования стали 40 с помощью оптической микроскопии. Результаты данных металлографических исследований приведены на рисунке 4 и таблице 2.



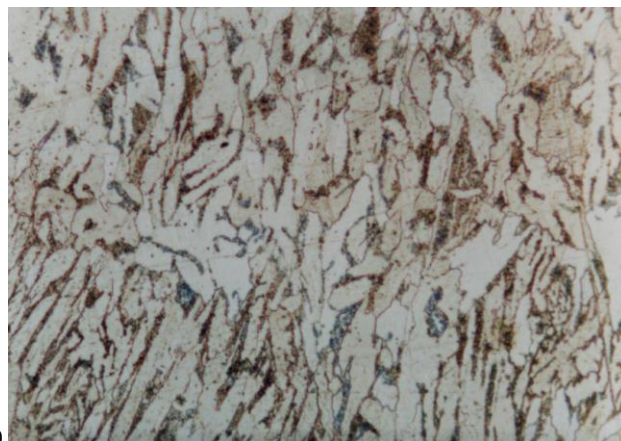
а)



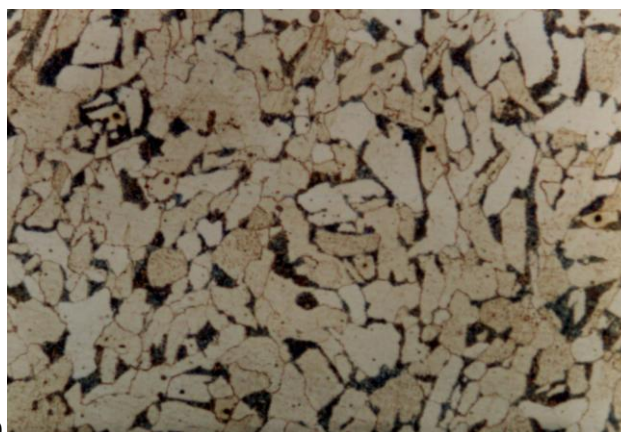
б)



в)



г)



д)

Рис. 4. Микроструктура стали 40, продеформированной в трапециевидных и выпукло-вогнутых бойках с равным отношением $m/n = 1$, увеличение $\times 100$: а – исходная микроструктура; б, г – после деформирования в трапециевидных бойках после первого и четвертого цикла деформирования соответственно; в, д – после деформирования в выпукло-вогнутых бойках после первого и четвертого цикла деформирования соответственно

Таблица 2. Размеры зерна до и после протяжки стали 40, мкм

№ цикла	Исходный размер зерна – 91 мкм			
	Выпукло-вогнутые бойки		Трапециевидные бойки	
	m/n =1	m/n <1	m/n =1	m/n <1
1	45,1	48,3	44,3	44,6
2	39,3	42,6	31,1	33,1
3	30,4	33,8	22,3	25,1
4	21,5	24,0	16,2	20,9

Выводы

Анализ полученных результатов показал следующее:

- при деформировании заготовок стали 40, как в трапециевидных, так и в выпукло-вогнутых бойках наблюдается существенное уменьшение размеров исходного зерна с увеличением циклов деформирования заготовок;
- при сравнении изменений микроструктуры металла деформированного в трапециевидных и выпукло-вогнутых бойках очевидно преимущество трапециевидных бойков, поскольку при их использовании структура металла эволюционирует более интенсивно;
- в обоих случаях наблюдается лучшая проработка исходной структуры при использовании бойков с длиной выступа равной длине впадины;
- наилучший результат в проработке исходной литой структуры наблюдается при использовании трапециевидных бойков с длиной выступа равной длине впадины, а наименее интенсивное изменение размера зерна исходной заготовки наблюдается при использовании бойков с выпукло-вогнутой поверхностью с отношением $m/n < 1$;
- наименьшее изменение размеров исходной заготовки наоборот наблюдается именно при использовании бойков с выпукло-вогнутой поверхностью с отношением $m/n < 1$ (Таблица 1). Кроме этого из работы [4] известно, что при

использовании выпукло-вогнутых бойков усилие деформирования так же меньше, чем при использовании трапециевидных бойков, что существенно позволит снизить энергосиловые параметры процесса деформирования заготовок.

На основе результатов, приведенных в данной работе, а также в работе [4] можно сделать вывод, что при выборе одной из двух технологий деформирования заготовок (ковка в трапециевидных или же выпукло-вогнутых бойках) с целью получения высококачественных поковок виде плит и пластин с мелкозернистой структурой и без дефектов, а также при меньших энергозатратах, предложенные выпукло-вогнутые бойки, по сравнению с известными трапециевидными бойками, являются наиболее благоприятными.

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Industry 4.0 and Multi-tasking machining

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Abstract: A clear trend of Industry 4.0 and smart manufacturing is to promote the increased use of multi-tasking machine tools. These machines are easily integrated into digital production systems and enable real-time data acquisition, remote monitoring and adaptive cutting processing. The integration of multi-tasking machine tools and digital manufacturing systems will improve the implementation of predictive maintenance, process optimization and production efficiency. Moreover, the development of robotics and AI along with the adoption of Industry 4.0 will increase the market share of these machine tools. The market demand is expected to increase further due to the rise of Industry 4.0. The paper analyzes the main advantages of multi-tasking machining, focusing on the advanced features of multi-tasking machine tools, as well as the latest trend of integrating additive manufacturing processes with CNC machining.

Keywords: INDUSTRY 4.0, MULTI-TASKING MACHINING

1. Introduction

The task of machine tools is to transform semi-finished products with certain mechanical properties into finished parts with the desired geometry, dimensions and quality of the machined surface. As the requirements for the production of parts with higher quality, lower machining costs and shorter delivery times increase, so does the need for machine tools with higher accuracy and machining efficiency. For this reason, machine tool manufacturers are focused on providing the industry with solutions to the key challenges it faces today: improving productivity, skilled labor shortages, energy prices, wage inflation, increasing competitiveness, environmental protection, i.e. how technology and advanced services lead to increased profitability in production. For example, increasing the level of automation of machine tools is one of the solutions to mitigate the negative effects of the lack of professional skills of workers and the tendency to increase their wages. Machine tools must be more productive and sustainable than ever before, i.e. they must allow for higher uptime (the degree of employment during working hours) and faster payback on the investment made in their acquisition.

Multi-tasking is synonymous with nouns like productivity, competence and efficiency. In today's world, where we are surrounded by advanced technology and tight deadlines, multitasking has evolved from a luxury to a necessity. Multi-tasking machine tools have become an important part of smart factories. They combine the functionality of two or more traditional machine tools to form a "super" machine. Integrating multi-tasking machining into the production process can effectively solve quality problems and significantly increase machining productivity because multitasking machining is highly efficient.

The term Industry 4.0 stands for the fourth industrial revolution, which is defined as a new level of organization and control over the entire value chain of the product life cycle, focusing on increasingly individualized customer requirements. Concepts such as „Smart Factory“, „Internet of Things“, „Cyber Physical Systems“ and „Machine to Machine“ are no longer considered science fiction and will soon become reality in the processes of the metalworking industry. The goal of using new technologies in the context of Industry 4.0 is to increase processing productivity (drastically shortening the time between product development and delivery to the customer), efficiency and energy savings. For this reason, major technological transformations are bound to occur. The integration of technological transformations and Industry 4.0 will make the machine tool market the cornerstone of modern production, especially the segment dedicated to the manufacture of multitasking machine tools.

The increasing application of the concept of Industry 4.0 and smart manufacturing in the manufacturing sector is definitely leading the industry to increasingly use multi-tasking machine tools. These machines can be integrated into digital manufacturing systems and enable real-time data acquisition, remote monitoring

and adaptive cutting. In this way, the implementation of predictive maintenance and the optimization of the machining process is supported.

The paper analyzes the main advantages of multi-tasking machining, focusing on the advanced features of multi-tasking machine tools and the latest trend of integrating additive manufacturing processes with CNC machining.

2. Multi-tasking machining

The introduction of new technologies and innovations has given rise to a new generation of machine tools known as multi-tasking machining systems. In the world of machining, multi-tasking means combining machining processes on one machine that are traditionally performed on several machine tools. „Complete machining“ is the key word: place the part in the machine once and manufacture it completely. The defined process and program must be perfect in advance, then machining in a single clamping operation becomes a reality. CNC multi-process machining systems are capable of performing a variety of operations with multiple tools and/or spindles in a single setup. Advances in computer technology have transformed these systems from stand-alone production units into complex work cells. Multi-process machine tools typically have multiple control axes (five or more) and, depending on the design, may have multiple spindles. In this context, these systems can contribute to significant manufacturing savings as they are able to machine complex workpieces with multiple features and geometries without the need for multiple setups and transfers between machines.

Multi-process machine tools represent the most dynamic segment of the machine tool industry today. Although their market share is relatively small, their sales are growing steadily as manufacturers increasingly recognize their advantages in machining complex parts. Machining complex parts in one setup and on one machine tool reduces workflows, lowers labor costs and increases productivity and machining quality by eliminating the need for multiple setups.

The tangible benefits of multi-tasking machining systems have attracted the attention of many sectors of the manufacturing industry, including the automotive, injection molds and aerospace industries. These industries see these machining systems as a means to achieve significant machining productivity, improve the quality of machined surfaces and increase profits. However, these machines represent a large capital investment, especially for small metalworking companies, and therefore the right choice of a multi-process machine tool depending on its purpose is an important decision for the company. Failure to make the right decision can have a detrimental effect on user satisfaction and the time it takes to recoup the investment. The savings in machine tool set-up, increased machining accuracy and reduced inventory can be significant if the machine is suitable for the company's production program. Therefore, production engineers and managers are faced

with the not-so-easy task of configuring and selecting a multi-process machine tool. Before implementing a multi-tasking system, a decision-maker must be clear about the production goals associated with the use of such complex technology and large capital investments. Currently, there is no industry standard to help solve this problem, and decision making depends on the knowledge and advice of experts in the field of production engineering.

Figure 1 shows a possible framework of factors involved in the decision-making process for a selection of a multi-tasking machining systems [1].

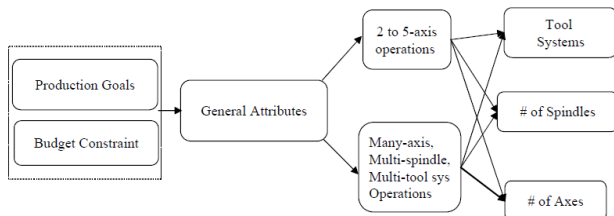


Fig. 1 The framework of factors for selecting a multitasking machining systems

Process integration is the ability to perform multi-axis turning, milling, drilling along different axes, grinding, gear making, etc. on one and the same machine. The latest trend is the development of hybrid multi-process machine tools that combine subtractive (by removing material) with additive processes.

3. The most important advantages of multi-tasking machining

The three main advantages of multi-tasking machining are accuracy, productivity and machining costs.

1. Greater accuracy of the end product

Since positioning is no longer required after each operation, accuracy is increased, especially for workpieces with complicated geometry and plane relationships.

2. Reduction of production and non-production times

The reduction in machining time is achieved by the simultaneous operation of several tools or the simultaneous operation of several tools on several spindles. Machines with two or more spindles enable synchronous and asynchronous operation. Synchronous operation means the production of the same product on all spindles and asynchronous production of different products at the same time. Asynchronous operation makes it possible, for example, to produce the "left" and the "right" part in the same operation or to machine the same part from all sides, so-called six-sided machining.

The time required for set-up is significantly reduced by having only one machine on which all machining operations are carried out in one operation without interrupting work, as shown in Figure 2 [2]. All machining steps can be automated, from the placement of the preparation material to the removal of chips and the removal of the finished part from the machine tool.

3. Reduction of production costs

Major savings in production costs result from the fact that machining is carried out on a single machine. These savings include: the need for a smaller number of machine tools, a smaller number of tools because only one machine tool needs to be equipped, lower power consumption, no need for intermediate storage, a smaller footprint for machine tools, cheaper machines for tool maintenance, etc. Figure 3 shows the "DONE IN ONE" concept of the company "Yamazaki Mazak", which represents the integration of all necessary machining operations to obtain a finished product from preparation on one machine in one operation and significantly reduce production costs.

The WFL Millturn Technologies GmbH & Co uses a similar slogan "ONE TIME CLAMPING - MACHINE COMPLETE".

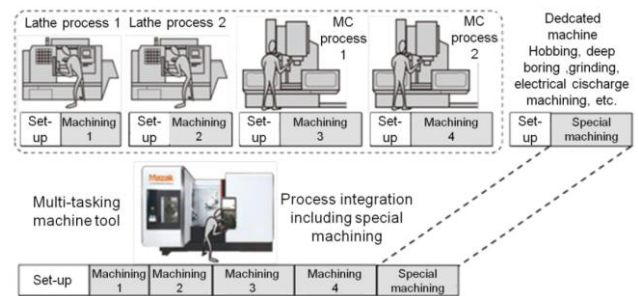


Fig. 2 Process integration by multi-tasking machine tool including special machining

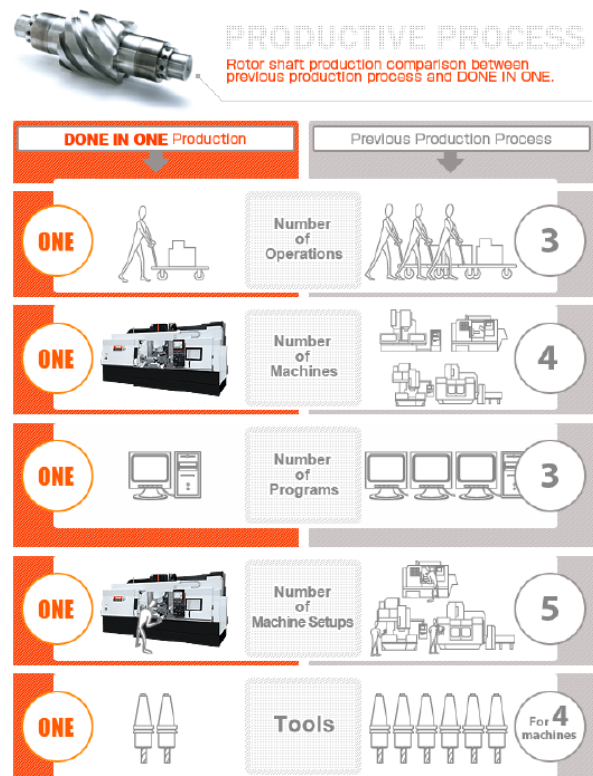


Fig. 3 "DONE IN ONE" concept (source: Yamazaki Mazak Co.)

Other potential benefits of using multi-tasking machine tools include:

- a higher throughput for small and medium batches,
- greater flexibility, which makes it possible to constantly change the characteristics of the workpieces to be machined.

The great flexibility of these machine tools results from their design and the possibility of programming the machine without having to work on the machine itself. The design of multi-tasking machines is increasingly modular, which means that different configurations of machine tools may be required depending on requirements. Machine programming is independent of the machine and there are a number of programs available to simulate the machining process. By simulating the machining process, it is possible to gain insight into the position of the workpiece and the path of the tool (it is possible to change the geometry of the workpiece or start manufacturing a new product with virtually no interruption to machine operation).

The manufacture of aircraft components, for example, requires the use of precision manufacturing processes such as turning, milling, drilling, jig boring, grinding, polishing, etc. in multiple

setups. Aircraft part manufacturing often involves complex shapes, large part sizes and the use of exotic metals – all features that complicate the production process. On the other hand, the use of multi-tasking machines offers considerable advantages for the production of these components. In the case study [3], which involved the production of some typical components such as covers, housings, valves, etc., the objective was to quantify the techno-economic advantages of using multi-tasking machine tools compared to the individual use of several machine tools. An attempt was made to compare the production of aircraft components with multiple machine tools, i.e. multi-tasking machines, in terms of production time and costs, number of set-ups, etc.

The results of a comparative study between the use of multi-machine tools and multi-tasking machine tool for the production of aircraft components are shown in Figures 4 and 5. It can be clearly seen that the use of multi-tasking machine tool can significantly reduce the number of adjustments and therefore the overall time and cost of manufacturing these components.

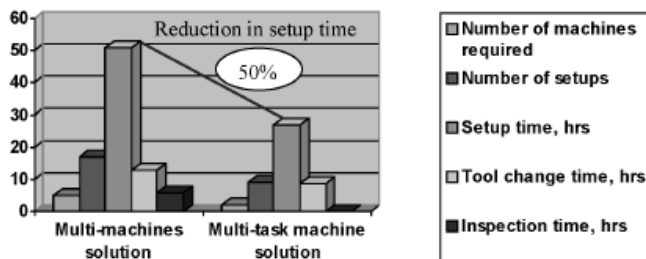


Fig. 4 Time comparison between multi-machines and multi-tasking machine tool

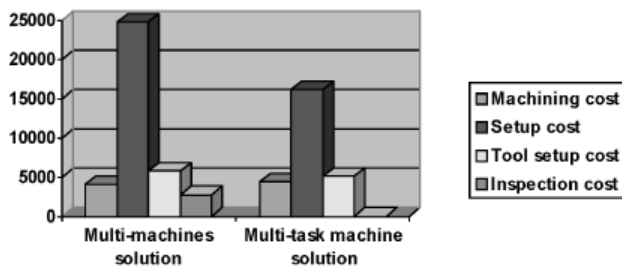


Fig. 5 Cost comparison between multi-machines and multi-tasking machine tool

4. Advanced features of multi-tasking machine tools

Multi-tasking machine tools were originally designed to integrate the turning and milling functions of machining centers. However, further development enabled the integration of special machining operations that were previously considered very difficult to integrate. Newer multi-tasking machine tools allow the integration of some special machining operations, such as: *deep boring with a long boring bar, deep hole milling with a special high-rigidity tool holder, taper drilling with a U-axis tool, hobbing of gears with an integrated shaft, grinding of turbine blades, turning with rotary round inserts*, etc.

Until now, special machines have been used for many deep boring applications because it is difficult to machine them with universal machines. Multi-tasking machine tools enable deep boring by long boring bar of up to 1000 mm. Figure 6 shows a detail from the workspace of a multi-tasking machine tool with a deep drilling tool.

The production of conical bore (conically shaped holes), e.g. in valve components, is very difficult because a good surface is

required, which is necessary for the high tightness of the valve. The drilling of tapered holes cannot be done with a milling spindle, but can be done with a special CNC-controlled tool head with a "U" axis mounted in the machine spindle, Figure 7. A tool with a "U" axis has a steering axis in the radial direction of the tool spindle, so that the tip of the tool can be steered in the radial direction when the milling spindle rotates. With this method, it is possible to produce a complex internal taper or a curved surface with high accuracy.



Fig. 6 Deep boring on multi-tasking machine tool (source: Yamazaki Mazak Co.)



Fig. 7 Boring by U-axis tool (source: D'andrea TA-C160)

Hobbing of gears integrated into the shaft can also be performed on multi-tasking machine tools by synchronizing the rotation of the main spindle with the milling spindle, Figure 8. These gears can be found in many assemblies, e.g. in aircraft engines, construction machinery and the like. The production of gears is normally carried out on special machine tools.



Fig. 8 Machine gears with multi-tasking machine tool (source: Yamazaki Mazak Co.)

5. Hybrid multi-tasking machine tool

Metalworking processes can be divided into three categories. The first one is subtractive processes (machining, grinding, polishing, laser cutting and so on). The second one is shaping machining (casting, forging, stamping, injection molding and so on) and the third one is additive processing (Directed Energy Deposition - DED, Laser Metal Deposition - LMD, Powder Bed Fusion - PBF, Selective Laser Melting - SLM and so on).

Reducing manufacturing costs and overall processing time is critical for industrial systems to maintain a competitive advantage. Production should enable the achievement of high added value. The implementation of Industry 4.0 strategies includes, among other things, the hybridization of manufacturing processes. This is why the latest trend in the development of multi-tasking machine tools is moving precisely in the direction of hybridization. This means that different processing processes are combined in a hybrid production device based on multifunctional CNC machine tools, such as multi-axis machining centers for milling or turning.

The current hybridization of production processes involves the integration of additive manufacturing processes with cutting processes, i.e. subtractive processes in which material is removed from the preparation, together with automatic 3D scanning and dimensional control functions. Such hybrid multi-tasking machine tools are used for the production of solid parts from metal powder or for the application of special coatings in the production of multi-metal parts and the repair of worn or damaged products of high value.

A new hybrid manufacturing method (AM/CNC cutting) has developed very rapidly in recent years for many applications: the production of complex parts with high accuracy and good finish, the production of parts with hidden elements, the repair of worn parts in a single set-up and the production of parts from multiple materials using 3D printing. This method is particularly suitable for the production of small batches of difficult-to-process materials, such as alloys used in aviation, high-hardness materials used in the energy industry, or for mold making and medical products.

The algorithm for the hybrid process (AM+CNC cutting) is shown in Figure 9. Based on the 3D CAD model, the part is created using the previously transferred data in STL format and the CNC control program is generated with the selected CAM system. In the next step, the part roughly machined using the AM process is finished by CNC milling or polished using special tools.



Fig. 9 General concept of technological integration of AM and cutting processes (source: Siemens)

The main problem in developing the integration of AM and CNC machining is the installation of the AM module on a new or used CNC machine tool, without special modifications or after a certain finishing. One of the first hybrid multi-tasking machine tools was manufactured by Aero-Met Corp in 2004 for the production of the F-15 fighter jet. This machine integrated laser welding with a CNC milling machine. Figure 10 [4] shows tool magazine of the HSC hybrid turning and milling center.

One of the most practical applications of hybrid multitasking machining is the repair of large and complex parts, mainly for the aerospace industry. A special process based on laser cladding or

selective laser melting is used for this purpose. This leads to considerable cost reductions, especially for high-quality components. In laser repair technologies, a certain volume of material is removed in the vicinity of the damage, then the missing material volume is refilled and the surface is finished by cutting and/or polishing. The repair of the blades is shown in Figure 11.

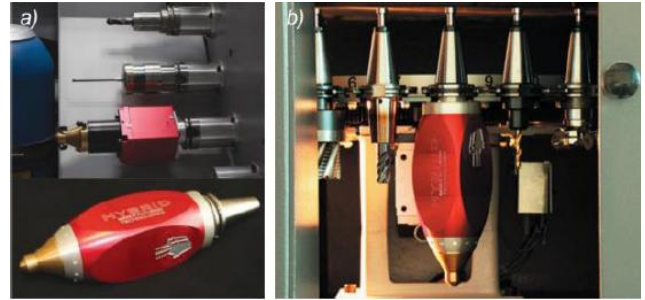


Fig. 10 Tool magazine of the hybrid multi-tasking machine tool

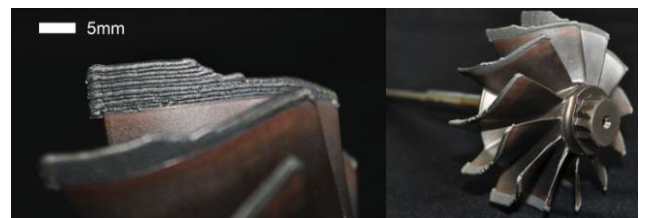


Fig. 11 The repair of blades

6. Conclusion

Industry 4.0 is changing the production environment. The integration of advanced sensors and IoT devices has revolutionized the architecture of machine tools by creating a highly connected and automated manufacturing environment. This enables real-time process monitoring and control, allowing workshops to optimize efficiency and reduce waste. Thanks to Industry 4.0, CNC machine tools are now able to self-diagnose problems and correct errors in the production process faster than humans can.

Multi-tasking machine tools are machines that combine multiple processes to reduce the number of operations required to produce a part. They are an important step in reducing part handling, clamping and unnecessary tooling. All of this leads to fewer human factor errors. The development of multi-tasking machining has intensified with the emergence of the Industry 4.0 concept. In almost all studies on Industry 4.0, additive technologies are cited as one of the pillars of Industry 4.0. This fact has also led to the development of hybrid multi-tasking machines. These machine tools are increasingly becoming a reality in the manufacturing environment.

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Simulation of light propagation in a photonic crystal fiber

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Abstract: A group of numerical methods suitable for describing the propagation of light in a Photonic Crystal Fiber (PCF) are discussed. PCFs can be classified according to the mechanism of light propagation. The methodology of the analysis is briefly reviewed to understand how changing the different physical parameters of the fiber and the design affects its optical properties. By analyzing the systematic studies presented, a design with the desired optical fiber properties can be realized.

PCFs can be made from just one material with two-dimensional photonic crystals or periodic arrays of air holes parallel to the fiber axis to form a shell and core shape. Several types of PCFs have been considered. The mechanism for trapping light in the fiber core is explained. The use of the wave methods for electromagnetic field analysis is discussed. The application of variation principles and weighted residual methods is shown. The advantages of the finite element method (FEM) are indicated. The vector FEM for obtaining the modes in photonic crystal fibers is considered.

Keywords: OPTICAL WAVEGUIDE, NUMERICAL METHODS, LIGHT PROPAGATION, MODES, FINITE ELEMENT METHOD, PHOTONIC CRYSTAL FIBER

1. Introduction

The optical fiber is made in the shape of a thin cylinder. In it introduces light that interacts with the material. Optical fibers are used for measurement of different parameters, for gain of signals, for transmission of information and in the manufacture of lasers. They are used widely in telecommunications as environment for transfer on information between two points with a high speed. They work like optical sensors for measurement of physically values and are also used for many other purposes.

The analysis of the optical fibers and devices requires the carry out of experimental or numeric research. The experiment takes away time and requires large quantity of resources. Theoretical research is founded on numeric simulations. They use an adapted analytical or numerical method depending on the fiber under study. The goal is to be understood how the change on the different ones physical parameters of fiber affects the optical fiber properties and how to realize a design with desired properties.

2. Construction and features

The optical fiber is made with a shape of a thin dielectric cylinder - fig. 1.

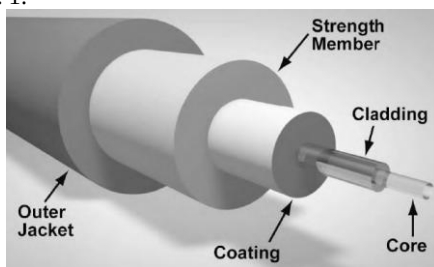


Fig. 1 Structure of a silicon optical fiber

It is built by a core with high index of refraction, in which propagates the light. The core is surrounded from cladding, with a little lower index on refraction from the core and which provides mechanical protection of the fiber from physical damage and protects the glass surface from moisture and dust particles.

The size of the core and difference between index of refraction of the core and of the cladding play main role at determination of the fiber properties. Important optical parameter on each transparent environment is the index on refraction n which is a ratio of speed of the light in the material v and speed of the light in vacuum c .

$$n = \frac{v}{c} \quad (1)$$

The change of the index on refraction by the length of the wave leads to the expansion of the duration of the pulse in time and in length (spatially). The index on refraction on melted silicon dioxide strongly depends on the length of the wave . The change of the index of refraction at smaller wave length is too sharp, which leads to high value of the dispersion.

The propagation of light in an optical fiber can be explained by Snellius ' law. Some of the light rays traveling from the core to the cladding reach the core/cladding surface at an angle greater than the critical angle. This causes total internal reflection. These rays are reflected back into the core and do not pass into the cladding. This keeps the light in the core of the fiber. All other rays are refracted and exit the core.

In optical systems, the attenuation (loss of power) and the dispersion (broadening of the pulse) limit transmission possibilities. Their values should be small or zero so that their effect can be acceptable. The dispersion of silicon material is shown at fig. 2, and the internal losses - at fig. 3 [1].

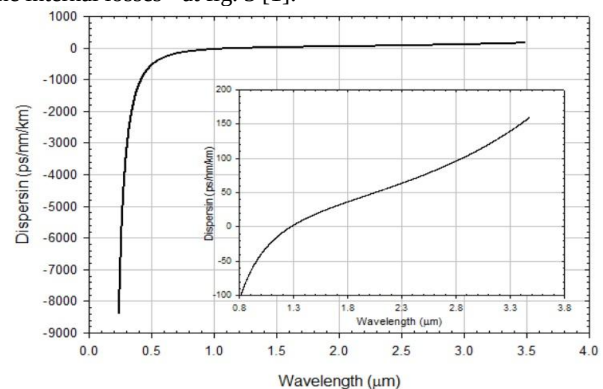


Fig. 2 Dispersion of silicon material

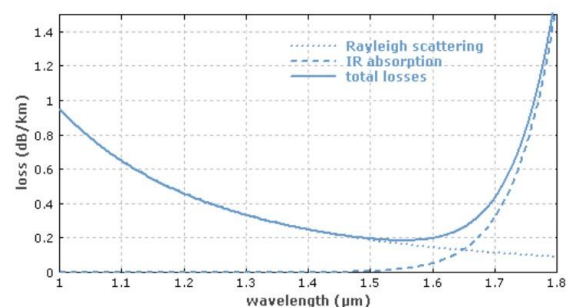


Fig. 3 Internal losses of silicon material

Some applications require a non-zero or greater variance value. This is the case for non-linear effects where non-zero variance is required to significantly affect the signal. Large dispersion values are required in specially designed fibers to compensate the dispersion of conventional telecommunication optical fibers. The dispersion must be controlled to suit the required application. Regardless of the manufacturing method, there are two types of optical fibers: single mode fibers (SMF) and multimode fibers (MMF).

The SMF core radius is much smaller than MMF . In SMF, only the fundamental mode can propagate through the core, while the

number of modes in MMF is approximately $(V^2/2)$, where the V parameter is [2]:

$$V = \frac{2\pi a}{\lambda} \sqrt{n_1^2 - n_2^2} \quad (2)$$

In (2), a is the radius of the fiber core, λ is the wavelength of light, n_1 is the refractive index of the core and n_2 is the refractive index of the fiber cladding.

The design of PCF is different from conventional silicon fibers. PCFs can be fabricated from a single material with two-dimensional photonic crystals or periodic arrays of air holes parallel to the fiber axis to produce a shell-and-core shape [3]. At fig. 4 several types of PCFs are shown: (a) pure Si core fiber with cladding air holes; (b) fiber with air tubes in the core where light is trapped due to the bandpass effect; (c) the core is made of pure silica and the holes in the cladding are filled with a high-refractive-index liquid, and (d) hollow cylindrical multilayer fibers with a solid cladding - Bragg fibers.

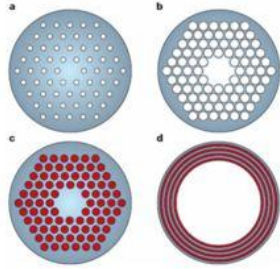


Fig. 4 PCF fibers with different design

At fig. 5 and fig. 6 are shown the cross-sections of helical PCF fibers with air tubes in the cladding with different structure.

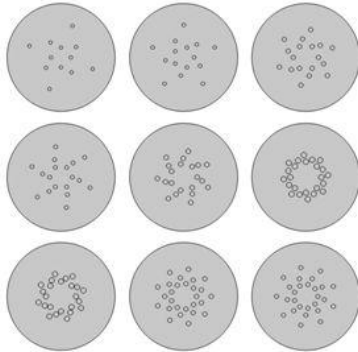


Fig. 5 Cross section of ES-PCF fiber

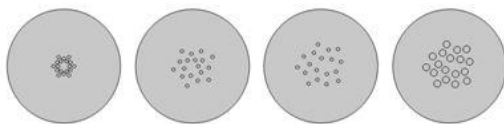


Fig. 6 Cross section of ES-PCF, AS-PC, FS-PCF fibers

Position and size of the holes in the cross-section of the PCF fiber control distribution and properties of the light. Their forms have different mathematical presentations.

Photonic crystal fibers can be classified into two main categories according to the mechanism of light propagation. The first are fibers with a high refractive index of the core. In them, light propagates similarly to conventional fibers. The second type of PCF are fibers with a low refractive index of the core, known as hollow core fibers / HC/. The core of The HC fiber is made by a material with a lower refractive index than the cladding and the light is guided either by PBG - photonic band gap or anti-resonance effect. HC fibers are further sub-classified into HC-PBF, Bragg fibers, Kagome fibers and HC-NCF /Hollow-Core Negative Curvature Fiber/ - hollow-core fibers with negative curvatures at the core boundaries, where light is confined in a core with a lower refractive index than the cladding. HC-NCF fibers were created in 2010.

The number of modes supported by the PCF is determined similarly to conventional optical fibers by the V parameter. PCFs do not have a well-defined core and a constant refractive index value of

the cladding. The refractive index of the cladding is a function of wavelength, which changes depending on the interaction of the light with the two materials (core and air) of the cladding. At longer wavelengths, the light spreads inside the holes and causes the refractive index to change depending on the design. The formula for V_{PCF} is shown below [4].

$$V_{PCF} = \frac{2\pi\Lambda}{\lambda} \sqrt{n_1^2 - n_{cl}^2(\lambda)} \quad (3)$$

where Λ is the aperture spacing, and $n_{cl}(\lambda)$ is the average refractive index of the PCF cladding.

In single mode, the guiding of light depends on the refractive index of the core and the average cladding index of the photonic crystal, which is a function of wavelength. In conventional optical fibers, there is a cut-off frequency above which the fiber is no longer single-mode. The single-mode operation region in PCFs is expanded because the average refractive index of the photonic crystal is wavelength dependent. At shorter wavelength, the mode field is more concentrated in the glass material. As the wavelength increases, the field penetrates more into the air holes. Therefore, at shorter wavelengths, the average cladding index is close to the material index. This results in a small index difference between the core and the cladding so that the value of V_{PCF} is small even at shorter wavelengths. Due to the dependence of the refractive index on the wavelength, the PCF can be designed to be single-mode when the condition is satisfied:

$$V_{PCF} < \pi \quad (4)$$

3. Analysis methods

Analysis of the optical devices uses intensively analytical and numerical methods. Analytical methods apply to solving electromagnetic problems at simple constructions like slabs, grooved and ribbed waveguides. They give accurate solutions, but are limited and inapplicable for real cases involving complicated geometries and inhomogeneous areas.

The analysis of complicated optical waveguides structures with spatial inhomogeneity area is not possible. In that case is doing approximations and assumptions for problems which must be resolved with numerical methods. This brings known permissible error. The approximations which done classify the numerical methods in two basic classes.

The asymptomatic numerical methods require fundamentally approximation in Maxwell Equations. This is limiting the use on these methods for general cases - for example for large metal and conductive objects. Their advantages are the low computational resources and the high efficiency [5].

The second class numeric methods are full wave methods. At these methods the approximation does numerically and there is not initially physical approximation. These methods are classify additionally according to the used formula, integral or differential, according the domain in which they work, time or frequency, as some from the methods can be applied in both areas. They include three basic steps for solving of the problem. First the problem must be defined through a control equation that fetched from the equations of Maxwell. The second step is discretization on the domain into non-overlapping subdomains, for present arbitrary inhomogeneous dielectric waveguides, so that everyone subdomain or element to be homogeneous. The discretization leads to set of equations, which are described in matrix form. The last step requires decision of the matrix of unknown values using effective algorithms. Below are briefly described the most popular full wave methods.

The methods of the frequency area are appropriate for research on narrowband applications in stationary condition, while the methods of the time area are appropriate for broadband transient applications. The discretization in the integral formula includes the important surface of the problem, as by this way are decreasing computational resources. This however, leads to bad presentation of complicated structures and inhomogeneous materials. The integral formula can be used for research of distraction issues and open domain. In differentials formulas discretization includes the full volume. This requires more calculations, but can effectively presented inhomogeneous environments and complex structures.

The differential formulas they can be applied to a borderline problem.

There is no universal choice for the best method. Every method has advantages and disadvantages and on a case-by-case basis chooses the appropriate one. Every method however differs in the preliminary processing on the equation of Maxwell for obtaining the final formula.

Often encountered aspect at full waves methods is discretization of the systemic domain on subdomains. So the solution is up almost regardless from the system [6].

A representation of the E and H components of the z-axis wave propagation as a harmonic function of time was sought:

$$E(x, y, z) = E_v(x, y) \exp(-j\beta_v z) \quad (5)$$

$$H(x, y, z) = H_v(x, y) \exp(-j\beta_v z), \quad (6)$$

where E is the intensity on the electrical field, and H is the intensity of the magnetic field, v is a mode index of relevant wave type [2].

In a 2D analysis for approximation of the distribution of the field they use triangular elements and polynomial approximation. The real wave function approximates with a linear function or with a square function. The polynomial approximation from higher range leads to more accurate results, however complicates the analysis and requires more memory. Broadly used are triangular elements from first range with 3 nodes.

The vector formulation of the FEM is used when the modes are hybrid and the longitudinal and transverse field components can be coupled. It can be output in different ways depending on the field components being used:

- transverse electric field components ;
- transverse magnetic field components;
- the two transverse field components;
- the two longitudinal field components;
- all six field components;
- all components of the electric field;
- all components of the magnetic field.

The last two ways are more efficient in terms of computing resources. However, the electric field formulation requires further integration to enforce the boundary conditions when the material changes at the boundary between the two elements. In the magnetic field formulation, the change in material at the boundaries does not require the imposition of a boundary condition since both materials are non-magnetic . Using six components requires more computing resources for storage and processing. The Rayleigh-Ritz procedure is used to obtain the matrix equation. First, the functional of the magnetic field vector formula is defined as:

$$F = \iint_{\Omega} (\nabla \times \mathbf{H})^* \cdot (\epsilon_r^{-1} \nabla \times \mathbf{H}) d\Omega - \omega_0^2 \iint_{\Omega} \mathbf{H}^* \cdot \mathbf{H} d\Omega \quad (7)$$

The domain is divided into small elements and the field in each element is defined as:

$$\mathbf{H} = \sum_{i=1}^m N_i H_i \quad (8)$$

where m is the node number in the element, H_i is the magnetic field per node i , and N_i are the basis functions (shape functions).

Equation (8) in matrix form is:

$$\mathbf{H} = [\mathbf{N}]^T \{\mathbf{H}\}_e \quad (9)$$

where T stands for transpose , $[\mathbf{N}]^T$ is the matrix of the basis function a $\{\mathbf{H}\}_e$ is column vector of field value in node.

Substituting (9) into (7) and applying the variational principle gives:

$$\iint_{\Omega} (\nabla \times [\mathbf{N}]^T \{\mathbf{H}\}_e)^* \cdot (\epsilon_r^{-1} \nabla \times [\mathbf{N}]^T \{\mathbf{H}\}_e - \omega_0^2 [\mathbf{N}]^T \{\mathbf{H}\}_e) d\Omega = 0 \quad (10)$$

Writing it in matrix form gives:

$$[\mathbf{A}]\{\mathbf{H}\} - \omega_0^2 [\mathbf{B}]\{\mathbf{H}\} = 0 \quad (11)$$

where ω_0^2 is the principal value and $\{\mathbf{H}\}$ is the principal vector.

$[\mathbf{A}]$ is the complex Hermitian matrix and can be reduced to real symmetric in the case of lossy dielectrics. $[\mathbf{B}]$ is a real symmetric matrix. The two matrices are defined as:

$$[\mathbf{A}] = \iint (\nabla \times \mathbf{H})^* \cdot \epsilon^{-1} (\nabla \times \mathbf{H}) d\Omega \quad (12)$$

$$[\mathbf{B}] = \iint \mathbf{H}^* \cdot \mu \mathbf{H} d\Omega \quad (13)$$

Some solutions of (11) may be spurious, not physical. They are obtained because some mathematical solutions of the eigenvalues of the equation do not satisfy the divergence condition ($\nabla \cdot \mathbf{H} = 0$)

automatically. The penalty function method is applied to eliminate or suppress false decisions. The purpose of the penalty function is to impose a bias-free constraint on the decision variables. Processing time increases slightly. The expression is:

$$\omega^2 = \frac{\iint (\nabla \times \mathbf{H})^* \cdot \epsilon^{-1} (\nabla \times \mathbf{H}) d\Omega + \left(\frac{\alpha}{\epsilon}\right) \int (\nabla \cdot \mathbf{H})^* (\nabla \cdot \mathbf{H}) d\Omega}{\iint \mathbf{H}^* \cdot \mu^{-1} \mathbf{H} d\Omega} \quad (14)$$

The formula includes the penalty term in the vector formulation that is used to find the mode solutions for the waveguides. The next problem is the discretization of the domain into smaller subdomains. The discretization of the domain or Networking is critical step in the FEM because the network determines computational requirements like time for storage and processing. M the cut plays important role for accuracy on the results. The process divides the domain on small ones subdivisions (elements). The elements must be adjacent and without distance between them, to cover the whole domain. There is different kinds elements dependent from the domain which must discretizes.

For a 1D problem, a linear element is used with two nodal points, one at each end of the element. In 2D, the element is a triangle or rectangle. A triangular element of the first order has three nodal points and a rectangular element has four. Higher order elements have more nodal points depending on the degree of the element and are more precise. Higher order elements lead to complex formulas because the degree of the interpolation function is related to the degree of the element. Triangles represent complex domains more accurately than rectangles because the boundaries can be more accurately approximated by triangles – Fig. 7.

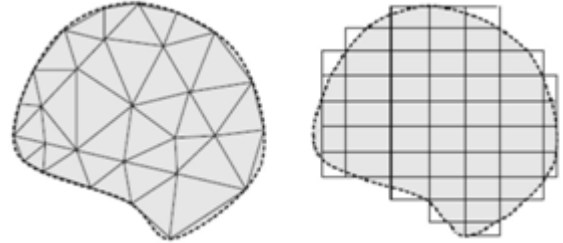


Fig. 7 Comparison of meshes of triangles and rectangles

The element is represented by an interpolation function that should approximate the field in the element with respect to the real physical problem. Compensating for the difference between accuracy and available resources is required. The error should be tolerable and the computer's processing time should be acceptable.

Most often, interpolation functions for representing elements are polynomials. A polynomial must contain all possible terms. The polynomial is unique and the orientation of the coordinates does not affect the shape function. It must have a number of members equivalent to the nodal points. There must be three terms in the first-order triangular element to form a complete polynomial.

PML (Perfectly Matched Layers) method is used to obtain the domain boundaries. PML allows unwanted unphysical reflected radiations to be absorbed at the boundaries. In PML, an artificial medium with a dielectric constant similar to the material is placed in the core domain. The impedance of both is identical, so there is no boundary reflection. The boundary absorbs waves traveling outward from the main domain at any angle and frequency.

The method on the moments (MoM), has an advantage at problems including open regions. Applies everything mostly in frequency district. This is the widest the one used method in antenna analysis. The mathematical formulation of electromagnetic fields with is made through discretization of the integral equation. MoM is computational effective but requires more complicated mathematics from others methods.

The finite differences method (FDM) is the widest used method at electromagnetic problems due to that it is clear and easy for application. The domain is split on network and the solution is for every point of the network. He applies the differential Maxwell equations, for brought out the wave equation and finds answer for the modes. The differential operator are replaced with operators for difference.

A similar method with the same concept is the method of the finite difference in the time domain (FDTD) [7]. It is used for the analysis of problems in the time area by directly discretization of the Maxwell equations. Both methods are very efficient, because they require a little operations on each point of the network [8]. The disadvantage of FDM is that the mesh must be uniform, to work well the method.

4. Conclusion

FEM, FDM and MoM are the main numerical methods used in electromagnetic analysis. For analysis of modern optical fibers and waveguides with a complex core and cladding structure is chosen one of these methods. At random borders of PCF structures, FEM is preferred because it makes a better approximation on their borders.

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Influence of variable compression ratio on emissions of a single cylinder- 4 stroke engine fueled with/etanol/gasoline blends

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Abstract: Impact of changing compression ratio by varying the combustion chamber geometry on the engine performance was investigated, SI single cylinder air-cooled engine fuelled with unleaded gasoline and pure ethanol was used. These tests were conducted on three different compression ratios of, 7:1 8.5:1, and 10:1 with a wide-open throttle, and three different ignition timing, before and after top died centre.

. The results showed that the BMEP (brake mean effective pressure), BTE (brake thermal efficiency), and BSFC (brake specific fuel consumption) obtained with the use of gasoline blends at all CRs were generally increased when they were compared to those of pure gasoline. In general, ethanol provided a lower exhaust emission compared to gasoline's emissions at all CRs. Furthermore NOx emissions was affected much more than other exhaust emissions when changing the compression ratios compared to un leaded gasoline

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KEYWORDS: ETHANOL, COMBUSTION CHARACTERISTICS, SPARK IGNITION ENGINE PERFORMANCE, COMPRESSION RATIO.

1. Introduction.

Considering the current global economic crisis, the interest in alternative fuels is extremely high. Separately, one of the goals of researchers is the development of high efficiency and clean engines. It is very important to examine that, the alternative fuel used as substitute must be produced from the renewable sources Means should be devised to use this fuel without bringing any modifications in the geometry of the engine. Alcohol has provided an answer to this problem. Alcohol fuels such as methanol, and ethanol etc. have been appearing as good nominees as alternative fuels for the vehicles equipped with the SI (spark ignition) engines, because they are fluid and have several physical and combustion properties similar to gasoline So Ethanol is well thought-out to be the most fitting fuel for spark ignition (SI) engines [1-3] In the literature, many experimental studies dealing with the effects of alcohol usage in the internal combustion engines on the engine performance, exhaust emissions and combustion characteristics have been made. Gasoline and pure ethanol have been used as fuel on a fuel-injected experiment engine , According to the obtained results, with the increase of ethanol ratio in the mixture fuels, it has been observed that the burning velocity, break thermal efficiency and in-cylinder gas pressure have increased and NOx and CO emissions have decreased [4,5] . Bio-alcohols are compounds obtained from specific agricultural productions or from plant residues and organic waste. They have a high interest because: they

have very low sulfur content, are biodegradable and are obtained from renewable sources such as biomasses [6-8]. Another studied showed that, the performance and the exhaust emissions of an SI engine using ethanol gasoline blends of ethanol containing different percentage of ethanol will bring torque and brake specific fuel consumption (BSFC) of engines to increase slightly when using blended fuels,. More investigation regarding different fuels were used such as ternary bio ethanol, methanol gasoline blends and showed an improvement in engine performance and emissions compared with gasoline.[9-11].

Ethanol is generally used in SI engines by mixing it with gasoline in well-definite fractions, injecting it into the inlet manifold and recently by direct injection within engine cylinders.(12-15). Finally, since heat of vaporization and flame propagation speed of ethanol are higher than those of gasoline, using ethanol in gasoline fuel blends can ensure higher volumetric efficiencies and quicker combustions (16, 17). For all of the above reasons, ethanol can be used in SI internal combustion engines both on its own (as neat ethanol without any blending) and by blending it with pure gasoline in several fractions [18, 19]. The experiments were conducted on a air cooled single cylinder engine fuelled with unleaded gasoline and pure ethanol. The effects of compression ratio on BSFC, BMEP, and BTE, were investigated. Table (1) shows engine specifications.

Table 1: Engine specifications.

Engine type	Air-cooled single - cylinder four stroke petrol engine	Compression ratio	variable
Power	1.2KW at 2500rpm		
Bore	65.1mm	ignition timing	Variable
Stroke	44.4mm		
Fuel	Gasoline, RON 95, gasoline blends		

2 Experimental

2.1 Engine

The tests were performed on a single-cylinder, four-stroke, CT 152 with power 1.2KW and air-cooled, gasoline engine. The engine had a cylinder bore of 65.1 mm, a stroke of 44.4 mm, and an original CR of 1:5, also five variable compression ratios are available and adjustable by varying the combustion chamber geometry. The engine includes a sensor to measure the exhaust gas temperature. The sensor, ignition cut-off as well as air and fuel supply are connected to the CT 159 test stand. In order to determine the engine torque, force transmission to brake was connected via pulley on the test rig. The schematic diagram of experimental setup is showing in Fig 1.



Figure 1: Schematic diagram of experimental setup

2.2 Fuel

The fuel used in this experiment is standard unleaded gasoline of RON 95, H/C=1.86; composition (saturated = 48.26%, olefins = 16.2%, naphthenes = 3.66%, aromatic = 30.2%). and Pure ethanol.

3- Results and Discussion

3.1. Engine characteristics

The variation of BMEP (brake mean effective pressure) at the CR values of 1:4, 1:5.5, 1:7, 1:8.5 and 1:10 are seen in Fig. 2. This variation in naturally aspirated engines is primarily due to the variation in volumetric efficiency as a result of a change in the combustion chamber geometry by changing compression ratios. [20]. As it is very well known that, the heat of vaporization and oxygen content of alcohol fuels, are much more than those of gasoline fuel, consequently alcohol fuels have a faster stoichiometric flame speed than that of gasoline [21]. Higher stoichiometric flame speed causes to comparatively faster and more complete combustion of fuel in the engine cylinder, which decreases heat losses from the cylinder walls which was clear in our case when pure ethanol were used, thus increasing brake thermal efficiency (BTE) fig 3. That is why the BTE and the volumetric efficiency increase when alcohols are used in the SI engine. In general, it could be observed that BMEP was variable during the process with changing the compression ratio from smaller to higher for both fuel, on the other hand BTE had increased with an increased CRs. These results coincide with other researchers when they have used biofuel and pure ethanol as fuel [22, 23] figure 2, 3. As seen in fig 2,3 it was observed that the thermal efficiency was higher when using biofuel as pure ethanol compared with unleaded gasoline. These phenomena caused an increment in the BMEP and BTE. The maximum values of BMEP found in C5 condition and in C5 for BTE

As it is known that LHV of biofuel is lower than that of gasoline, the amount of pure ethanol used in the engine test should be about 12% more than that of gasoline to achieve the same heat energy output. Consequently the BSFC is increased when pure ethanol biofuel is used comparing to pure gasoline fig 4.

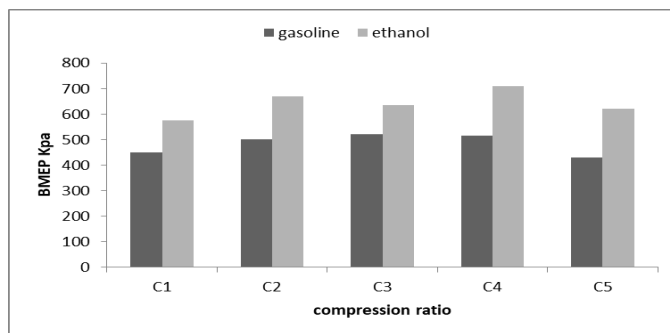


Figure 2: brake mean effective pressure at different engine compression ratios

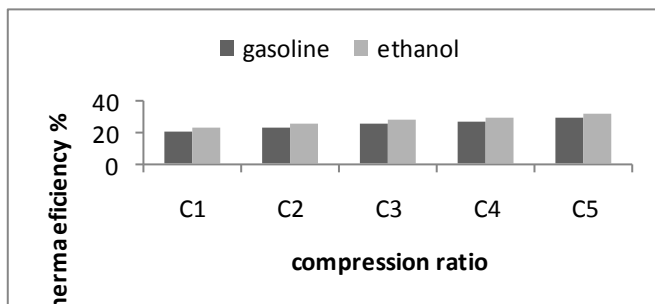


Figure 3: brake thermal efficiency at different compression ratios

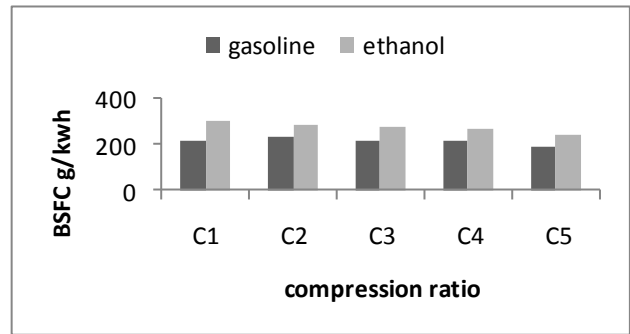


Figure 4: brake specific fuel consumption at different engine compression ratios

Conclusions:

The above study present a clear view progresses made to improve the performance parameters of SI engine using pure ethanol comparing to gasoline. Some key findings of this study are as follows:

Using gasoline as pure ethanol showed improvement in engine thermal efficiency and brake power as observed during this study, brake specific fuel consumption increased for pure ethanol content at different engine conditions compared to gasoline. BSFC increased by 12% ethanol. Varying the compression ratio of the engine has affected brake mean effective pressure inside the cylinder and the performance parameters of the engine, also pure ethanol has increased the BMEP by 10% on average.

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Industry 4.0 Approach for Development of Automatic Sanitation Unit

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Abstract: In wet wipe machines, equipment such as tanks, pumps, pipes, and valves that come into contact with the wet wipe solution, conveyor belts, and steel surfaces with which the liquid comes into contact, must be disinfected at regular intervals under hygienic production rules. Disinfection is carried out using hot water, alcohol-based disinfectants, surfactants, detergents, oxidizing agents, or a mixture of all these methods. In current applications, liquids are drained manually from preparation units or tanks, and machine surfaces are cleaned manually. Cleaning and sanitation is done by hand. At the same time, performing some cleaning scenarios is harmful to human health because of hot steam or water, chemical cleaning steam, etc. So, it is impossible to ensure the hygiene level of systems. In this study, safe by design and prevention approaches were used and a system equipped with several measurement sensors was designed to work with different sanitary liquids and their preparation units according to sanitary recipes, producing a report at the end of the cleaning process. There are devices such as pH meters, temperature sensors, pressure sensors, and several water analyzers in the system, and it is decided that cleaning is completed by processing the data from these sensors. This article describes the system developed in compliance with industry 4.0 applications

KEYWORDS: SANITATION, WET WIPE MACHINES, MACHINE DESING, INDUSTRI 4.0

1. Introduction

Wet wipes have become an essential tool for maintaining personal hygiene. These wipes are designed to address a wide array of needs, from cleansing and refreshing to sanitizing, and they play a crucial role in daily personal care routines. As wet wipes are intimately linked with personal hygiene, ensuring the highest standards of cleanliness and safety in their production is paramount.

Wet Wipes and Personal Hygiene:

Wet wipes are versatile products widely used for personal hygiene. They offer a convenient and effective way to clean and freshen up while on the go. These wipes are commonly employed in various situations, including:

Hand and Face Cleaning: Wet wipes are often used for quick hand cleaning when access to water and soap is limited, providing a solution for maintaining cleanliness in various situations.

Baby Care: In childcare, wet wipes serve as a fundamental tool for diaper changing and gentle cleaning of a baby's delicate skin.

Makeup Removal: They are also widely used in makeup removal routines due to their gentle cleansing properties, particularly for sensitive skin.

General Cleansing: Whether during travel or in public spaces, wet wipes offer a convenient way to maintain personal hygiene.

Relevance to Personal Hygiene in Production:

Given the close association between wet wipes and personal hygiene, it's imperative that the production process ensures the highest standards of cleanliness and safety. Hygienic production rules and the use of disinfection processes in the machinery are critical to guarantee the safety of these products.

In reality, control of hygiene during wet wipe production involves two aspects: Although the goal of sanitation is to prevent contamination completely, nevertheless it often occurs. Sometimes, sanitation is seen as a cost that does not provide any immediate financial return to a company. In addition, in developed countries, there is an increasing trend for busy consumers to purchase goods that require maximum hygiene.

Along with the increasing attention being paid to sanitation has come an increasing supply and complexity of chemicals and

equipment to be used in cleaning procedures. It is sometimes difficult for practitioners to decide which chemical to use and which cleaning procedure to adopt.

Wet wipes are a product used for hygienic purposes, and the prerequisite for the machines that produce wet wipes to produce hygienic products is that the machine itself is hygienic.

One of the important aims of this study is to remove the different odors of different products from the system during the transition from product to product. In addition to hygiene purposes, it is possible to preserve the different odors of wet wipe products and to prevent the odors from mixing, thanks to effective sanitation.

The scope of this study is to design and develop a system that will fully automatically perform the sanitation processes that are currently carried out manually in wet wipe production machines.

2. Material and methods

The machine's design, aiming to maintain the highest levels of hygiene, is crucial to producing safe wet wipes for personal use. The machine's features, such as modular design for easy cleaning, careful material selection, intuitive automation controls, and stringent safety features, directly impact the hygiene standards of the produced wet wipes.

In response to these challenges, this study employs a "safe by design" and "prevention-first" approach to address the issue of hygiene in wet wipe production machines. The primary objective is to design a system that automates the cleaning and sanitization process, thereby reducing the dependence on manual labor and eliminating potential risks to human health.

This innovative system is equipped with a suite of measurement sensors, each serving a unique purpose. The sensors include pH meters, temperature sensors, pressure sensors, and various water analyzers. These sensors collectively enable to monitor the system and control the cleaning process with precision.

System Operation:

The system is designed to work with a variety of sanitary liquids and their preparation units, following specific sanitary recipes to ensure effective disinfection. The automation of the cleaning process is driven by real-time data collected by the various sensors. This data includes:

pH Levels:

pH meters provide insights into the acidity or alkalinity of the cleaning solution, ensuring it remains within the specified range for effective disinfection.

In this study, to clean the wet wipe solution from the inner surfaces of the pipes, in the first stage; anionic and cationic surfactants are used. In the second stage, rinsing is done with deionized water. A pH meter decides the application time of deionized water, and water application continues until the pH value reaches 7. The pH meter makes analog measurements and provides continuous information to the PLC system. When the target value, the neutral level, is reached, the system closes the water inlet. Figure-1 shows the Endress-Hauser Orbisint CPS11 pH sensor used in the system.



Figure-1: Endress-Hauser Orbisint CPS11 pH sensor

Temperature Control:

Temperature sensors play a crucial role in maintaining the optimal temperature for the cleaning solution, thereby enhancing its disinfecting capabilities.

While hot water is used as a sanitation fluid, hot water is pumped into the system until it equalizes the liquid temperature values at the farthest point of the system and liquid tank. Thus, it is ensured that the sanitation process is carried out successfully at every point of the pipe system. Temperature sensors are connected to the PLC system and the temperature level is constantly controlled with analog data. Figure-2 shows the Endress-Hauser Thermophant T TTR35 temperature sensor used in the system.



Figure-2: Endress-Hauser Thermophant T TTR35 temperature sensor

Pressure Monitoring:

Pressure sensors help in managing the pressure within the system, avoiding potential issues that may impact the cleaning process.

It is very important to make sure there is fluid in the system during the sanitization process. This is monitored by the pressure sensor. Analog data received from the pressure sensor is constantly monitored by the PLC system. Figure-3 shows the Endress-Hauser Cerabar PMP51 pressure sensor used in this study.



Figure-3: Endress-Hauser Cerabar PMP51 pressure sensor

Water Quality Analysis: Water analyzers assess the quality of water used in the cleaning process, ensuring that it meets the required standards for effective sanitation.

The electrical conductivity values of pure water and those containing impurities are different. Using this basic information, it is possible to ensure that the sanitation process is done correctly. For this purpose, after the rinsing process is completed (before the rinsing water is discharged from the line), the conductivity value is measured with an electrical conductivity sensor and monitored by PLC. Figure 4 shows the Condumax 16d electrical conductivity sensor that used for electrical conductivity measurement.



Figure 4: Condumax 16d electrical conductivity sensor

Data-Driven Cleaning:

Based on the data collected by these sensors, the system makes real-time decisions, adjusting parameters to optimize the cleaning process. This data-driven approach ensures that the cleaning process is not only efficient but also highly effective in achieving the desired level of hygiene.

Furthermore, the system generates a comprehensive report at the end of each cleaning cycle, detailing the parameters monitored, the actions taken, and the overall effectiveness of the sanitization process. This report serves as a valuable record for quality control and regulatory compliance.

Selection of Material:

AISI 304 SS was used to manufacture the sanitation system. Stainless steel is a popular material choice for such units due to its excellent properties that make it well-suited for sanitation and hygiene purposes. Stainless steel is a corrosion-resistant and non-reactive material that is easy to clean, making it ideal for environments where cleanliness is a top priority. It doesn't rust, stain, or corrode, which ensures a longer lifespan for the sanitation

unit. Stainless steel surfaces are smooth, easy to clean, and resistant to bacterial growth, making it a hygienic choice. The absence of pores and cracks in stainless steel reduces the potential for contamination. Stainless steel is known for its strength and durability. It can withstand harsh cleaning agents and repeated use without deteriorating, ensuring the longevity of the sanitation unit.

Figure 5 shows the tank used in the system. Figure 5a shows the design phase, and 5b shows the tank made of stainless steel.

Figure 6 shows the pipes and the flowmeters on the system. Figure 6a shows the design phase, and 6b shows the pipes made of stainless steel and flowmeters.

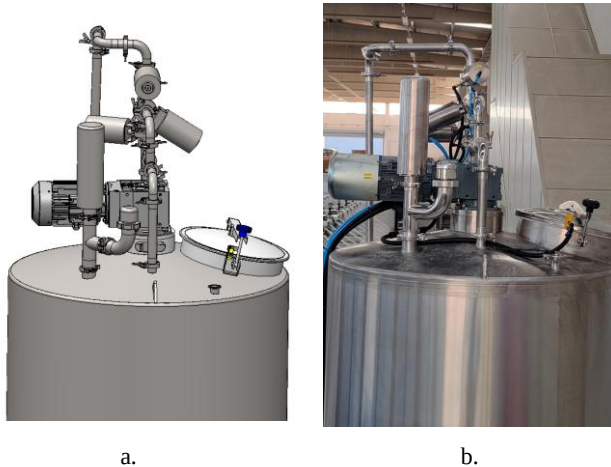


Figure 5: The tank used in the system. a) design phase b) the tank made of stainless steel.

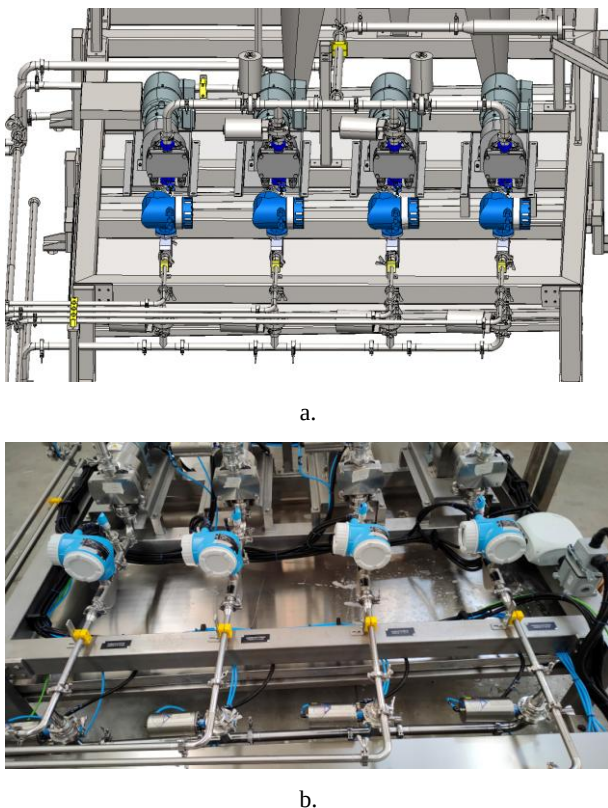


Figure 6: The pipes and the flowmeters on the system a) design phase b) the pipes made of stainless steel and flowmeters.

4. Conclusion

The development of an automated system for the cleaning and sanitization of wet wipe production machines represents a significant advancement in the industry. By integrating multiple measurement sensors and utilizing data-driven decision-making, this system offers a highly efficient and consistently hygienic solution to an ongoing challenge. This paper explores the technical details and practical implications of the system, providing a comprehensive overview of its operation and the potential benefits it brings to the field of wet wipe production.

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Review of the chemical and active compounds of the lyophilized essential oil of *Thymus vulgaris* L. with special reference to the preservation of the quality of the finished product

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Abstract: The article reviews the chemical and active compounds of the lyophilized essential oil of *Thymus vulgaris* L. and its preservation qualities. *Thymus vulgaris* is a medicinal plant belonging to the Lamiaceae family, with a long history of use for its therapeutic properties. The essential oil of *T. vulgaris* has been widely studied for its antimicrobial, antioxidant, and anti-inflammatory activities. The amounts and types of chemical compounds can vary depending on the genetic differences or environmental conditions of the plant materials. The primary components of the essential oil responsible for most of its biological effects include thymol, carvacrol, and p-cymene. The essential oil of *T. vulgaris* has been reported to exhibit a wide range of pharmacological activities, including antimicrobial, antioxidant, anti-inflammatory, antifungal, and antiviral activities. In recent years, there has been increasing interest in the use of *T. vulgaris* essential oil as a natural preservative in food products.

Keywords: THYMUS VULGARIS ESSENTIAL OIL, LYOPHILIZATION, PSEUDO-TERPENEDES, CHEMOTYPES, STABILITY

1. Introduction

A. Background information on *Thymus vulgaris* L. and its essential oil

The genus *Thymus* belongs to the family Lamiaceae, subfamily Nepetoideae, tribe Mentheae, subtribe Menthinae. [1] *Thymus vulgaris* L. is a medicinal plant that has been used for centuries for its therapeutic properties. It is a perennial herb that belongs to the Lamiaceae family and is native to Europe and North Africa. Notwithstanding, the primary habitat of this genus is found around the Mediterranean Sea. Given their sun-worshipping tendencies, *Thymus* plants thrive in climates with moderate to warm temperatures, well-drained to dry soils typically found on rocks, stones, or sand, and in sun-drenched areas. [2]

Thyme's potent preservation qualities made it a preferred choice among Egyptians for embalming. Dioscorides' writings from the first century AD indicate that thyme was primarily used as a medicinal herb. Thyme was considered an antidote in ancient Rome and was consumed before or during meals to protect against poisons. Its renown led to it becoming one of the plants favored by emperors. In 1340, during the Black Death, thyme was utilized as the main ingredient in medical concoctions and ointments applied directly to blistered skin. [3,4]

The taxonomic classification of plants belonging to the *Thymus* genus is complicated due to the high level of variability in their morphological, micromorphological, and chemical characteristics. This variability is caused by environmental factors and genetic differences resulting from hybridization, which lead to variable chromosome numbers and expressed gynodioecy, a sexual polymorphism where natural populations contain both female and hermaphrodite plants. These factors make taxonomic studies in this genus particularly challenging, particularly for certain taxonomic groups. [5-7]

The essential oil derived from the leaves of *T. vulgaris* has been widely studied for its antimicrobial, antioxidant, and anti-inflammatory activities. [8] The study led by O Boruĝa et al has presented the most thorough examination of *Thymus vulgaris* chemotypes, recognizing at least 20 distinct types based on their essential oil makeup. Furthermore, this research was the first to analyze and characterize the enantiomeric distributions of *T. vulgaris* monoterpenoids. [9]

The amount and types of these chemical compounds can vary depending on the genetic differences or environmental conditions of the plant materials, which may differ based on their geographical location. [10] The primary components of the essential oil, which are responsible for most of its biological effects, include thymol, carvacrol, and p-cymene. [11]

In general, chemotypes that contain phenolic compounds such as thymol and carvacrol have a lower proportion of their dominant monoterpene compared to nonphenolic chemotypes like geraniol, alpha-terpineol, and linalool. This is because phenolic chemotypes have high levels of precursors like gamma-terpinene and paracymene in their oil. The essential oil of the nonphenolic thuyanol chemotype is characterized by four distinct monoterpenes,

which together make up a smaller proportion of the oil than the dominant monoterpene in the other nonphenolic chemotypes. [5]. Numerous studies have been conducted to explore the chemical makeup and biological activities of *Thymus vulgaris* essential oil. As stipulated in European Pharmacopoeia 10.0 (Ph. Eur. 10.0), the minimum essential oil content in *T. vulgaris* is 1.2%, with a minimum of 40% thymol and carvacrol. [12]

The essential oil of *T. vulgaris* has been reported to exhibit a wide range of pharmacological activities, including antimicrobial, antioxidant, anti-inflammatory, antifungal, and antiviral activities. These activities have been attributed to the presence of various bioactive compounds, such as thymol, carvacrol, and p-cymene, which have demonstrated significant in vitro and in vivo effects. [11, 13, 14] In addition, thyme essential oil has been shown to significantly decrease levels of triglycerides, total cholesterol, and glucose. [15]

In recent years, there has been increasing interest in the use of *T. vulgaris* essential oil as a natural preservative in food products. The essential oil has been reported to exhibit excellent antimicrobial activity against a wide range of foodborne pathogens, including bacteria, fungi, and viruses. This has led to its use as a natural alternative to synthetic preservatives in the food industry. Further research needs to be conducted to find economically and environmentally more feasible options that can fulfill the requirements of consumers regarding composition, taste, and odor. [16]

Overall, *T. vulgaris* essential oil is a promising natural product with a wide range of pharmacological and biological activities. Its use as a natural preservative in food products offers a safe and effective alternative to synthetic preservatives, and its potential applications in the food industry are vast.

B. Importance of preserving the quality of the lyophilized essential oil of *Thymus vulgaris* L.

Lyophilization, also known as freeze-drying, is a non-convective drying technique that is relatively new among artificial drying methods. It uses low temperatures and shorter processing times. [17] The process of lyophilization entails drying the sample by first freezing the water within it and then removing it by sublimation under vacuum conditions. Sublimation is the key principle in this process, in which water goes directly from a solid state (ice) to a gaseous state without passing through the liquid state. The lyophilization process comprises three main stages: freezing to transform most of the water into ice; primary drying to sublime the ice; and secondary drying to separate any remaining unfrozen water through desorption. Annealing is an optional step in lyophilization that may occasionally be used to crystallize the formulation component. [18] The process is performed at low temperatures and pressures, making it ideal for preserving compounds that are sensitive to heat or unstable in aqueous solutions over extended periods. This technique is particularly effective for preserving compounds that remain stable in their dry form. What sets lyophilization apart from other dehydration methods is that it eliminates the presence of liquid water and maintains low

temperatures, which significantly reduces degradation and microbiological reactions. As a result, the final product is of exceptional quality. [19]

Although lyophilization offers numerous benefits, it has consistently been regarded as a costly process. The expense associated with lyophilization, however, can differ based on various factors such as the type of raw material utilized, packaging options, capacity of the plant, length of the cycle, and so on. Recently, lyophilization has been widely adopted as a method for preserving various herbs and spices due to its numerous advantages. As reported by Thamkaew et al., lyophilization is effective in maintaining the essential oil content of many types of herbs and spices better than other drying and preservation techniques. Nevertheless, the impact of freeze-drying on the active compounds of plants is not entirely consistent, and the findings in the literature are sometimes contradictory. [20]

According to a study conducted by Antal et al., the yield of isolated essential oil from freeze-dried lemon balm leaves is significantly influenced by chamber pressure and freezing temperature, to a considerable extent. The results demonstrated that the use of high-pressure freeze-drying (250-300 Pa for 14 hours) resulted in a higher concentration of essential oil (0.252 v/w%) compared to the low-pressure method (50-80 Pa for 12 hours), which produced an essential oil content of 0.191 v/w%. This difference can be attributed to the fact that the volatile compounds in lemon balm are primarily located in peltate glandular trichomes on the leaf surface, and low pressure in the freeze dryer chamber can negatively affect these glandular hairs, leading to a substantial loss of essential oils. [21]

Based on numerous studies, lyophilization has been found to be more effective in preserving the major volatile compounds compared to other drying methods. In the case of *Thymus vulgaris* L., lyophilization was able to maintain the total volatile compounds quite well. The changes observed in the thyme constituents isolated through simultaneous distillation-extraction (SDE) were similar to those seen in sage, although some variations were noted. For instance, the content of β -caryophyllene in the freeze-dried herb increased by 37%. [22] The outcomes for freeze-dried thyme were consistent, showing an increase in the primary volatile compounds β -caryophyllene and thymol. The concentrations of these compounds were 282 and 6907 mg/kg, respectively, which were higher compared to the fresh plant materials (β -caryophyllene at 213 mg/kg and thymol at 6465 mg/kg). Furthermore, it was observed that the concentration of thymol, which is abundant in the foliage of *Thymus vulgaris* L., was higher in lyophilized samples compared to those dried through convective methods. [23] The reported thymol content of freeze-dried thyme leaves was found to be higher than that of oven-dried and shade-dried leaves. [24]

According to existing literature, lyophilization seems to be a promising method for preserving the volatile profile of plants. Nevertheless, its efficiency can be affected by factors such as the type of plant, the location of volatile accumulation, and the nature of the volatile compounds present. Moreover, the technical parameters of lyophilization play a critical role in determining the quality of the final product. However, there is currently insufficient

information available regarding the adverse effects of lyophilization on volatile compounds in herbs and spices, which limits our understanding of the contradictory effects of lyophilization on the essential oils of these plants. [25]

C. Brief overview of the chemical and active compounds found in the essential oil

The research conducted by Grigore et al discovered that out of the 15 components analyzed, which comprised 99.91% of the detected compounds, p-cymene (8.41%), γ -terpinene (30.90%), and thymol (47.59%) were the primary constituents. This finding supports the classification of the essential oil as belonging to the thymol chemotype, which is consistent with previous reports. [26] The analysis of the essential oil revealed that other elements were present in a combined amount of less than 13.01%. Notably, the chemical composition of the essential oil differed significantly from previous reports for the same type of thyme grown in Morocco and Spain. [27,28] Previous research conducted in Poland, Iran, Spain, and Italy have identified p-cymene, γ -terpinene, and thymol as major components in the essential oil of *T. vulgaris*. [10,11,29,30] The disparities in these cases are largely due to the distinct chemotypes present.

II. Chemical composition of the essential oil

The primary constituents of essential oils are typically responsible for determining their biological properties. These constituents can be broadly categorized into two distinct groups based on their biosynthetic origin. [31,32] The primary components of thyme oil are terpenes and terpenoids, while the secondary components include aromatic and aliphatic compounds. A total of 30 constituents were identified in thyme oil, with thymol (39.44%), p-cymene (23.6%), γ -terpinene (12.51%), ledol (2.24%), and Aromadenrene (2.12%) being the main components, comprising 79.91% of the oil. These findings are consistent with those previously reported by Omidbeygi et al. (16-17), who stated that thymol is the major component of thyme essential oil. [33,34]

Our concurrence with the findings of Viuda-Martos et al lies in the determination of thymol as the predominant compound (representing 48.64% of the sample), and p-cymene as the secondary compound (comprising 22.94% of the sample). [35] There are many reports on the chemical composition of the oils isolated from the plants belonging to the genus *thymus*. The major constituents of thyme essential oil were thymol (45.3%), p-cymene (26.1%) [36], while found that thymol (32.23%), γ -terpinene (21.19%) and p-cymene (20.27%) were the main components in thyme essential oil from Egypt [37].

On other side the chemical composition and enantiomeric distribution of *Thymus vulgaris* essential oils were investigated by Satyal et al and shown in Table 1. Clearly indicating the complexity of the compounds that the species *Thymus vulgaris* L. can contain. [38]

Table 1. The compositional makeup and the stereoisomeric distribution of enantiomers present in the essential oils derived from *Thymus vulgaris*. [38]

RI	Compound	#1		#3		#4		#5	
%	d/l	%	d/l	%	d/l	%	d/l		
752	3-Methyl-1-penten-3-ol	tr							
783	Methyl α -methyl butyrate	0.10		0.07		tr		tr	
850	(3Z)-Hexenol							0.05	
922	Tricyclene	0.05		tr				0.09	
924	α -Thujene	tr		tr	91:9	0.71	81:13	0.43	10:90
932	α -Pinene	0.47	1:99	0.21	1:99	1.75	85:15	1.32	52:48
947	α -Fenchene							tr	
948	Camphene	1.17	99:1	0.38	99:1	0.25	0:100	1.19	10:90
971	Sabinene	tr		0.05	98:2	2.03	78:22		
977	1-Octen-3-ol	0.43		0.42					
977	1-Octen-3-ol + β -Pinene					0.97	20:80	0.54	20:80
983	6-Methylhept-5-en-2-one			0.05					

983	3-Octanone					tr		tr	
988	Myrcene	0.09		0.44		4.09		1.59	
996	3-Octanol	tr		0.07		tr			
1004	(3Z)-Hexenyl acetate	tr							
1004	p-Mentha-1(7),8-diene							tr	
1006	α-Phellandrene					tr	55:45	0.11	
1008	δ-3-Carene							tr	
1016	α-Terpinene			tr		2.65		1.3	
1019	o-Cymene							0.06	
1024	p-Cymene	0.09		0.18		1.09		20.07	
1028	Limonene	0.05		0.39	85:15	2.85	86:14	0.39	80:20
1030	β-Phellandrene			tr		0.37		0.09	
1031	1,8-Cineole	0.37		0.31		0.30		0.72	
1033	m-Cymene							tr	
1034	Lavender lactone + (Z)-β-Ocimene	tr							
1045	(E)-β-Ocimene	tr						0.05	
1057	γ-Terpinene			0.09		4.58		9.03	
1063	3-Methylbut-2-enyl butanoate	tr							
1069	cis-Sabinene hydrate			0.31		30.77	97:3	0.17	
1070	cis-Linalool oxide (furanoid)	0.28							
1071	Pinol							tr	
1084	Terpinolene					0.97		0.07	
1085	trans-Linalool oxide (furanoid)	0.23						tr	
1089	p-Cymenene							tr	
1099	Linalool	76.15	1:99	7.15	97:3	7.89	3:97	5.00	1:99
1101	trans-Sabinene hydrate			tr		4.98		tr	
1103	Hotrienol	0.07							
1104	Nonanal	0.05				tr			
1106	α-Pinene oxide			tr					
1107	1-Octen-3-yl acetate	tr				tr			
1124	cis-p-Menth-2-en-1-ol					0.65			
1136	trans-Limonene oxide					tr			
1142	trans-p-Menth-2-en-1-ol					0.25			
1147	Camphor	1.79	100:00	0.11	0:100	0.10	0:100	1.42	95:5
1148	α-Cyclogeraniol			tr					
1154	β-Pinene oxide					0.05			
1162	Lavandulol	tr		tr				tr	
1169	cis-Linalool oxide (pyranoid)	tr							
1171	Borneol	0.40	100:00	1.00	100:00	0.28	100:00	1.5	71:29
1174	trans-Linalool oxide (pyranoid)	tr							
1178	p-Mentha-1,8-dien-4-ol					tr			
1180	Terpinen-4-ol	0.06		0.17	70:30	9.5	30:70	1.25	40:60
1184	(3Z)-Hexenyl butanoate	tr							
1186	p-Cymen-8-ol							tr	
1194	α-Terpineol	0.11	65:35	0.09	65:35	2.69	91:9	0.16	60:40
1196	cis-Piperitol					0.14			
1197	cis-Dihydrocarvone	tr		tr				tr	
1205	β-Cyclogeraniol			tr					
1206	Decanal	tr							
1208	trans-Piperitol					0.16			
1217	7-Ethylidenebicyclo[3.3.0]octan-3-one					0.90			
1220	6,7-Epoxyneral			tr					
1223	Nerol	tr		0.97					
1223	7-Methylenebicyclo[3.3.1]nonan-3-ol					6.07			
1225	Citronellol	tr		0.35					
1228	Thymol methyl ether							0.19	
1230	6,7-Epoxygeraniol			tr					
1234	4-t-Amylcyclohexanone	0.08							
1237	Neral	tr		0.61		tr			
1237	Carvacrol methyl ether							0.32	
1243	Carvone			tr				0.09	
1249	Linalyl acetate	14.26	1:99			3.4	0:100		
1249	Geraniol			59.75		0.24		0.05	
1266	Geranial	tr		1.25		tr		tr	
1271	(2E)-Decenal	tr							

1279	Isothymol						0.07	
1282	Lavandulyl acetate	tr						
1284	Bornyl acetate	0.21		0.14		0.07		
1284	neo-iso-3-Thujanol acetate						tr	
1288	Thymol			0.42		tr	47.06	
1296	Carvacrol	0.05					3.24	
1296	Geranyl formate			0.09				
1331	2,3-Epoxygeraniol			0.06				
1341	cis-p-Menthadienyl acetate			0.19		4.75		
1344	Citronellyl acetate					0.28		
1346	α -Terpinyl acetate					0.05		
1348	Citronellyl acetate			0.07				
1349	Eugenol						0.08	
1357	Neryl acetate	tr		0.18		tr		
1372	trans-p-Menthadienyl acetate					0.05		
1375	α -Copaene						tr	
1377	Geranyl acetate	0.06		16.72		0.48		
1383	α -Bourbonene	0.20		tr		0.09		
1388	β -Elemene	tr						
1403	Isocaryophyllene	tr		tr				
1419	β -Caryophyllene	2.27		3.67		2.03	1.79	
1429	β -Copaene	tr						
1429	cis-Caryyl propanoate					0.30		
1434	7-Methyl-3-methylene-7-octen-1-yl propanoate					tr		
1437	Aromadendrene						tr	
1454	α -Humulene	0.06		0.12		0.06	0.05	
1468	Geranyl propanoate	tr		1.26				
1473	trans-Cadina-1(6),4-diene						0.06	
1480	Germacrene D	0.26		0.05		0.58		
1489	Viridiflorene						tr	
1494	Bicyclogermacrene			tr		0.09		
1497	α -Murolene						tr	
1506	Geranyl isobutyrate			0.15				
1506	β -Bisabolene						tr	
1511	δ -Amorphene						0.07	
1516	δ -Cadinene	tr					0.16	
1531	trans-Cadina-1,4-diene						tr	
1547	Elemol			0.96				
1554	Geranyl butanoate	0.05		0.74				
1575	Germacrene-d-4-ol	0.10				tr		
1575	Spathulenol			tr				
1581	Caryophyllene oxide	0.41		0.50		0.10	0.13	
1595	Geranyl isovalerate			0.06				
1631	10- <i>epi</i> - γ -Eudesmol			tr				
1654	α -Eudesmol			0.17				

III. Antimicrobial and antifungal activity of the essential oil

Several in vitro studies have explored the antimicrobial and antifungal properties of *Thymus vulgaris* essential oil. These investigations generally entail assessing the essential oil's effectiveness against various microorganisms in carefully controlled laboratory settings. [39-41]

According to the research conducted by Sokovic et al, the data demonstrated significant inhibitory effects of *Thymus vulgaris* oil against several oral pathogens, such as *S. pyogenes*, *S. mutans*, *C. albicans*, *A. actinomycetemcomitans*, and *P. gingivalis*. These effects were assessed using both agar disk diffusion and broth microdilution methodologies. [39] In a study conducted by Nikolic et al, it was found that thymol was the major constituent of the essential oil obtained from three different *Thymus* species, namely *T. algeriensis*, *T. vulgaris*, and *T. serpyllum*. The antimicrobial activity of the essential oil was tested, and the results indicated that these three *Thymus* plant species could be utilized in the field of minor wound healing and oral cavity disorders, as well as serving as an antibacterial agent for oral hygiene purposes. [42]

Investigations conducted in a clinical setting with regards to *Thymus vulgaris* essential oil are often focused on its potential

therapeutic benefits, particularly its antimicrobial and antifungal properties. Prior literature has highlighted the existence of in vitro and preclinical evidence supporting these advantages. Nevertheless, it is crucial to acknowledge that the availability and quality of clinical evidence in this particular field may be limited.

The antimicrobial properties of *Thymus vulgaris* essential oil can be primarily attributed to its bioactive constituents, particularly thymol and carvacrol, which are the primary contributors. These compounds' efficacy stems from their ability to disrupt the organization and operation of microbial cells. The mechanism of action is based on the fact that thymol and carvacrol are lipophilic (fat-soluble) compounds that have an affinity for lipid-rich structures, such as microbial cell membranes. They can disrupt the integrity of the cell membrane, leading to the leakage of cellular contents, which in turn disrupts the normal functioning of the microorganism and ultimately results in cell death. [40] The essential oil derived from *Thymus vulgaris* possesses not only its own antimicrobial properties but also exhibits synergistic effects when combined with other antimicrobial agents, leading to heightened antimicrobial activity and a diminished likelihood of microbial resistance. [43]

The antifungal properties of *Thymus vulgaris* essential oil, which are similar to its antimicrobial activity, are primarily attributed to specific bioactive compounds found in the oil, particularly thymol and carvacrol. These two compounds can interact with and disrupt the structure of fungal cell membranes, penetrating the lipid bilayer of the cell membrane and leading to changes in permeability, which ultimately result in cell death. Additionally, thymol and carvacrol have been reported to inhibit the activity of various fungal enzymes that play essential roles in fungal metabolism, which can disrupt the normal functioning of the fungus [44].

IV. Preservation of the quality of the finished product

The process of lyophilization is a precise method of dehydration that aims to preserve the volatile compounds found in essential oils, such as thymol and carvacrol, which are responsible for the antimicrobial and antifungal properties of *Thymus vulgaris* essential oil. The goal of lyophilization is to preserve these bioactive compounds in their original form, thereby ensuring their efficacy. Preserving the aroma and flavor of essential oils is a significant challenge in processing, and lyophilization has proven to be a beneficial solution in this regard. This technique minimizes exposure to high temperatures, which can degrade the sensory qualities of essential oils, thus helping to maintain their aroma and flavor. A study conducted by Sárosi et al found that lyophilized spices were the most preferred by consumers based on their organoleptic properties, even though significant essential oil loss can occur during the freeze-drying process. [45]

The process of lyophilization effectively removes water content from essential oils, thereby reducing the risk of degradation through oxidation and hydrolysis. By diminishing the water activity, lyophilized *Thymus vulgaris* essential oil may exhibit an extended shelf life in comparison to non-lyophilized versions. Lyophilization not only enhances the stability of essential oils but also diminishes their susceptibility to degradation during storage. This attribute is particularly valuable in applications where a stable and long-lasting product is of utmost importance [46].

V. Conclusion

A. Summary of findings

The article discusses the chemical and active compounds of the lyophilized essential oil of *Thymus vulgaris* L., with a focus on its preservation qualities. The therapeutic properties of the plant have been recognized for centuries, and it has been used for various medical purposes. The study by Borugă et al presents the most comprehensive examination of *Thymus vulgaris* chemotypes based on their essential oil composition. The primary components responsible for the essential oil's biological effects are thymol, carvacrol, and p-cymene [9]. The essential oil has been reported to exhibit various pharmacological activities, including antimicrobial, antioxidant, anti-inflammatory, antifungal, and antiviral activities. Recent interest has been in using the essential oil as a natural preservative in food products, as it exhibits excellent antimicrobial activity against various foodborne pathogens. Further research is needed to find economically and environmentally feasible options that can fulfill consumer requirements regarding composition, taste, and odor.

B. Future directions for research

Recent progress in the field of essential oils has shed new light on the properties and applications of *Thymus vulgaris* L. essential oil. Current research is exploring advanced extraction methods, such as supercritical fluid extraction and microwave-assisted extraction, to enhance the yield and preserve the bioactive compounds of *Thymus vulgaris* L. essential oil. Furthermore, there is a growing interest in investigating the potential synergistic effects between *Thymus vulgaris* L. essential oil and other natural preservatives, with the goal of creating sustainable and eco-friendly alternatives in various industries. Future research may focus on further examining these synergistic effects and assessing the versatility of *Thymus vulgaris* L. essential oil in new product formulations.

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Nano-structured Electrode Materials with Reduced Amount of Platinum Aimed for Hydrogen Evolution. Part I: Effect of cobalt

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Abstract: The subject of this study is electrochemical and structural characterization of nano-dimensioned composite electrode materials for hydrogen evolution consisted of Co, Pt or CoPt metallic phase and TiO_2 , both grafted on multiwalled carbon nanotubes (MWCNTs) as a support material. The main idea was to replace platinum entirely or to some extent as an electrode material. The electrode materials with different The common composition of the studied electrode materials was 10%Me + 18% TiO_2 + MWCNTs, where Me = Pt, CoPt (1:1, wt.), CoPt (4:1, wt.) and Pt. The structural and surface changes, as well as their influence on electrocatalytic activity were analyzed by means of XRD, TEM, SEM and FTIR. It was found that Co considerably reduces Pt particle size, from 11 nm (in pure Pt metallic system) to 3–4 nm (in mixed CoPt systems). This is a reason for better activity of the electrode material with CoPt (1:1) metallic phase than that with pure Pt, while the CoPt (4:1) with very low quantity of Pt approaches the activity of the electrode material with pure Pt.

Keywords: HYDROGEN EVOLUTION, ELECTRODE MATERIALS, COBALT, PLATINUM, ANATASE

1. Introduction

One of the most important issue of the hydrogen economy as the most promising alternative energy system, is the choice of active and effective electrode materials as a site for taking place of the electrode reactions in the hydrogen electrolyzers and fuel cells [1]. Platinum has the largest commercial application as the most active catalytic material. But, the use of Pt will be limited, due to its high cost and low abundance [2]. The situation of limited Pt resources and a high energy needs, the price of Pt will be incredibly increased. Therefore, the crucial challenge of the hydrogen economy is to reduce the amount of Pt in the electrode materials or totally replace by some non-noble materials with activity close or even better than Pt. According to the physical approach, increasing of real surface area of the electrode material, i.e. smaller particle size lead to increasing of the catalytic activity [3]. This is the concept for involving of nanomaterials in electrode materials. The chemical approach suggests increase of the intrinsic catalytic activity through mixing the catalytic metal with other metals or its compounds [4]. Strong synergetic effect can be achieved by mixing of metals/compounds with opposite electronic character. According to Jakšić's hypo-hyper d-concept [5,6] based on the the Brewer resonance bond-valence theory for intermetallic compounds [7], the mixing of hyper d- electronic transition metals (with more electrons in the outer d-shell and good individual catalysts) with hypo d- electronic transition metals (with less electrons in the outer d-shell and poor individual catalysts) shows a pronounced synergetic effect for hydrogen evolution (HE). TiO_2 as an anatase has shown the highest interaction with metals considered as good catalysts [8, 9]. Hypo and hyper d-components may be not only in the elemental state, but also in higher oxidation states. Depending on the valence state of the hypo and hyper d-components, these electrode materials can be distinguished into 5 types [10]: i) intermetallic compounds (MoPt_3 , MoNi_3 , MoFe_3 , $\text{Ti}_{1-x}\text{Ni}_x$, etc.) [11], ii) mixed sulphides/phosphides (Ni-W-S , Ni-W-P , Fe-Ni-P etc.) [12,13], iii) Reny-Ni based electrocatalysts (Ni-W-S , Ni-W-P , Fe-Ni-P etc.) [14,15], iv) mixed oxides ($\text{TiO}_2\text{-RuO}_2$, $\text{TiO}_2\text{-IrO}_2$, $\text{Ru}_x\text{Ti}_{1-x}\text{O}_2$ etc.) [16] and v) hypo metal + hypo oxide Pt- TiO_2 , Co- TiO_2 , Ni- TiO_2 etc.) [1].

The aim of this research is electrochemical and structural study of the electrode materials with reduced quantity or without Pt, aimed for (HE). Mixed Co-Pt and pure Co and Pt nanoparticles deposited on nano-scaled catalyst support consisted of multiwalled carbon nanotubes (MWCNTs) and TiO_2 (anatase), were prepared for studying.

2. Materials and Methods

The studied electrode materials were consisted of 10 wt.% metallic phase (Co, CoPt or Pt, see Table 1), 18 wt. % TiO_2 as anatase and MWCNTs. Precursors for metallic and oxide phase were organometallics (Me-2,4-acac, Me = Co or Pt, Alfa Aesar, Johnson Matthey, GmbH and Ti-isopropoxide, Aldrich, 97%). As a carbon

substrate, MWCNTs (Guangzhou Yorkpoint Energy Company, China) were used. The studied electrode materials were prepared by sol-gel procedure, elsewhere [17].

Table 1: Composition of the studied electrode materials.

Sample N°	Metallic phase (10%wt.)	Oxide phase (18%wt.)	Support material (72%wt.)
1	Pt	TiO_2	MWCNTs
2	CoPt (1:1,wt.)	TiO_2	MWCNTs
3	CoPt (4:1,wt.)	TiO_2	MWCNTs
4	Co	TiO_2	MWCNTs

Porous gas-diffusion electrodes (GDE) of the studied samples were prepared and tested for hydrogen evolution in both, alkaline and acid electrolytes (aqueous solutions of 3.5 M NaOH and 0.5 M H_2SO_4 , p.a., Merck). The procedure for GDE preparation is described elsewhere [18]. Electrochemical measurements using steady-state galvanostatic method, were performed using AMEL equipment (Function Generator AMEL 568, Potentiostat/Galvanostat AMEL 2053 and software package SOFTASSIST 2.0). Pt wire was used as a counter electrode and Hg/HgO as a reference electrode. The electrochemical line for testing the studied electrodes is shown in Fig.1.

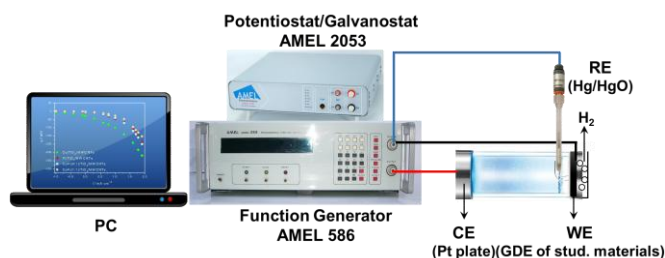


Fig. 1 Electrochemical instrumentation line for testing the studied electrodes

The structural characterisation was performed by means of FTIR, XRD, TEM and SEM analysis. FTIR spectra were recorded using KBr pellets at room temperature with Perkin-Elmer System 2000 interferometer. XRD measurements were carried out by X-Ray diffractometer Philips APD 15, with CuK_α radiation. The crystallite size was calculated using the Scherrer equation [19]. Transmission electron Microscope JEOL JEM - 200 CX was used in scanning and transmission regime. SEM observation was carried out on Scanning Electron Microscope JEOL, model JEM 200 CX.

3. Results and Discussions

In Figures 2 and 3 are shown polarization curves of the studied electrode materials for hydrogen evolution reaction in alkaline and acid electrolyte, respectively. In Figures 4 and 5 are shown derived Tafel plots from polarization curves shown in Figures 2 and 3 for platinum based electrode, Pt/ TiO_2 /MWCNTs. The values of Tafel plots and overpotentials at reference current density of $60 \text{ mA} \cdot \text{cm}^{-2}$

for all studied electrode materials, are summarized in Tables 2 and 3. These curves and parameters express the electrocatalytic activity for HE of the studied electrode materials. The lower the overpotential, the higher the electrocatalytic activity for HE.

The first conclusion that can be drawn from the polarization curves (Fig. 2 and 3) is that the catalytic activity of all electrode materials is considerably higher in alkaline electrolyte than that in acid one. The reason for this is the weak chemical stability of cobalt and its tendency to dissolve in an acid environment. So, the difference in the activity of catalyst with pure Co (more than twice) and Co with 20% in metallic phase (even triple), is the most remarkable. In the case of catalyst with equal content of Co and Pt, this difference is lower (1.5 times), while in case of pure platinum system is the lowest (1.3 times).

A second observation is the order of electrocatalytic activity of the different metal systems. In the equal quantity of the whole metallic phase, it is expected the most active to be pure Pt electrode. But, according to the presented results, in both electrolyte, better activity has shown the electrode with mixed metallic phase in the equal amount ratio (Co:Pt = 1:1). Also, the activity of the other mixed electrode material with considerable reduced amount of platinum (Co:Pt = 1:1) is not so lower than that of pure Pt electrode. The order of the electrocatalytic activity expressed through the overpotential at reference current density of $60 \text{ mA} \cdot \text{cm}^{-2}$, in alkaline electrolyte is the follow: $\text{CoPt}(1:1)[-130\text{mV}] > \text{Pt}[-145 \text{ mV}] > \text{CoPt}(1:1)[-160\text{mV}]$. The pure Co electrode has shown far lower electrocatalytic activity, i.e. much higher overpotential of 235 mV at $60 \text{ mA} \cdot \text{cm}^{-2}$.

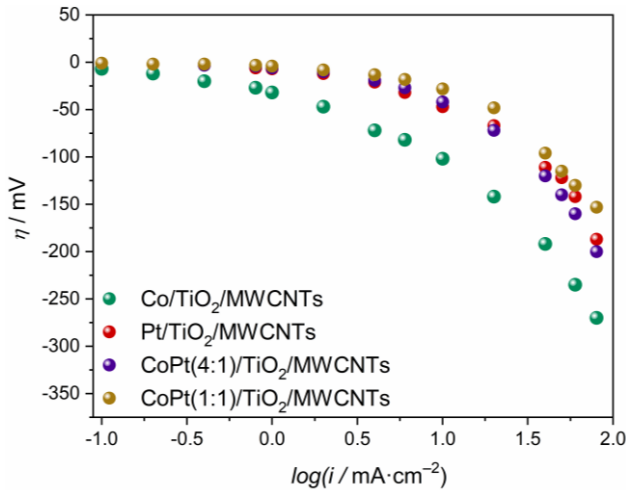


Fig. 2 Polarization curves in the plot $\log i - \eta$ for the studied electrode materials in 3.5 M KOH .

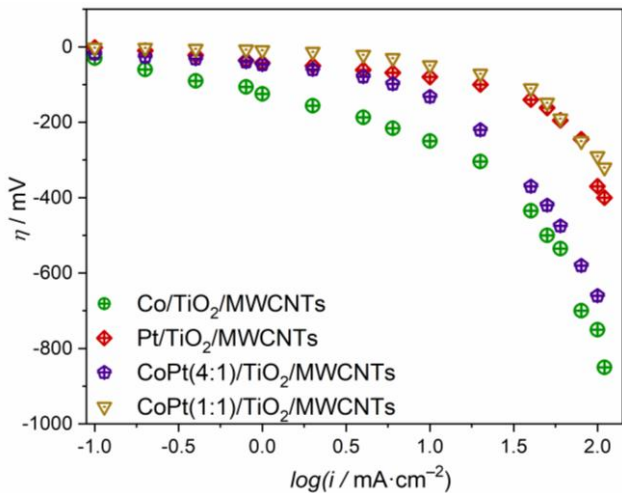


Fig. 3 Polarization curves in the plot $\log i - \eta$ for the studied electrode materials in $0.5 \text{ M H}_2\text{SO}_4$.

In acid electrolyte the order of activity is the same, but the ratio between the activities is different. The electrodes with pure Pt and mixed metallic phase $\text{CoPt}(1:1)$ show very close overpotentials at reference current density (-195 and -190 mV , respectively), while the activity of electrode with mixed metallic phase $\text{CoPt}(4:1)$ is so far from those of the previous two (-475 mV). The reason of its poor activity is very low stability of cobalt in acid solutions. As in previous case, the electrode with pure Co phase was shown as the poorest catalyst for HE with overpotential of -535 mV at reference current density of $60 \text{ mA} \cdot \text{cm}^{-2}$.

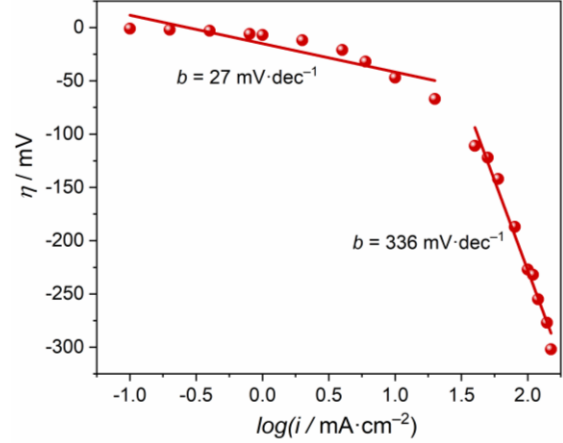


Fig. 4 Tafel slopes in the plot $\log i - \eta$ for the $\text{Pt/TiO}_2/\text{MWCNTs}$ electrode material in 3.5 M KOH .

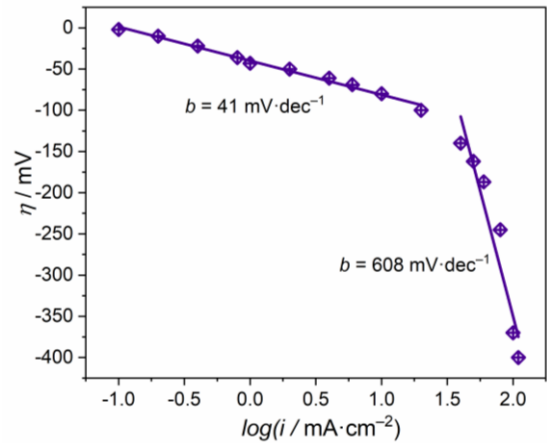


Fig. 5 Tafel slopes in the plot $\log i - \eta$ for the $\text{Pt/TiO}_2/\text{MWCNTs}$ electrode material in $0.5 \text{ M H}_2\text{SO}_4$.

Table 2: Tafel slopes and overpotential at the reference current density of $60 \text{ mA} \cdot \text{cm}^{-2}$ for HE of the studied electrode materials in 3.5 M KOH .

Sample N°	Met. phase (10%wt.)	b_1	b_2	b	η_{60}
1	Pt	27	336	57	-145
2	CoPt (1:1,wt.)	17	357	49	-130
3	CoPt (4:1,wt.)	26	374	62	-160
4	Co	47	391	87	-235

Table 3: Tafel slopes [$\text{mV} \cdot \text{dec}^{-1}$] and overpotential [mV] at the reference current density of $60 \text{ mA} \cdot \text{cm}^{-2}$ for HE of the studied electrode materials in $0.5 \text{ M H}_2\text{SO}_4$.

Sample N°	Met. phase (10%wt.)	b_1	b_2	b	η_{60}
1	Pt	41	608	101	-195
2	CoPt (1:1,wt.)	26	474	92	-190
3	CoPt (4:1,wt.)	73	743	197	-475
4	Co	114	920	236	-535

The third inference is that the studied electrode materials show two different Tafel slopes, one in lower current range and the second in the higher current range (Fig. 4 and 5). The Tafel slopes are also an indicator for catalytic activity. The slighter the Tafel slope, the higher the electrocatalytic activity or the steeper the Tafel slope, the lower the electrocatalytic activity. According to the values of Tafel slopes shown in Tables 2 and 3 (in the low current region, b_1 , in high current region, b_2 or value for whole scanned current region) for both electrolytes (alkaline and acid) one can see the same order of the catalytic activities of the studied electrode materials.

These results obtained in aqueous electrochemical cell are in agreement with the results obtained in Proton Exchange Membrane (PEM) electrochemical cell, so called “Easy Test Cell”, for the same electrode systems [17]. Equivalent metallic systems deposited on non-stoichiometric titanium oxides “Magneli phase” were tested for oxygen reduction reaction (ORR) in a real (two-electrode) PEM alkaline hydrogen fuel cell (AHFC) and similar order of the electrocatalytic activity was registered [20].

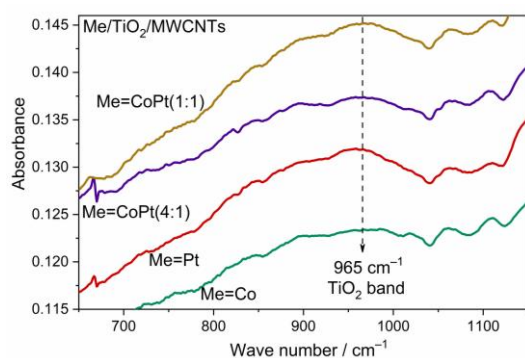


Fig. 6 FTIR spectra of the studied electrocatalysts.

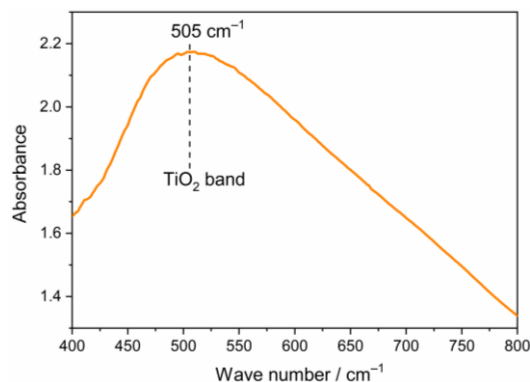


Fig. 7 FTIR spectrum of pure anatase TiO_2 .

Electrocatalytic activity of electrode materials is a sum of intrinsic and surface activity. The intrinsic activity means the ability of the electrode material to exchange electrons with the reactive ions, to adsorb discharged atoms at the electrode surface and to desorb hydrogen gas from the surface. Surface activity is mainly connected with the real surface area of the electrode material. The higher real surface means that the electrode reaction takes place faster. In order to determine whether the enhancement of the electrocatalytic activity is result of the improvement of intrinsic or surface activity, as well as to explain the unexpected better activity of electrode material with mixed metallic phase CoPt(1:1) related to electrode with pure Pt metallic phase, structural investigations were done by means of FTIR spectroscopy, X-ray diffraction (XRD) analysis and transmission electron microscopy (TEM).

Using FTIR analysis, the hypo-hyper d-interaction between the metallic phases and TiO_2 can be determined. Within the d-

metals/compounds d-bonds are predominant, which are responsible for adsorption/desorption processes [21] – very important part of the hydrogen evolution reaction. Therefore, the higher the interaction, the higher the electrocatalytic activity of the electrode. FTIR spectra of the studied catalysts are shown in Fig. 6. The only band of interest within the FTIR spectra is that of anatase titania. For all studied electrode materials, the maximum of this band is at 965 cm^{-1} . In Fig. 7 is shown FTIR spectrum of pure anatase TiO_2 obtained by identical procedure as the studied electrode materials. The maximum of the band originated from anatase is at 505 cm^{-1} . It is evident a shift of the TiO_2 band maximum for even 460 cm^{-1} . This shift is result of shortening of the bands in TiO_2 as result of interaction with metallic phase. This points out that in studied electrode materials there is strong hypo-hyper d-interaction and all of them possess improved intrinsic activity related to the activity of the electrode material with only metallic phase. But, the level of interaction in all materials is the same, thus it cannot be an explanation of better activity of the electrode materials with mixed metallic phase related to that with pure Pt.

We could find an explanation of this question with XRD and TEM analysis.

XRD spectra of the studied electrode material are shown in Fig. 8. In all studied materials TiO_2 was detected as crystalline anatase with crystallite size of $\sim 4\text{ nm}$. It was not observed peaks typical for cobalt, due to its very small particles. It was shown for other Co-based electrode materials in our previous studies [22,23]. Only the sample with pure Co as metallic phase has shown very weak and less pronounced peak at 44.22° , corresponding to (111) crystalline plane of cubic Co. In the spectrum of electrode material with pure Pt as metallic phase, a sharp and fine pronounced peaks of crystalline Pt were observed, with crystallite size of $\sim 11\text{ nm}$. These peaks in the spectra of electrode materials with mixed CoPt metallic phases are wider and less pronounced. Their positions are the same as those in the sample with pure Pt metallic system, pointing out that in the mixed CoPt electrode materials there is not CoPt intermetallic phase, but only a mixture of Co and Pt particles exists.

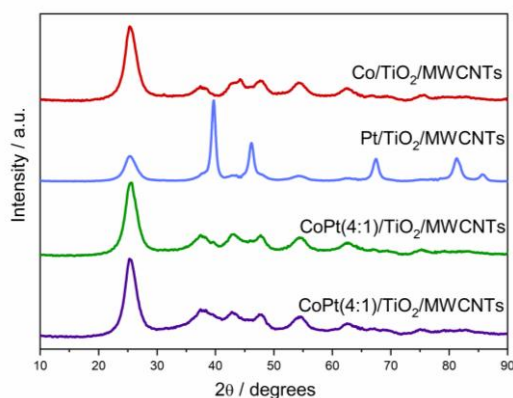


Fig. 8 XRD spectra of the studied electrode materials.

An assessment of the metallic particle size and observation of their dispersion over the electrode material surface, was carried out by means of TEM analysis (Fig. 9). The black spots are the metallic particles on the electrode material surface. The diameter of these black spots is $10\div 12\text{ nm}$ for the sample containing pure Pt. Very close value was calculated by the Sherrer equation using XRD data. The metallic particle size of the electrode materials with mixed metallic phase are considerably smaller ($d < 4\text{ nm}$). It is evident that results of XRD and TEM analysis are in good agreement. For all studied samples, the active catalytic phase – metallic particles are uniformly and good dispersed over the electrode material's surface.

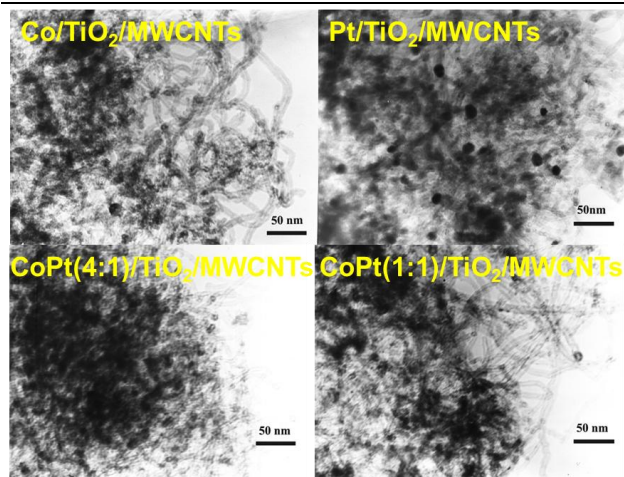


Fig. 9 TEM images of the studied electrode materials.

The main inference from XRD and TEM analysis is that the Pt particles in the presence of Co are much smaller ($\sim 3\text{--}4$ times). This points out that cobalt behaves as a promoter for decrease of the Pt particles size. This was noticed also by other authors [24,25]. The smaller the metallic particles size, the higher the surface area of the active catalytic phase and the greater the number of active catalytic centers which are better dispersed over the surface of electrode material. Therefore, the electrocatalytic activity toward hydrogen evolution is higher.

In Fig. 10, the SEM images of the CoPt(1:1)/TiO₂/MWCNTs is shown. The intertwined tube-like morphology can be seen as a result of MWCNTs. This morphology is more suitable than that of electrode materials deposited on carbon blacks [26]. The electrode's components are arranged into smaller clusters, creating more holes between them. This contributes to better inter-particle porosity of the catalysts, appropriate for passing through of the gas phase. Due to the geometric shape of MWCNTs, they have inner holes, causing trans-particle porosity of the electrode material. Both types of porosity have a favorable effect on the electrocatalytic activity. All other studied materials have shown similar morphology.

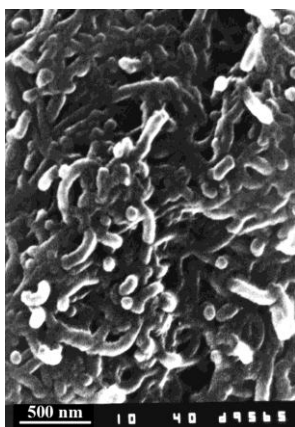


Fig. 10 SEM image of the CoPt(1:1)/TiO₂/MWCNTs sample.

4. Conclusions

The main goal of this research was to reduce or even replace Pt in the electrode material for HE. Platinum was replaced with cobalt, so the series of the studied electrode materials consisted of samples with pure metallic phase – Pt or Co and mixed metallic phase – CoPt, 4:1 and 1:1, wt. The electrode materials were composed of 10% metallic phase, 18% TiO₂ and the rest the catalyst support – MWCNTs. deposited on catalyst support consisted of TiO₂ and activated (MWCNTs) were prepared and

studied. The main conclusion points derived from the presented results, are the follow:

- All studied electrode materials have shown improved intrinsic electrocatalytic activity detected through the pronounced hypohyper d-interaction between metallic phase and TiO₂, proven by the FTIR analysis.
- According to the XRD and TEM analysis, cobalt has been shown to be a promoter for decrease of platinum particle size, reducing them for 3-4 times.
- Reduction of the Pt particles size, causes increase of the real surface area of the metallic phase as the main catalytic centers, which compensates the less amount of Pt in the electrode material. So, the activity of the electrode material with only 20% Pt in metallic phase is close to that of pure Pt containing electrode material, while the electrode material with 50% Pt in metallic phase exceeds its activity.

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Nano-structured Electrode Materials with Reduced Amount of Platinum Aimed for Hydrogen Evolution. Part II: Effect of MWCNTs modification

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Abstract: Direct Metal Laser Sintering (DMLS) is a revolutionary technology that allows a production of fully functional metal parts directly from a 3D CAD data, eliminating the investment to production tools and technologies which brings considerable cost and time savings. Metal parts made by DMLS technology are fully comparable with casted or machined parts. A range of application of DMLS technologies is very wide – from prototypes, through short-run production to final products. Advantages of DMLS technology are arising along with complexity of parts – more complex geometry of parts (in terms of shape and occurrence of the detail) make DMLS technology even more economically effective.

Keywords: HYDROGEN ECONOMY, CATALYST SUPPORT, MWCNTs MODIFICATION, COBALT, PLATINUM

1. Introduction

Living in the time of exhausted and limited reserves of fossil fuels [1], the “hydrogen economy” is emerging as a promising future energy supply system instead of the existing one based on fossil fuels [2]. The main focus of the hydrogen economy’s activities is directed to selection and development of the effective electrode materials for electrochemical devices for hydrogen production and its conversion to electricity. The modern electrodes materials are consisted of electrocatalytic phase (mainly metals, mixture of metals or mixture of metals and its compounds) and catalyst support (nano-dimensional carbon materials) [1]. The most used traditional electrode material contains platinum nanoparticles deposited on carbon blacks (Vulcan XC-72). In the first part of this paper series, the actual problems with platinum were explained, as well as the pathways for improvement of electrocatalytic activity of non-platinum metals [3]. Here we will explain the importance of the support materials and pathways for their improvement in order to enhance the electrocatalytic activity of the whole electrode material.

Metallic nanoparticles affinity to agglomerate in larger particles and show very poor dispersion, resulting in deterioration of the surface characteristics. This is a considerable limitation of their use as an electrocatalytic electrode material, in fact, they cannot be used as an electrocatalysts individually. To overcome this drawback, they must be applied to a support material. Therefore, the principal function of the support material is to provide a uniform dispersion of the metallic nanoparticles over the whole surface and to avoid their agglomeration. So, the support material should have superior surface characteristics. The other requirements that have to be assured for better performances of the electrode materials are [1]: *i*) high electrical conductivity. Because of the ratio between support material and metallic catalytic phase of 4–5:1, the support material should provide continuous exchange of electron with reacting ions; *ii*) good chemical and mechanical stability to provide long durability of the electrochemical devices and *iii*) to be “non-inert”, i.e. to provide interaction with metallic (catalytic) phase, which improve the electrochemical activity of the electrode material.

The most used support material in hydrogen economy is carbon black (Vulcan XC-72), as result of its appropriate properties, such as a high degree of ordering, surface characteristics and high electroconductivity [4]. The discovery of carbon nanostructures has attracted great attention to their application as a support material in the hydrogen economy. So, the newer carbonaceous materials such as carbon nanotubes (CNTs) and nanofibers were recognized as a very suitable for this purpose [5–7]. In comparison with Vulcan XC-72, CNTs show the following advantages: *i*) higher electroconductivity in range of 10^3 – 10^4 S·cm⁻¹ vs. 4 S·cm⁻¹ [8]; *ii*) higher specific surface area in range of 200–900 m²·g⁻¹ [8]; *iii*) Vulcan XC-72 possesses micropores smaller than 2 nm, which is not the case with CNTs [8]. This is important for the electrocatalytic purpose, because the fine nanostructured metallic particles can sink into the micropores, reducing the number of three-phase boundary reaction sites; *iv*) higher chemical stability, very important parameter for anodic reactions, where the electrochemical degradation of carbon

materials is shown by carbon graphitization [4]. This can be described by the fact that electrochemical corrosion takes place at the edge planes of graphite, whereas the basal planes are relatively inert. Therefore, a higher corrosion resistance was noticed in materials such as Pt/CNTs which are roll-ups of graphene sheets and possess a long-range order, as compared to Pt supported on carbon blacks which have a turbostratic structure and are composed of a mixture of graphite crystallites and amorphous carbon [9].

Because the manufactured MWCNTs always contain impurities such as amorphous carbon, alkali metal nanoparticles [10,11], a further treatment of carbon nanotubes is needed. The purification means remove of the impurities, while activation means making the surface more reactive as result of increased presence of functional groups. One of the most used purification/activation methods is treatment by nitric acid [6,12]. During purification process, shortening and opening of the MWCNTs occurs, implying more active surface.

The main goal of this research is to enhance the electrocatalytic activity of the Co-Pt based electrode materials through the purification/activation of the manufactured MWCNTs in concentrated nitric acid.

2. Materials and Methods

The first experimental step was a purification/activation of the manufactured MWCNTs (Guangzhou Yorkpoint Energy Company, China) in 28%wt. solution of HNO₃. Ultrapurified and deionized water was used for the preparation of the solution. The dispersed MWCNTs into the solution were stirred by magnetic stirrer (1000 rpm) for 4 h. The suspension full of MWCNTs was filtered by vacuum through a micro-filter. Final drying was performed at 95 °C for 12 h. The structural changes of treated MWCNTs related to the manufactured (non-treated), were studied using thermal analysis (TG/DTG), Raman spectroscopy and TEM microscopy. For thermal analysis a Perkin Elmer Pyris Diamond Thermogravimetric/Differential Thermal Analyzer was used. MWCNTs samples were heated in the temperature range of 25÷1000 °C with a heating rate of 20 °C·min⁻¹, in atmosphere of N₂. Scanning of the Raman spectra was performed using Micro-Raman multichannel spectrometer – Horiba JobinYvon LabRam Infinity (f x 10) using 532 nm YAG laser. Transmission electron Microscope JEOL JEM - 200 CX was used for TEM observation.

Surface changes were observed by cyclic voltammetry measuring the values of the double layer capacity [13,14]. The ratio of real versus geometric surface area S_R/S_G , of the electrodes was determined as a quotient of the catalyst’s double layer capacity C_{dl} versus the double layer capacity C_{dl0} of a pure oxide surface.

The preparation and composition of the studied electrode materials was identical as in the first part of this paper series [3]. The structural changes of the samples, was studied by infrared FTIR spectroscopy. The FTIR spectra were recorded using KBr pellets at

room temperature with a Perkin-Elmer System 2000 interferometer. Electrochemical characterization was performed using the same instrumentation line and methods as in the first part of this paper series [3].

3. Results and discussions

The electrocatalytic activity of the studied electrode materials expressed through polarization curves in the plot of current density-overpotential ($i-\eta$), are shown in Fig. 1. Corresponding values of Tafel slopes in the lower and higher current regions, as well as the overpotential at reference current density of $60 \text{ mA} \cdot \text{cm}^{-2}$ are listed in Table 1. The order of activity is the same as in the first part of this paper series: $\text{CoPt}(1:1) > \text{Pt} > \text{CoPt}(4:1):\text{Co}$, and the reason of this order was explained. But, if compare the electrocatalytic activity of each metallic phase with that of each metallic phase deposited on non-treated (manufactured) MWCNTs (presented in previous part), significant improvement can be observed. This comparison is shown in Figures 2 to 5.

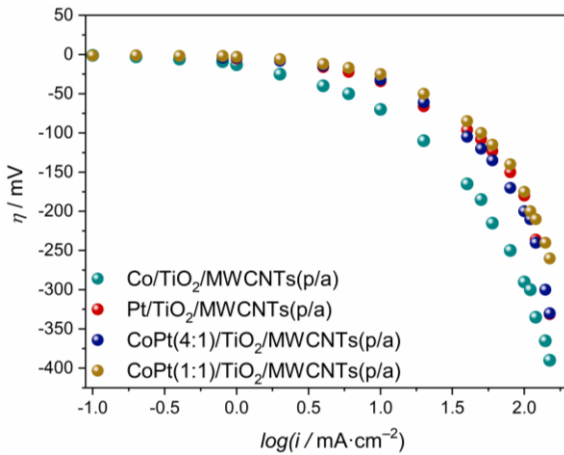


Fig. 1 Polarization curves in the plot $\log i-\eta$ for the studied electrode materials deposited on treated MWCNTs, in 3.5 M KOH

Table 1: Tafel slopes and overpotential at the reference current density of $60 \text{ mA} \cdot \text{cm}^{-2}$ for HE of the studied electrode materials in 3.5 M KOH.

Sample N°	Met. phase (10%wt.)	b_1	b_2	η_{60}
1	Pt	23	373	-125
2	CoPt (1:1,wt.)	17	302	-115
3	CoPt (4:1,wt.)	20	365	-135
4	Co	43	383	-215

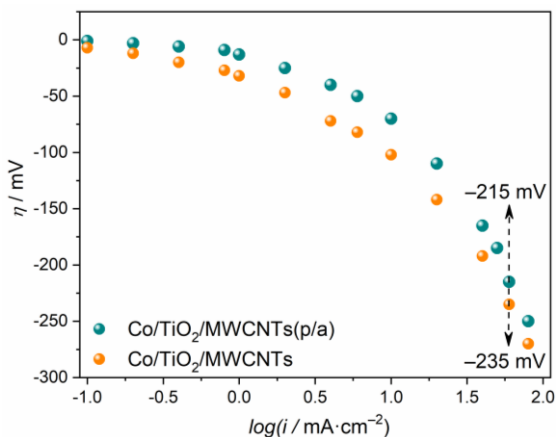


Fig. 2 Polarization curves in the plot $\log i-\eta$ for Co/TiO_2 system deposited on manufactured and treated MWCNTs, in 3.5 M KOH

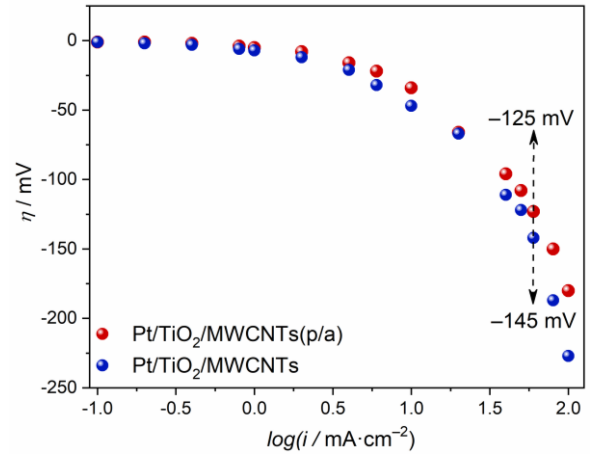


Fig. 3 Polarization curves in the plot $\log i-\eta$ for Pt/TiO_2 system deposited on manufactured and treated MWCNTs, in 3.5 M KOH

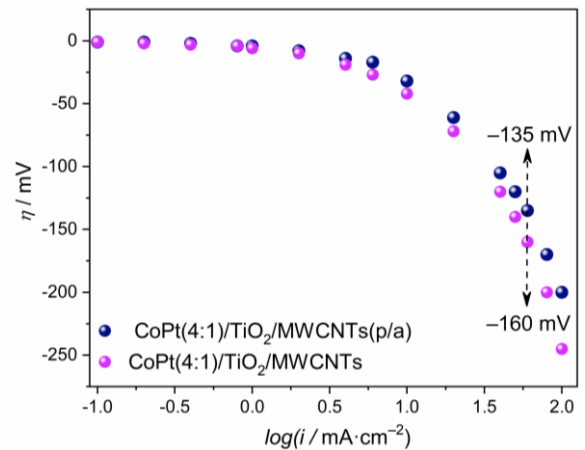


Fig. 4 Polarization curves in the plot $\log i-\eta$ for $\text{CoPt}(4:1)/\text{TiO}_2$ system deposited on manufactured and treated MWCNTs, in 3.5 M KOH

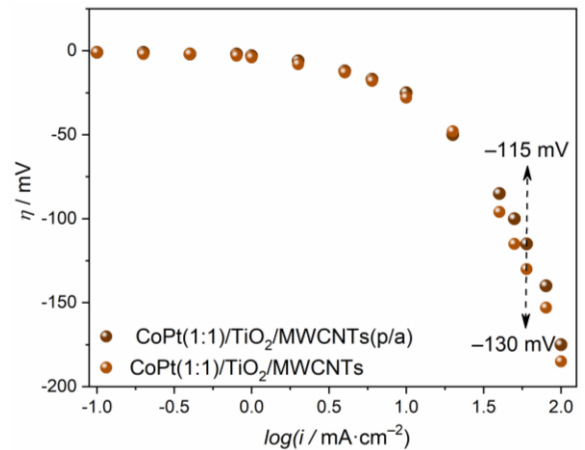


Fig. 5 Polarization curves in the plot $\log i-\eta$ for $\text{CoPt}(1:1)/\text{TiO}_2$ system deposited on manufactured and treated MWCNTs, in 3.5 M KOH

Confirmation of this improvement of electrocatalytic activities of the studied electrode materials are the values of Tafel slopes shown in Table 1 and in Table 2 in the first part of this paper series [3].

To check for some changes in the hypo-hyper d-interaction between the metallic phase and TiO_2 , as result of the MWCNTs treatment, FTIR spectra (Fig. 6) were recorded. All electrode systems show similar spectra and can be concluded that there is not additional hypo-hyper d-interaction as result of MWCNTs treatment. Therefore, the reason for improvement of the electrocatalytic activ-

ity should be sought in the structural or surface changes of MWCNTs as result of their treatment in nitric acid.

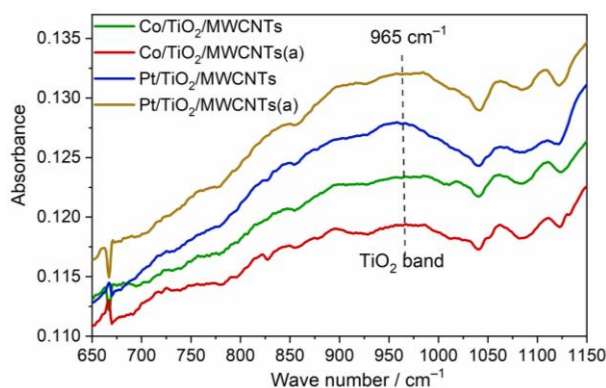


Fig. 6 FTIR spectra for electrode materials with pure metallic phase

Thermal analysis (TG/DTG) of the studied electrode materials has shown that the acid treatment caused higher thermal stability of the MWCNTs. In the DTG spectra shown in Fig. 7, one can see that all characteristic temperatures for the treated MWCNTs are shifted to the higher values. The DTG peak at 573 °C for non-treated MWCNTs is ascribed to the combustion temperature of amorphous carbon, while the peak at 757 °C corresponds to the combustion temperature of the MWCNTs. The corresponding combustion temperatures of amorphous carbon and MWCNTs for acid treated MWCNTs are 641 °C and 893 °C. According to the TG values of temperature shown in Table 2, weight loss of the non-treated MWCNTs starts at 523 °C, with complete oxidation at 617 °C. The corresponding temperatures for acid treated MWCNTs are higher – 585 °C and 847 °C respectively.

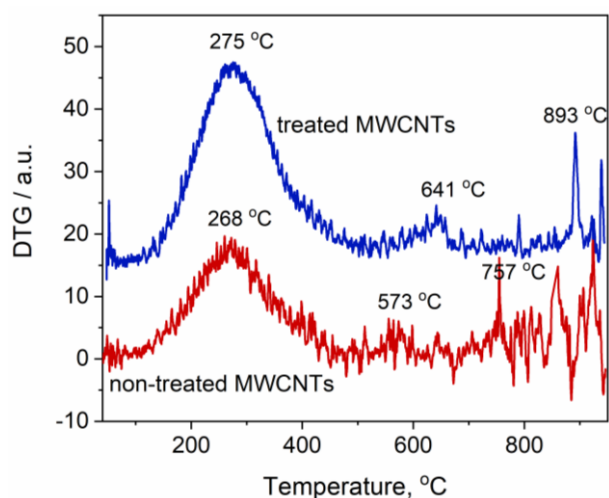


Fig. 7 DTG spectra of non-treated and treated MWCNTs

Table 2: Characteristic TG oxidation temperatures for the non-treated and treated MWCNTs.

Sample	TG ₁	TG ₂	TG ₃
Non-treated MWCNTs	173	523	617
Acid treated MWCNTs	180	585	847

The Raman spectra of the non-treated and purified/activated MWCNTs shown in Fig. 8 are consisted of two well pronounced peaks D and G. D peak at near 1350 cm⁻¹ expressing the presence of disordered carbon structure: defects such as pentagons or heptagons in graphite, vacancies from single to multiple, edges of the graphite crystal, amorphous carbon etc. [15]. G peak at 1585 cm⁻¹ is attributed to the highly oriented graphite [16]. A low pronounced and shouldered peak noted as D' can be observed at position of 1620 cm⁻¹. The presence of the D' peak points out that these carbon nanotubes are multiwalled [17]. The intensity ratio of the characteristic peaks (I_D/I_G) points out on the extent of disorder, i.e. the pro-

nounced presence of defects and impurities in the nanotubes. After the acid treatment of the MWCNTs the value of the I_D/I_G ratio from 1,32 decreases to 1,23. This indicates on the increase of crystallinity of the MWCNTs, i.e. removing of amorphous carbon and reducing the defects within its structure.

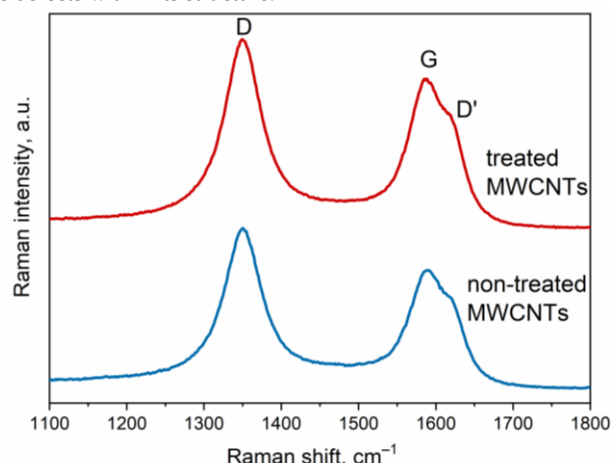


Fig. 8 Raman spectra of non-treated and treated MWCNTs

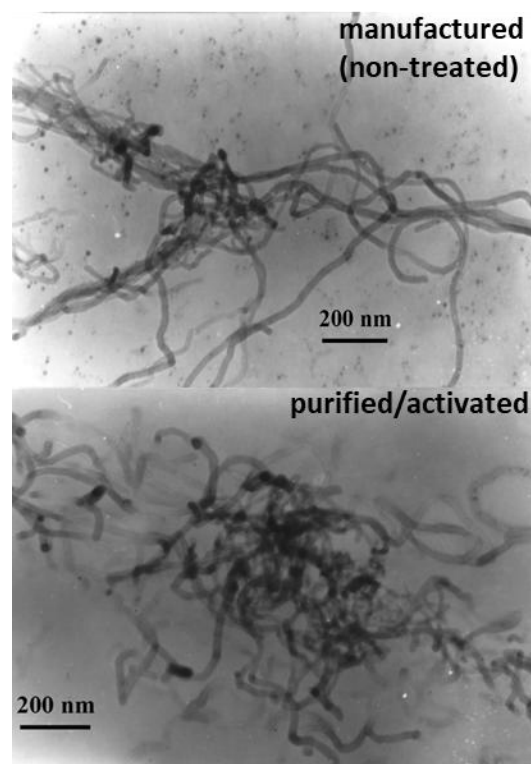


Fig. 9 TEM images of non-treated and treated MWCNTs

From the TEM images shown in Fig. 9, the shortening and opening of the MWCNTs can be clearly seen. This means increase of defects within the MWCNTs structure and increase of the I_D/I_G ratio is expected. But, the Raman results did not show that. The decrease of the I_D/I_G ratio can be explained by the high extent of the removal of amorphous carbon. The shortening and opening of the MWCNTs is an appropriate for electrocatalytic purpose, as result of increased MWCNTs reactivity, facilitating the process of applying the metallic phase over the MWCNTs surface. Also, a higher real surface area of MWCNTs could be expected.

This expectation was confirmed by the values of the double layer capacity for pure carbon phases and the ratio of real vs. geometric surface area (S_R/S_G). The measurements were performed in the region of potentials where only charging of double layer occurs with scanning rate from 1 to 10 mV·s⁻¹. The procedure for determination of C_{dl} for carbon blacks and carbon nanotubes, as well as electrocatalysts deposited on these carbon substrates, is presented elsewhere [18]. The results are shown in Table 3. The acid treated

carbon nanotubes have higher value for the double layer capacity than that of non-treated MWCNTs, i.e. they have more developed surface area expressed with higher ratio of real vs. geometric surface area (S_R/S_G). As was mentioned above, this is result of opening, shortening, and thinning of the nanotubes by HNO_3 treatment. Also, according to the C_{dl} and S_R/S_G values, MWCNTs show almost two times higher surface area than the traditionally used carbon substrate, Vulcan XC-72.

Table 3: Double layer capacity C_{dl} and ratio of real vs. geometrical surface area S_R/S_G for the studied carbon nanostructures.

Sample	C_{dl} , $\text{mF}\cdot\text{cm}^{-2}$	S_R/S_G
Non-treated MWCNTs	331	5520
Acid treated MWCNTs	355	5920
Vulcan XC-72	179	2980

4. Conclusions

According to the presented results, the following conclusions can be drawn:

- During the activation/purification of MWCNTs, two main processes occur: i) removing of other carbonaceous phases such as amorphous carbon and ii) shortening, thinning and opening of the MWCNTs.
- These phenomena favour the increase of the real surface area of the support material (MWCNTs) and consequently of the electrode material as a whole.
- All electrode materials deposited on the acid treated MWCNTs have shown improved electrocatalytic activity related to the corresponding systems deposited on non-treated MWCNTs.
- Compared with traditional electrode material (the same quantity of platinum, 10%wt. deposited on Vulcan XC-72), the best catalytic system 10%CoPt(1:1)/TiO₂/MWCNTs(p/a) has shown much higher electrocatalytic activity (−115 mV vs. −220 mV [19]) at reference current density of 60 $\text{mA}\cdot\text{cm}^{-2}$). Even the electrode material with pure Co phase (10%Co/TiO₂/MWCNTs(p/a)) exceeded the electrocatalytic activity of the traditional platinum electrocatalysts (−215 mV vs. −220 mV).

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Types of Lasers used in metal processing

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Abstract: This paper elucidates the salient features of CO₂, Nd: YAG, and fiber lasers in the context of their application in metal processing. Operating at 10.6 micrometers, CO₂ lasers exhibit variable power outputs, crucial for tasks such as cutting and welding. Nd: YAG lasers, working at 1.064 micrometers, demonstrate versatility in pulse modes, with their efficiency intricately linked to quantum defect and thermal effects. Fiber lasers, with an operational wavelength of 1.07 micrometers, showcase heightened efficiency (30-40%) owing to superior pump light absorption. While mathematical models provide foundational insights, the practical efficacy of these lasers' hinges on nuanced factors, necessitating advanced empirical investigations for optimized application.

1. CO₂ Lasers

CO₂ lasers are gas lasers that operate at a wavelength of 10.6 micrometers. The laser beam is generated in a gas mixture consisting of carbon dioxide, nitrogen, helium, and hydrogen. The energy from the electrical discharge excites the nitrogen molecules, which then transfer their energy to the CO₂ molecules. The excited CO₂ molecules emit photons, which are amplified to produce the laser beam [1].

The power output of CO₂ lasers can range from a few watts to over 20 kilowatts. The power density I (W/cm²) of the laser beam can be calculated using the equation $I = P/(\pi r^2)$, where P is the power output and r is the beam radius [2]. The power density is a critical parameter that determines the laser's ability to cut or weld metals Fig. 1.

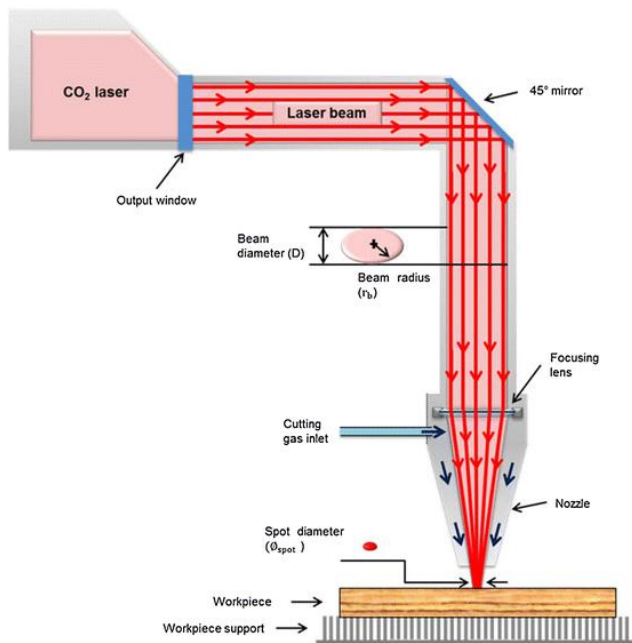
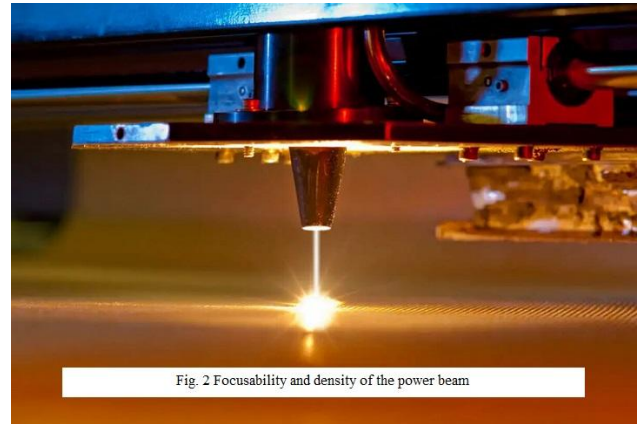


Fig. 1 Diagram of CO₂ laser cutting assisted by gas

The efficiency η of CO₂ lasers is typically around 10-20%. The efficiency can be calculated using the equation $\eta = P_{out}/P_{in}$, where P_{out} is the output power and P_{in} is the input power. The relatively low efficiency is due to various loss mechanisms, such as spontaneous emission, mirror losses, and electrical-to-optical conversion losses.

The beam quality factor M^2 , which describes the beam divergence relative to an ideal Gaussian beam, can be calculated using the equation $M^2 = \theta D/\lambda$, where θ is the full-angle beam divergence, D is the beam diameter, and λ is the wavelength. The beam quality

factor is a critical parameter that determines the focusability of the laser beam and thus the achievable power density Fig. 2.



The beam divergence θ can be calculated using the equation $\theta = \lambda/(\pi w)$, where w is the beam waist radius. The beam waist radius is the radius at which the beam intensity is reduced to $1/e^2$ of its peak value. The beam divergence is a critical parameter that determines the spread of the laser beam over distance [3].

The beam diameter D can be calculated using the equation $D = 2w$, where w is the beam waist radius. The beam diameter is a critical parameter that determines the size of the laser spot on the workpiece.

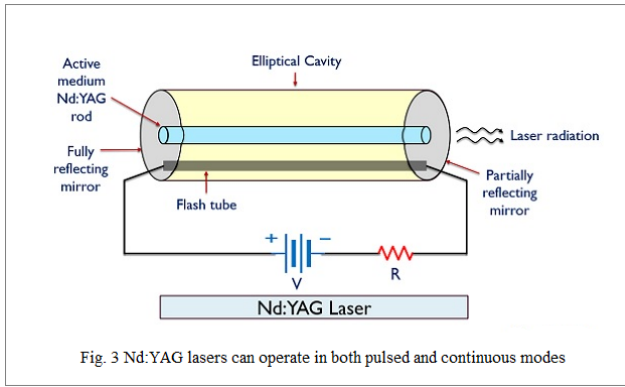
2. Nd:YAG Lasers

Neodymium-doped Yttrium Aluminum Garnet (Nd:YAG) lasers are solid-state lasers that operate at a wavelength of 1.064 micrometers [4]. The Nd:YAG crystal is pumped by flash lamps or diode lasers, exciting the neodymium ions. The excited ions emit photons, which are amplified in the Nd:YAG crystal to produce the laser beam [5].

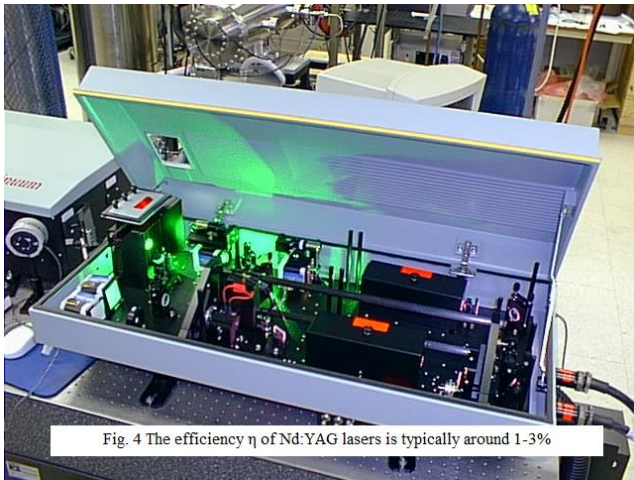
Nd:YAG lasers can operate in both pulsed and continuous modes Fig. 3. The pulse energy E (J) can be calculated using the equation $E = P\tau$, where P is the peak power and τ is the pulse duration. The pulse energy is a critical parameter that determines the laser's ability to drill or engrave metals.

The pulse duration τ can be calculated using the equation $\tau = E/P$, where E is the pulse energy and P is the peak power. The pulse duration is a critical parameter that determines the temporal shape of the laser pulse.

The pulse repetition rate f (Hz) can be calculated using the equation $f = 1/T$, where T is the pulse period. The pulse repetition rate is a critical parameter that determines the number of laser pulses delivered per unit time [6].

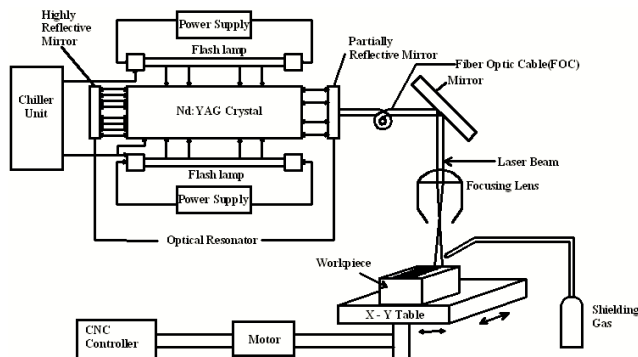


The efficiency η of Nd:YAG lasers is typically around 1-3% Fig. 4. The relatively low efficiency is due to various loss mechanisms, such as quantum defect, pump light absorption, and thermal effects.



The quantum defect Δ can be calculated using the equation $\Delta = (\lambda_p - \lambda_l) / \lambda_l$, where λ_p is the pump wavelength and λ_l is the laser wavelength. The quantum defect is a measure of the energy difference between the pump photons and the laser photons, which is converted into heat.

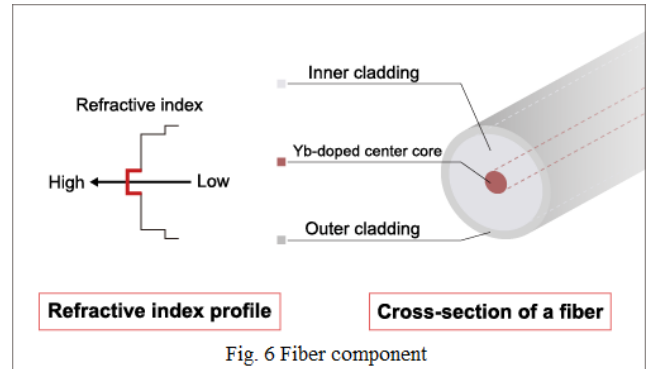
The thermal load Q (W) can be calculated using the equation $Q = P_{in}(1 - \eta)$, where P_{in} is the input power and η is the efficiency. The thermal load is a measure of the heat generated in the laser medium, which can cause thermal lensing and degrade the beam quality Fig. 5.



The beam quality factor M^2 can be calculated using the same equation as above. The beam quality factor of Nd:YAG lasers is typically close to 1, indicating near-ideal beam quality.

3. Fiber Lasers

Fiber lasers use an optical fiber doped with rare-earth elements such as erbium or ytterbium as the active medium. They operate at a wavelength of around 1.07 micrometers. The fiber's unique structure provides excellent thermal management and allows high power levels Fig. 6.

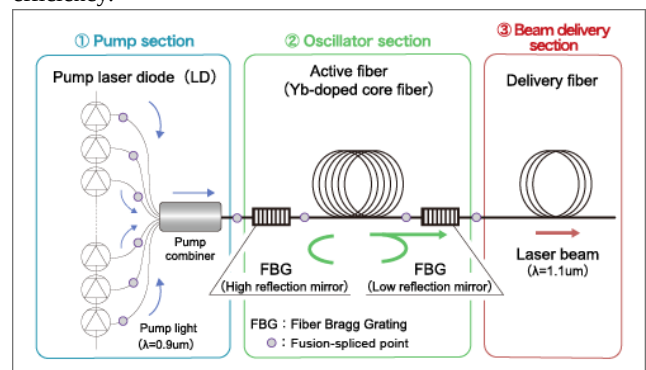


The power output of fiber lasers can range from a few watts to over 100 kilowatts. The power density and pulse energy can be calculated using the same equations as above [7].

The efficiency η of fiber lasers is typically around 30-40%, which is significantly higher than CO2 and Nd:YAG lasers. The high efficiency is due to the high pump light absorption and low quantum defect of the fiber medium.

The pump light absorption Fig. 7, α (m^{-1}) can be calculated using the equation $\alpha = \ln(1 - T)/L$, where T is the transmission and L is the fiber length [9]. The pump light absorption is a measure of the ability of the fiber to absorb the pump light, which is converted into laser light.

The quantum defect Δ can be calculated using the same equation as above. The quantum defect of fiber lasers is typically lower than that of Nd:YAG lasers, resulting in lower thermal load and higher efficiency.



The thermal load Q can be calculated using the same equation as above. The thermal load of fiber lasers is typically lower than that of Nd:YAG lasers, resulting in better thermal management and higher beam quality.

The beam quality factor M^2 can be calculated using the same equation as above. The beam quality factor of fiber lasers is typically close to 1, indicating near-ideal beam quality [8].

4. Conclusion

In summary, the realm of laser technology in the context of metal processing is predominantly anchored in the utilization of three

fundamental laser types: Carbon Dioxide (CO₂), Neodymium-doped Yttrium Aluminum Garnet (Nd:YAG), and fiber lasers. These lasers, each distinguished by their unique properties, find application in various metal processing scenarios, their suitability contingent upon key operational parameters, such as wavelength, power output, mode of operation, efficiency, and beam quality [10]. The amalgamation of these factors significantly dictates the operational characteristics and potential applications of each laser type.

Carbon Dioxide (CO₂) lasers operate primarily in the infrared spectrum, with a typical wavelength of around 10.6 micrometers. Their high-power output and excellent beam quality make them well-suited for cutting and engraving applications in materials like metals. Neodymium-doped Yttrium Aluminum Garnet (Nd:YAG) lasers, on the other hand, emit in the near-infrared region and possess versatile attributes, rendering them suitable for cutting, welding, and marking tasks in metals. Fiber lasers, a more recent entrant to the scene, are characterized by their high efficiency, compactness, and maintenance-free operation. They have found increasing popularity in metal processing applications, particularly in the field of high-speed and high precision cutting and welding [11].

The mathematical models and equations elaborated upon herein provide a foundational understanding of the operating principles governing these laser systems. These models consider aspects such as gain medium properties, resonator design, and optical cavity configurations. While such models are essential for predicting the behavior of laser systems, they should be considered idealized representations, as the actual performance of lasers in metal processing is contingent on a multitude of factors. These factors encompass, but are not limited to, the intricate interplay of beam quality, mode structure, and system design.

For instance, beam quality is a crucial parameter that influences the ability of a laser to focus its energy on a specific spot, impacting the precision of cutting and welding. Mode structure refers to the spatial and temporal distribution of laser energy within the beam, which can affect the resulting heat-affected zone and overall processing quality. System design, which encompasses aspects like optical components and cooling systems, plays a pivotal role in determining the overall efficiency and reliability of the laser system [12].

To advance our understanding and optimize the performance of laser systems in metal processing, a two-pronged approach is crucial. First, advanced mathematical modeling is imperative for a more nuanced and accurate representation of laser behavior under real-world conditions. These models must consider not only the intrinsic characteristics of the lasers but also the external factors that affect their performance. Secondly, experimental studies, involving controlled tests and data collection, are indispensable for validating and refining the models, ultimately leading to improved laser system design and operation.

In conclusion, the successful utilization of lasers Fig. 8, in metal processing hinges on a profound understanding of the intricate interplay between laser properties and the myriad external factors influencing their performance. Advancements in laser technology and its applications in this field necessitate a holistic approach that combines theoretical models with empirical experimentation, thereby ensuring the continued evolution and refinement of laser systems for metal processing applications.

	Fiber lasers	YAG lasers	CO2 lasers
Beam quality	Excellent	Fair	Good
Footprint	Excellent	Poor	Poor
Electrical efficiency	Good	Fair	Poor
Reliability	Excellent	Poor	Poor
Maintenance	Excellent	Poor	Poor
Remote processing	Excellent	Fair	Fair
Initial investment	Good	Good	Excellent

Fig. 8 Successful utilization of lasers per type

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Permissible number of switches on per hour of electric motors for horizontally moving crane mechanisms

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Abstract: Paper deals with determining the permissible number of switches on per hour depending on the load and operating mode parameters - starting and stopping times, pause duration, etc. The criterion is that the overheating of the stator winding does not exceed the overheating at nominal mode and load. The basis of the chosen method is the assumption that the electric motor is assumed to be a conditionally uniform body, i.e. a body made of the same material with an infinitely large thermal conductivity and therefore having the same temperature throughout its volume under all possible modes and loads. The results of the calculations with a computer program implemented are presented in tabular form.

Keywords: INDUCTION MOTORS, DUTY CYCLE TYPE, LIFTING CRANES, STARTUP PROCESS, HEATING, ELECTRIC DRIVE

1. Introduction

An electric motor (EM) is a machine that converts electrical energy into mechanical energy needed to drive various mechanisms. The EM is the main component of the electric drive (ED). In some modes of operation of the ED, the EM performs a reverse conversion of energy, i.e. operates in electric generator (recovery) mode. Due to their widespread use, EMs account for over 45% of the world's electricity consumption. A wide variety of EMs are available in either *International Electrotechnical Commission* (IEC) or *National Electrical Manufacturers Association* (NEMA) design.

It has been estimated that induction motors are used in seventy to eighty per cent of all industrial drive applications [1]. In turn, induction motors (IMs) owe their wide distribution for solving various engineering tasks to their relatively simple construction, the small number of moving parts and the high wear resistance of the motor elements. It is primarily due to the absence of a collector and the associated friction, sparking, wear of the brushes and contact elements. An important advantage of these machines is their direct power supply from an alternating current (AC) mains. Another advantage of IMs that is decisive for the possibility of being used in high-cycle applications is their compact design. At the same power output, these EMs are characterized by smaller dimensions and the least specific weight per unit of power compared to other types of motors. They are reliable and easy to service, but above all they have a very high efficiency. Their starting-regulating characteristics are not very good, since the starting torque is small and the starting current is high, but these negative features are tolerable. Along with this, however, it should be pointed out that IMs, unlike other electrical machines, are too sensitive to the change of some of the main indicators of the quality of electrical energy and especially to the fluctuation, asymmetry, non-sinusoidality and frequency of the voltage of the supply mains. Their undoubted advantages and disadvantages need to be critically compared for any application [1].

For infrequent starts, absence of need for speed regulation and need to improve power factor, the use of synchronous motors is preferable.

The start-up of EMs is a very important process in operation. Therefore, along with the operating characteristics, which determine the behavior of the machine in a steady-state mode in the limits from idling to nominal load, the values that characterize the starting processes in the EM are also of great importance. These primarily include starting current and starting torque. The starting torque determines that load on the motor shaft at which the machine can rotate normally. The starting current is an important metric for two reasons:

- When switching on the IM to a mains with a voltage and power comparable to its own, the starting current can cause a significant voltage drop. This worsens or even completely disrupts the normal operation of the consumers switching on in this mains;

- Since the starting current is significantly greater than the rated one, the temperature of the windings rises. In frequent starts, and also when spinning mechanisms with large inertial masses, the issues of heating the machine on start-up can be of significant importance. From this point of view, it is of interest to determine the start-up time of the IM and the energy losses during rotation, which are released in the machine in the form of heat. The heating of the EM depends on the losses separated in it, and the losses themselves - on the load of the EM. In order to know the losses, the load must be known at every moment of the EM's operation (starting, steady-state mode, stopping). For this purpose, the so-called load diagrams representing moment, power and current dependences as a function of time must be drawn.

Driving machines and mechanisms EMs must ensure high performance, safe and economical operation. The fulfillment of this condition is possible only with a correct selection of EM power based on two main factors: by overload and by heating. Motor power versus overload is selected by using the torque or current overload factor to determine the required rated torque and current. Usually, one factor is used to select the power, and the other is used to check the selected EM. Broadly speaking the procedure is to select the EM on the basis of the assumption that the losses (and therefore the temperature rise) vary with the square of the load [2].

The choice of motor power in terms of heating largely depends on the insulation materials used in the EM construction. Due to the low thermal strength of the materials used to insulate the windings, the rated power of the EMs is limited by their heating. According to IEC, each insulation has a corresponding temperature class with admissible temperature: class Y – 90°C; class A – 105°C; class E – 120°C; class B – 130°C; class F – 155°C; class H – 180°C; class N – 200°C; class R – 220°C. NEMA identifies four insulation classes: A, B, F and H with the corresponding allowable temperatures.

The warm-up check of an EM consists of a comparison of the maximum temperature of the insulation of the windings with the permissible temperature for the corresponding class of insulation, and the maximum temperature must always be equal to or less than the permissible. Even a small excess of the operating temperature of the insulation above the permissible limit greatly reduces the normal life of the EM. For example, exceeding the temperature of the insulation by 10°C compared to the permissible one, reduces the service life by 2 times! In case of various short-term deviations from the nominal mode of operation of EMs, deviations from permissible temperature extremes are not taken into account. Nevertheless, for EMs in a heated state, certain overloads, expressed by the increase in current, are allowed. These overloads are:

- at a current 1.25 times the rated one, work is allowed for no more than 30 min.
- at a current 1.50 times the rated one, work is allowed for no more than 2 min.

For technical and economic reasons, it is required that during normal operation of the EMs, the durability of the insulation should not be less than 15-20 years. By the way, in Bulgaria and other countries there are in operation EMs produced 50-60 years ago.

If the power of an EM is selected by heating, then it has to be checked for overloading.

In addition to overheating and overloading, EMs are also selected by nominal data and type.

2. Modes of operation of electric motors regarding their heating

A large part of AC motors can be used without problems in technical applications, for which up to 10-15 starts or stops per minute are typical. Limitations in the field of application of the majority of developed IMs are due to a complex of factors. First of all, the first stage of the duty cycle is characterized by a large starting current, which causes the release of thermal energy. The heat thus generated must be dissipated when the EM is running in a steady-state mode. If there is no technologically defined minimum period of time between separate EM starts, all the necessary prerequisites for EM damage exist. The number of admissible starts of IMs depends on the inertia of the loads external to the EM, frictional losses and the operating mode of the machine.

Nowadays, in our lives, EMs are almost everywhere, from aerospace, ships, cars to washing machines, fans, vacuum cleaners, electric robots, etc. Electric motors are used in almost all application scenarios, and the drive device controls them. But almost different types of EMs have different running times. Some EMs are always in operation, and some of them run for a short period of time during the work cycle or alternately run during the cycle. Therefore, based on this, the concept of EMs duty system was introduced [3].

Electric motors in many applications are started once - at the beginning of the working day. Applications where it is necessary to start and restart the EM during a certain time are no exception. Typically, this includes the notion of normal ED operation. The duration of operation or the duration when the EM is switched off, as well as the magnitude and change of the load, reflected in the load schedule, determine the mode of operation. Determining the operating mode is an important element of selecting an EM. The main feature of the operating modes is heat distribution. The operation of an EM is accompanied by heating, which is explained by the processes taking place in it. For better cooling, the EM should be designed and manufactured more massive - bigger and heavier. So it is possible to increase the continuous load of the EM to 70-80%, but at a rather high cost - both in money and due to the loss of part of the payload (which will be "eaten" by the increased weight of the EM).

The relationship between the time of operation and rest or repeated modes at different loads is defined as the *duty cycle*. The duty, or time rating, denotes the length of time the EM is expected to be able to carry the rated load under usual service conditions [1]. Operating mode is the load condition(s) to which the rotating electrical machine is subjected, including if necessary starting, electrical braking, idling and rest, with their duration and time sequence [4]. The duty cycle is the ratio of the time during which an EM operates to the total cycle time. Duty cycle can be expressed as a ratio or as a percentage.

Most of the EMs and components used in practice wear out. Therefore, with a longer duty cycle (mode) the duration of use ("life") will be less and vice versa. For loads with continuous sustained operation for extended periods, e.g. fans that run continuously for hours or days, EMs can be selected on a constant load basis. But EMs, which are mounted on automatically controlled units such as compressors and pumps, start and stop

several times an hour. There are also EMs that stop and start many times per minute - for example in lifting mechanisms (cranes and elevators). In such EMs with frequent starts, the heating is mainly from the losses during the transient processes (main start and stop). Therefore, these EMs are checked for the permissible switches on per hour. Permissible switches on per hour means the number of start-ups where the average temperature after a large number of start-ups will be equal to the maximum permissible.

When changing the controlling and/or disturbing action in relation to EMs, various transient processes occur - electromagnetic, mechanical, thermal, which reflect the transition of the ED from one steady state to another. Strictly speaking, a consolidated transient process takes place, characterized by the change of all variables and most parameters of the ED. A complete consideration of transient processes, taking into account the involvement of all factors, is required very rarely and at the same time is very difficult or practically impossible. This is especially true for modern complex ED systems. Usually, depending on the requirements of practice and the necessary accuracy, the influence of secondary factors that are not essential to the operation of the ED is neglected.

The nature of transients is influenced by the following three types of inertia:

- mechanical inertia of the rotating and progressively moving parts of the ED and the working machine;
- electromagnetic inertia of the inductances of the electric machine and control apparatus;
- thermal inertia from the heating of EM parts and some of the elements of the control system.

Each type of inertia has a different effect on transient processes, slowing down their progress. The influence of each type of inertia is characterized by a corresponding time constant, which simultaneously combines several parameters of the ED. The mechanical inertia is determined by the mass of the progressively moving parts and the moment of inertia of the rotating parts, most often applied to the EM shaft. The electromagnetic time constant characterizes electromagnetic inertia. The heating time constants (thermal time constants) characterize the thermal inertia. Transient processes in which only mechanical inertia is taken into account are called mechanical. Transient processes in which, in addition to mechanical inertia, electromagnetic inertia is also taken into account are called electromechanical.

International Electrotechnical Commission (IEC) is a European-based organization that publishes and promotes worldwide, the mechanical and electrical standards for EMs, among other things. IEC uses designations (categories) of duty cycles (modes) to describe the operating conditions of EMs (IEC 60034-1:2022) [5]. The fourteenth edition of IEC 60034-1:2022 cancels and replaces the thirteenth edition published in 2017. *The National Electrical Manufacturers Association* (NEMA) is the largest association of electrical equipment manufacturers in the United States. Founded in 1926, it advocates for the industry, and publishes standards for electrical products. The IEC Duty Cycle Ratings are different from those of NEMA's. Where NEMA usually specifies continuous, intermittent or special duty (typically expressed in minutes), the IEC uses ten different duty cycle designations - S1 ... S10 [6]. The standards, shown in Table 1, apart from specifying EM operating parameters and duty cycles, also specify temperature rise (insulation class), frame size (physical dimension of the EM), enclosure type, service factor and so on.

In typical modes, serial EMs should work until the reliable operation of the machine is guaranteed by the manufacturer, if the EM operates in the mode specified in its passport at the rated load. Quick failure is usually due to the fact that the EM was selected without taking into account the required nominal mode. For example, the EM of a crane lifting mechanism with frequent starts may "burn out" if it is designed for lighter operating conditions.

Table 1: Operating criteria of different duty cycle types

№	Ref.	Duty Cycle Type	Description
1	S1	Continuous running duty	Operation at constant load without interruption and with sufficient duration to reach the thermal equilibrium.
2	S2	Short-time duty	Operation at constant load during a given time (10, 30, 60 and 90 minutes), less than required to reach the thermal equilibrium, followed by braking, shutdown and cool down enabling the machine to reach an ambient temperature.
3	S3	Intermittent periodic duty	A sequence of identical duty cycles, each including a period of operation at constant load and a rest (without connection to the mains). For this type of duty, the starting current does not significantly affect the temperature rise.
4	S4	Intermittent periodic duty with starting	A sequence of identical duty cycles, each consisting of a significant period of starting, a period under constant load and a rest period.
5	S5	Intermittent periodic duty with electric braking	A sequence of identical duty cycles, each consisting of a significant period of starting, a period under constant load, followed by rapid electric braking and a rest period.
6	S6	Continuous operation periodic duty	A sequence of identical duty cycles, each consisting of a period of operation at constant load and a period of operation at no-load. There is no rest period.
7	S7	Continuous operation periodic duty with electric braking	A sequence of identical duty cycles, each consisting of a period of starting, a period of operation at constant load, followed by an electric braking. There is no rest period.
8	S8	Continuous operation periodic duty with related load/speed changes	A sequence of identical duty cycles, each consisting of a period of operation at constant load corresponding to a predetermined speed of rotation, followed by one or more periods of operation at another constant load corresponding to the different speeds of rotation (e.g. duty). There is no rest period. The period of duty is too short to reach the thermal equilibrium.
9	S9	Duty with non-periodic load and speed variations	Duty in which, generally, the load and the speed vary non-periodically within the permissible range. This duty includes frequent overloads that may exceed the full loads.
10	S10	Duty with discrete constant loads and speeds	Operation characterized by a specific number of discrete values of load (not more than four discrete values of load or equivalent loading) maintained for a sufficient time to allow the machine to reach thermal equilibrium. The minimum load during a duty cycle may have value zero and be relevant to a no-load or de-energized and at rest condition.

*Thermal Equilibrium is the state reached when the temperature rise of the machine does not vary by more than 2K per hour.

In order to dimension the EMs correctly it is extremely important to specify the kind of operation the EM is to perform. Regulation CEI 2-3, dossier 8284, in accordance with European (European Committee for Electrotechnical Standardization – CENELEC EN 60034-1) and international standards (IEC 60034-

1), distinguishes 10 types of duties, whose operating criteria are specified below [7, 8]. The following three modes are adopted as the main operating modes of EMs: continuous, short-time and periodic. The heating conditions of EMs are different, which is why different methods of power selection are needed. For each mode, specially designed EMs are used.

Explanations for individual duty types (load cycles) [6]

S1: All parts of the EM are heated and the temperature becomes constant. When the user does not indicate the working duty, the manufacturer shall consider it to be a continuous working system. In mode S1, EMs of conveyors, compressors, pumps, fans, as well as control drives in factories work.

S2: This mode is typical for EDs of valves and gates. Electric motors of this kind of working system are commonly found in cranes, household appliances drives, and so on. Designation for example: S2 60 min.

S3: This mode is characterized by a cyclical change in the state of the EM - after work, there is a pause for a short time and then the process is repeated. The temperature does not have time to reach a constant value, and during shutdown the machine does not have time to cool down to the ambient temperature. The duty cycle is too short for thermal equilibrium to be reached. The starting current does not significantly affect temperature rise. Recommended values for the *cyclic duration factor* are 15, 25, 40, and 60%. The duration of one duty cycle is limited to 10 min. Induction motors, driving lifting equipment (cranes, hoists, elevators), electric tools, as well as punching and drilling machines, etc., are specifically designed and work most often in this mode. The shorter the cyclic duration factor, the more the rated power can be increased with the respect to continuous duty, whereby, with the normal version, the breakdown torque should be taken into consideration. Designation for example: S3 25%.

$$\text{Cyclic duration factor: } CDF = \frac{N}{N + R} \times 100\%$$

Explanation of symbols used in this and the following duties

N = operation under rated condition; R = at rest and de-energized; D = acceleration; F = electrical braking.

Modes S4 – S10 are introduced to simplify the puzzle of random mode equivalents by rated load, by expanding the nomenclature of the latter.

S4: Identical start-up, steady-load, and rest cycles alternate. The cycle time is too short to reach thermal equilibrium, but the inrush current affects the temperature rise of the EM. Significant for this mode is the presence of large losses during startup. In this mode, the EM is stopped either by the load or by a mechanical brake, which does not load it thermally and cools down (but not completely). The EMs of this working duty are widely used in metal cutting machines, drilling machines, mine hoists, etc. The following parameters are required to fully define this mode: cyclic duration factor, number of switches on per hour: SF (h^{-1}), moment of inertia of the load J_L and the moment of inertia of the motor J_M . Designation for example: S4 25% 120 h^{-1} $J_L = 0.2 \text{ kgm}^2$ $J_M = 0.1 \text{ kgm}^2$.

$$\text{Cyclic duration factor: } CDF = \frac{D + N}{D + N + R} \times 100\%$$

S5: Identical starting cycles, constant load operation, a sudden electrical shutdown period, and a quiescent period alternate, but the starting current affects the temperature rise. The cycle time is too short to reach thermal equilibrium. Significant for this mode is the presence of large losses not only when starting, but also when stopping. This mode is typical for EMs in the field of mechanical engineering – billet rolling mills, manipulator drives, mine hoists, etc. The following parameters are required to fully define this mode: cyclic duration factor, number of switches on per hour: SF

(h^{-1}), moment of inertia of the load J_L and the moment of inertia of the motor J_M . Designation for example: S5 40% 120 h^{-1} $J_L = 2.6 \text{ kgm}^2$ $J_M = 1.3 \text{ kgm}^2$.

$$\text{Cyclic duration factor: } CDF = \frac{D + N + F}{D + N + F + R} \times 100\%.$$

S6: Repeated cycles of operation with constant load and operation without load (idling) alternate, when the machine does not reach a constant temperature, but also does not cool down. There are no rest periods. The cycle time is too short to reach thermal equilibrium. The period of each cycle is no more than 10 minutes. The recommended values for the coefficient of relative duration of the cycle are 15%, 25%, 40% and 60%. Commonly used in presses, cutting machines, etc. Designation for example: S6 40 %.

S7: Repeated cycles alternate, which include starting, constant load operation, and electrical braking. There are no rest periods. The cycle time is too short to reach thermal equilibrium. When stopping, there are significant losses, during which the machine heats up. Mainly used in ginning machine. Designation for example S7 500 h^{-1} .

S8: It is more complicated. This is a complex mode, alternating identical start-up periods, operating at a constant load and a specified speed, followed by one or more periods of operation at other constant loads and different speeds. There are no rest periods. The cycle time is too short to reach thermal equilibrium. This type of mode is observed in EMs operating with a change of poles. Designation for example S8 30 h^{-1} .

S9: In this mode, mainly the load and the speed vary non-periodically within the permissible limits. Overloads are observed which can greatly exceed the full load. For this mode, suitable values of the full load must be taken as the basis of the concept of overloading. It is characteristic of driven mechanisms used in rolling mills, extracting devices for cast iron, steel, ferroalloys, copper, zinc, etc. It is more complicated, and is often regulated according to actual conditions, such as wind power generation.

S10: Compared with S8, it can be considered that there are a lot of constant load motions, which require various loads and time, but do not include acceleration and deceleration. The EM work duty refers to the specific method of controlling the movement of the EM. It is a kind of work instruction to avoid the EM from overheating and burning out. It is also a kind of user demand. At the same time, it also guides you to select a suitable EM according to the working duty. However, in practical applications, the working duty of many EMs are diversified, and one or more working duty are required at the same time to meet different application scenarios.

Features of different duty cycle types are explained in Table 2.

Table 2: Features of different duty cycle types

Duty	Start	No Load	Thermally stable load	Non-thermally stable load	Variable speed and load breaking	Power off	Periodicity
S1			•				
S2				•		•	
S3				•		•	•
S4	•			•		•	•
S5	•			•	•	•	•
S6		•		•			•
S7	•			•	•		•
S8	•			•	•		•
S9				•		•	
S10				•			•

3. Some technical considerations

Lifting and transport equipment plays a key role in the processes of mechanization and automation of specific activities

related to lifting, lowering, transportation, loading, unloading and other manipulation actions of different size, mass and type of cargo in the industry. This sector is also of great importance for the overall development of mechanical engineering in Bulgaria [9].

Industrial cranes have a very wide application in various fields of industry, which are characterized by cargo flows in various volumes. Their main function is to lift and lower loads, and they can be used for stationary or mobile applications with rail travel, i.e. to also serve to carry loads. The great variety of cargoes and the need for their transportation and cargo-unloading activities predetermine the market demand for lifting and transport equipment and equipment specialization.

The long-standing traditions that imposed high standards of professional performance and reliability of lifting equipment manufactured in Bulgaria distinguish this lifting equipment (cranes and electric hoists) on a global scale and become an emblem of high quality on the global market. No small part of this reputation is due to the progressive research and brilliant engineering innovations in the field of IMs, which were created and put into service as early as the 1950s and 1960s. Crane mechanisms driven by DC motors are still in operation in the industry. Currently, the number of AC electric drive cranes is increasing due to the improvement of frequency control ED systems.

The intensity of the machine's operation, the frequency of use and the load - these are all factors that directly affect the life expectancy of industrial cranes and hoists. These factors, together with the distance traveled and the speed, have an impact on the life of the so-called carriage when the equipment includes one. Operating the equipment under conditions exceeding its specification parameters can be detrimental to its life and result in damage and early depreciation. Typically, the standard equipment of cranes and hoists includes three-phase EMs, load limiters and limit switches necessary to protect the machine from overload. Both single-speed and two-speed EMs with a simple design or with a conical rotor are used to drive the horizontally moving mechanisms. In EMs with a conical rotor, mechanical brakes do not need special electromagnets. Band or disc mechanical brakes with special electromagnets are used for other EM types.

Another type of lifting mechanisms are elevators. Elevators are stationary lifting devices with periodic action, intended for raising or lowering people or goods in a cabin or platform moving between two or several permanent stops in a specially constructed shaft. If there is no such shaft, and the stairwell is small and does not allow the construction, then in the mass case, an external elevator is made along one of the walls. By the way, Bulgaria currently has about 120,000 elevators in operation.

The development of technology leads to rapid progress in elevator technology. A modern solution is to include more elevators in a common system. The market demands are small size, high speed and higher heights, quick stopping and low noise level. In recent years, the elevator market has witnessed a significant technological evolution towards systems with gearless traction, which allows the construction of reliable, quiet and comfortable installations, overcoming the limitations of traction with traditional gearing [9].

There has been a huge interest in the purchase and installation of elevators in recent years. Until recently, the largest number of orders came from hotels, new construction and business buildings, but more and more customers are those who have old cooperatives without an elevator or small new blocks for which this service is saved. The prices move in a very wide range, depending on three main factors - local or imported production, size and load capacity, luxurious interior design, etc.

4. Main exposition

With small cycle durations of the intermittent periodic duty modes (S3, S4 and S5), the share of power and energy losses

during starting and stopping increases in the total balance of losses for one cycle, and limiting the mode in terms of heat become the cycle duration or the number of EM starts per hour. Compliance with these limitations is especially important for EDs with a high switching frequency of IMs with a squirrel cage rotor, because the heat released by them (mainly in the rotor) must be transferred from the EM itself to the environment. This does not apply to the more DC EMs and IMs with a wound rotor, because in them a large part of the heat released during operation is carried out through the resistances outside the EM.

Often times, due to the technological process, it is necessary for some mechanisms to have a large number of switches on per hour: 600÷800 and even up to 2000. Moreover, in such modes, the cooling efficiency of self-ventilating EMs decreases, which requires reporting when a check is made on admissible switching frequency.

The power of the EM for these cases must be selected so that after the large number of cycles the average temperature rise is within the permissible limits. The determination of the permissible number of switches on per hour will be made when comparing the energy lost in one cycle with the energy taken to the cooling medium, assuming that minimum deviations of the EM temperature from the average level are guaranteed. The EM is assumed to be a conditionally uniform body, i.e. a body made of the same material with an infinitely large thermal conductivity and therefore having the same temperature throughout its volume under all possible modes and loads. When heating, a part of the heat is released into the environment, and another goes to increase the temperature of the body. Heat is released from the body in three ways: radiation, convection, and thermal conduction.

In the studies of the heating of the EMs, coefficients taking into account the deterioration of the cooling respectively at a reduced speed are adopted, i.e. start and stop – α and with the EM stationary – β . For IMs with self-ventilation, the coefficients are accepted: $\alpha = 0.5$ and $\beta = 0.25$. These coefficients depend on the heating time constants and heat transfer coefficients. Thus, α can be expressed in terms of β : $\alpha = \frac{1+\beta}{2}$.

Motor energy losses for one cycle are made up of starting ΔW_{ST} and stopping ΔW_{BR} energy losses as well as steady-state losses ΔP_{tL} . Let at rated speed the power output to the environment is ΔP_N . Then in the pause period due to the deterioration of the heat dissipation of the self-ventilating EM, the heat dissipation power will be $\beta \Delta P_N$, and in the start and stop period $\frac{1+\beta}{2} \Delta P_N$.

The energy balance for one cycle can be written in the form:

$$\Delta W_{ST} + \Delta W_{BR} + \Delta P_{tL} = \frac{1+\beta}{2} \Delta P_N (D + F) + \beta \Delta P_N R + \Delta P_N N \quad (1)$$

The cycle parameters can be represented in the form:

$$t_0 = \frac{3600}{SF} (1 - CDF); \quad CDF = \frac{D + F + N}{T_{CYCLE}} \times 100;$$

$$N = \frac{3600}{SF} CDF - (D + F); \quad T_{CYCLE} = \frac{3600}{SF}$$

After substituting in (1) the values of D and F and solving with respect to SF , we get:

$$SF_1 = 3600 \frac{(\Delta P_N - \Delta P_{OP}) CDF + \Delta P_N \beta (1 - CDF)}{\Delta W_{ST} + \Delta W_{BR} - (D + F) \left(\Delta P_{OP} + \frac{1+\beta}{2} \Delta P_N - \Delta P_N \right)} \quad (2)$$

For squirrel cage IMs, the third term in the denominator can be neglected compared to $\Delta W_{ST} + \Delta W_{BR}$, since it does not exceed 2-4% of this amount, that's why:

$$SF_2 = 3600 \frac{(\Delta P_N - \Delta P_{OP}) CDF + \beta \Delta P_N (1 - CDF)}{0.97 (\Delta W_{ST} + \Delta W_{BR})} \quad (3)$$

If in steady-state mode the EM is operating at rated load $\Delta P_{OP} = \Delta P_N$, formula (3) can be simplified:

$$SF_3 = 3600 \frac{\beta \Delta P_N (1 - CDF)}{0.97 (\Delta W_{ST} + \Delta W_{BR})} \quad (4)$$

From (3) it can be seen that the number of switches on per hour depends on the static load, which determines the power losses during operation ΔP_{OP} , on the cyclic duration factor CDF , on the coefficient of deterioration of the cooling at a stationary state of the EM β and on the energy losses in the transient modes. As ΔP_{OP} decreases, SF increases, reaching its largest value at idle. As the load increases, SF decreases and reaches the smallest value at nominal mode. SF is significantly influenced by energy losses in transient processes (starting and stopping). These losses are proportional to the moment of inertia J and therefore with its increase SF decreases. At first glance, it seems that as the power of the EM increases, SF grows. But with greater power, the moment of inertia of the EM grows, which leads to increased energy losses.

It also follows from (3) that at $(\Delta P_N - \Delta P_{OP}) > \beta \Delta P_N$ the permissible switching frequency does not depend on CDF . When $(\Delta P_N - \Delta P_{OP}) > \beta \Delta P_N$, as CDF increases, a larger number of switches on per hour can be allowed. If $(\Delta P_N - \Delta P_{OP}) < \beta \Delta P_N$, as CDF increases, SF decreases. For a rated load in a set mode with the increase of ΔW_{ST} and ΔW_{BR} , the permissible frequency of switches on is achieved by independent ventilation of the EM, which works equally intensively during the entire duty cycle of the ED. A substantial increase in SF can be obtained by reducing energy losses in transient processes. In this regard, as it turns out, the frequency control of IM with a squirrel-cage rotor provides minimal transient losses compared to other control modes.

A computer program has been created to calculate the permissible number of switches on per hour. Formulas (2), (3) and (4) are used in the program. All EM data is entered in base units, and the cyclic duration factor and coefficient of deterioration of the cooling at a stationary state of the EM β , are dimensionless. Formula (2) is the exact formula for calculating the permissible number of switches on per hour, and (3) is the approximate. If $\Delta P_{OP} = \Delta P_N$, then formula (4) is used. If this condition is met, then three results are obtained by all three formulas. If condition $\Delta P_{OP} = \Delta P_N$ is not met, then the calculations are performed according to (2) and (3). The program performs these operations by itself, without the operator indicating which of the formulas to perform the calculation. There is no limit on the power of the EMs in the program. It is intended for IM with a squirrel-cage rotor, since there the starting currents have the greatest influence on the heating of the EM, and from there on the permissible number of switches on per hour. The number of switches on per hour, which according to the technological mode are required by a given EM under consideration, must be less than calculations by formulas (2), (3) and (4).

5. Results obtained

The object of research are IMs with a squirrel-cage rotor for driving the mechanisms for horizontal movement of cranes. Rated powers are from a standard series of manufacturers of such EMs. The common one is the synchronous rotation frequency, which in this case is 1500 min⁻¹. The results are presented in Table 3. The

values for SF_1 were obtained by formula (2), and for SF_2 – by formula (3). Formula (4) is not used because condition $\Delta P_{OP} = \Delta P_N$ is not fulfilled. Some of the data for the EMs under consideration are taken directly from a technical data book, while others (power and energy losses, start and stop times) are calculated. The resisting torque is arbitrarily taken as 60% of the EM's rated torque. It is known that if the resistive torque decreases, SF increases and reaches its largest value at idle. From the calculations, it can be seen that the results obtained from formulas (2) and (3) differ by 2-4%, which are the permissible limits.

Table 3: Values of quantities considered

№	P_N , kW	ΔP_N , W	ΔP_R , W	ΔW_{ST} , J	ΔW_{BR} , J	D , s	F , s	CDF	SF_1	SF_2
1	1.1	770	420	800	1370	0.40	0.55	0.25	689	644
2	2.2	428	230	480	620	0.40	0.50	0.54	754	721
3	3.0	1900	890	3050	6600	0.50	0.60	0.44	383	377
4	4.0	760	689	1930	3820	0.35	0.60	0.40	175	166
5	5.5	2270	980	3900	10300	0.56	1.30	0.25	330	323
6	7.5	2400	980	5000	13600	0.56	1.30	0.40	259	257
7	11.0	3190	1560	9200	18680	0.67	1.20	0.40	219	214
8	13.0	3990	1950	1200	24400	0.77	1.39	0.25	210	205
9	15.0	4875	2650	1310	30890	0.62	1.00	0.25	241	239
10	22.0	4660	2690	1890	31280	0.76	1.05	0.40	247	239

6. Conclusions

The treated topic is actual, as the results of some developments in this area have not yet been put into practice. Electric drives of crane mechanisms directly affect productivity and create opportunities for the rational flow of technological processes. From the other hand, the consensus is that the crane business is conservative. An innovative approach is required, combining some of the new design technologies, novelties in crane components on the market, modern control and propulsion with the experience gained over the years.

Among the leading technological trends in drives, summarized by the analysts, is the increasingly targeted market demand for specialized solutions for specific applications. Typical examples are drinking and wastewater pumping equipment, HVAC systems, elevators, and faucets. Investing in a purpose-built solution creates greater confidence for users, who are convinced that they can rely on optimized hardware, firmware and technical documentation that precisely matches the application area.

Leading EM and ED manufacturers are united around the proposition that key *Industry 4.0* technologies such as artificial intelligence and machine self-learning will play a fundamental role in the development of modern drives as well. Consumers already expect every device to have smart functions, but their self-serving integration alone does not lead to serious technological progress, experts believe. The real winners in the race will be those manufacturing companies that succeed in harnessing innovations such as machine learning to collect performance data from ED in real time. The possibilities for automated adaptation of work parameters and processes "on the fly" based on the collected information will prove to be the real winning advantage over the competition.

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Investigation on durability testing of polyethylene (PE) geocells

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Abstract: In this article, the residual strength of PE geocells after accelerated aging is experimentally investigated. The characteristic is of key importance for the application of geocells, as it is related to their service life. The durability test is defined as essential in the applications standards of the product-EN 13 255:2016, EN 13 251:2016.

KEYWORDS: GEOCELLS, RESISTANCE TO OXIDATION, DURABILITY, AGING.

1. Introduction

Geocells are increasingly being used in construction, with the accelerated standardization of their use further enhancing their use [1]. They represent a polymer structure bounded by ultrasonic welding (fig.1). Geocells provide good strength and have filtering properties. They have a standardized application for erosion control, railways, highways, etc according to EN 13250, EN 13251 etc. The product is relatively new and its application is growing, therefore the study of the characteristics is more and more relevant. The growing application also leads to higher requirements of all product characteristics. Along with all the mechanical characteristics that are subjects of researches - hardness, tensile strength, strength of internal structural junctions, yield strength, etc., an important aspect for use of these products is their service life [2].



Fig. 1 Geocells

2. Materials and methods

Mainly geocells are made of polyethylene. Its use is due both to its technical characteristics - chemically resistant to acids and bases, high physical and mechanical properties, etc., as well as economically - widely distributed and available virgin and recycled material. [3] Its complex of properties has established it as the main material for the manufacture of geocells. A PE mix of HDPE and LDPE, in a ratio of 6:1, with additions of masterbatch and UV stabilizers was chosen for the material. The choice is based on the following reasons - polyethylene is the most common material for geocells and one of the materials for which the standard EN 13438:2019 is applicable. The recycled to virgin ratio is 50 to 50%. The average thickness of the strips is 1.38 mm. 20 standardized samples were tested - width $200 \text{ mm} \pm 1 \text{ mm}$ and with a length providing 300 mm distance between the jaws. The samples must be produced up to 24 hours before the test. The tests are made in an accredited laboratory.

The service life characterizes minimum period in which product can perform its application, provided that it is properly maintained. There is a tendency for more and more products to be tested for durability, as a key characteristic [4]. The durability test according to the standard is valid for 5 years, application that the chemical composition is not changed, a change of polymer in the composition or a change of the concentration of polymer in the composition. Processed materials can be used without restrictions if the primary product meets the requirements.

The tested samples are first subjected to the Screening test method for determining the resistance to oxidation according to ISO 13438,

which is characterized by storage in water under certain conditions and aging in a dryer. [5]. For polyethylene products, method A is used. The test consists of the following:

- Storage of the samples in water for 28 days with a water temperature of $-80^{\circ} \pm 1^{\circ}$ (fig. 2).
- Aging in a dryer should be at a temperature of $100^{\circ} \pm 1^{\circ}$
- Duration in the dryer is chosen for testing 50 years service life [6]. - 56 days



Fig 2. Storage in water of the samples

The samples should hang freely in the dryer (fig. 3).



Fig.3 Internal volume of the dryer

Control samples are stored for 6 hours in a bath and 6 hours in a dryer under the same conditions. The dryer must have a sufficient volume to store the samples and be equipped with a ventilation hole, that allows controlling the temperature determined by the standard (fig. 4).

After aging, the two groups are tested for tensile strength and relative elongation according to EN 12 226. [7], [8]. The samples should be tested in both directions - machine direction {MD} and cross machine direction. The calculations of the residual strength and residual elongation at brake are carried out according to the following formulas :



Fig. 4 The vent of the dryer

$R_F = F_e / F_c$ (in %);

Where

R_F -percentage retained tensile strength

F_e -tensile load on exposed samples

F_c -tensile load on controlled samples

$R\epsilon = \epsilon_e / \epsilon_c$ (in %)

$R\epsilon$ -percentage retained elongation at brake

ϵ_e -elongation brake on exposed samples

ϵ_c -elongation brake on controlled samples.

(1)

(2)

3 Results and discussion

The results are tabulated in tables- 1,2,3,4,5,6,7,8.

Tab.1 Results of tensile strenght,MD,controlled samples

Tensile strength	Unit	Standard	Result	Deviation of testing
Sample No 1	kN/m	EN 12226	26,35	No
Sample No 2	kN/m	EN 12 226	24,25	No
Sample No 3	kN/m	EN 12 226	23,78	No
Sample No 4	kN/m	EN 12 226	25,54	No
Sample No 5	kN/m	EN 12 226	24.47	No

Average. 24.86

Tab. 2 Results of elongation at brake,MD,controlled samples

Elongation at brake	Unit	Standard	Result	Deviation of testing
Sample No 1	%	EN 12 226	205	No
Sample No 2	%	EN 12 226	210	No
Sample No 3	%	EN 12 226	220	No
Sample No 4	%	EN 12 226	210	No
Sample No 5	%	EN 12 226	205	No

Average 210

Tab. 3 Results of tensile strenght,CMD,controlled samples

Tensile strength	Unit	Standard	Result	Deviation of testing
Sample No 1	kN/m	EN 12 226	17,95	No
Sample No 2	kN/m	EN 12 226	17,98	No
Sample No 3	kN/m	EN 12 226	16,19	No
Sample No 4	kN/m	EN 12 226	17,88	No
Sample No 5	kN/m	EN 12 226	18,23	No

Average 17.65

Tab. 4 Results of elongation at brake,CMD,controlled examples

Elongation at break	Unit	Standard	Result	Deviation of testing
Sample No 1	%	EN 12 226	145	No
Sample No 2	%	EN 12 226	155	No
Sample No 3	%	EN 12 226	135	No
Sample No 4	%	EN 12 226	140	No
Sample No 5	%	EN 12 226	140	No

Average 143

Tab. 5 Results of tensile strength,oxidized samples,MD

Tensile strength	Unit	Standard	Result	Deviation of testing
Sample No 1	kN/m	EN 12226	22,24	No
Sample No 2	kN/m	EN 12 226	20,35	No
Sample No 3	kN/m	EN 12 226	21,41	No
Sample No 4	kN/m	EN 12 226	22,57	No
Sample No 5	kN/m	EN 12 226	21,08	No

Average 21.53

Tab. 6 Results of elongation at brake,oxidized samples,MD

Elongation at break	Unit	Standard	Result	Deviation of testing
Sample No 1	%	EN 12226	175	No
Sample No 2	%	EN 12 226	170	No
Sample No 3	%	EN 12 226	175	No
Sample No 4	%	EN 12 226	180	No
Sample No 5	%	EN 12 226	205	No

Average 181

Tab. 7 Results of tensile strength,oxidized samples,MD

Tensile strength	Unit	Standard	Result	Deviation of testing
Sample No 1	kN/m	EN 12226	16,45	No
Sample No 2	kN/m	EN 12 226	14,52	No
Sample No 3	kN/m	EN 12 226	17,10	No
Sample No 4	kN/m	EN 12 226	16,53	No
Sample No 5	kN/m	EN 12 226	16.15	No

Average 16.15

Tab. 8. Results of elongation at brake,oxidized samples,CMD...

Tensile strength	Unit	Standard	Result	Deviation of testing
Sample No 1	%	EN 12226	110	No
Sample No 2	%	EN 12 226	115	No
Sample No 3	%	EN 12 226	105	No
Sample No 4	%	EN 12 226	110	No
Sample No 5	%	EN 12 226	110	No

Average 110

According to EN 13255:2016 and related standards for the application of geocells, a product that is composed of new or recycled polyethylene can be considered sufficiently durable (for 50 years) in natural soils with a pH between 4 and 9 and a soil temperature ≤ 25 °C if it passes the residual strength setting test after oxidation (28 days at 80 °C in water and 56 days in a dryer at 100 °C)[9]. The results have significant repeatability, which is indicative of their validity. The results cannot be used to calculate another durability period, because of the specificity of the test standard.

4. Conclusion

The following conclusions can be drawn from the investigation:

- Testing of PE geocells (with a ratio of HDPE to LDPE 6;1, with a ratio of 1:1 virgin and recycled raw materials) showed a residual strength of over 50%, which under the test conditions corresponds to a 50-year service life.
- All requirements of the exam standard have been met.
- The repeatability of the results and the low value of their range shows that the test is correct.
- The test results can be used as a basis for researching other products made from PE with the same or similar ratios of HDPE and LDPE.
- The study shows results significantly above the required 50% residual strength, but the results cannot be used to directly prove a longer service life of the products, because of the specificity of the test. This will be the subject of other studies, as well as comparative analysis with other standardized tests relating to service life and durability.

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Effect of zirconium dioxide on the obtaining of layers synthesized by zol-gel technology for photovoltaic applications

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Abstract: Thin films deposited on glass substrates by sol-gel containing ZrO_2 show photocatalytic activity, which are compared with TiO_2 - which is used as a standard photocatalytic material applied in photovoltaics. By modifying ZrO_2 , coatings on glass surfaces were obtained, which are characterized by high properties, which are a prerequisite for use in photovoltaics. The coatings are dense and nanocrystal line according to SEM and XRD studies and optically transparent according to UV-VIS-NIR spectra.

Keywords: SOL-GEL METHOD, COATINGS, ZrO_2 , PHOTOVOLTAIC

1. Introduction

In the preparation and research of effective compounds and materials for applications such as photovoltaics, particular attention is paid to titanium dioxide. It is known that it occurs in the form of 4 polymorphic modifications: anatase, rutile, brookite, TiO_2 (B). Titanium dioxide is characterized by a series of physicochemical properties - desired and preferred for use as a photovoltaic. It has high chemical, thermal and corrosion resistance. A particularly important quality that distinguishes it from most photovoltaic materials is that it is non-toxic and can be easily obtained through a series of cheap and accessible methods. Due to its very good optical and electronic properties, it is preferred for obtaining solar cells "solar cells (SC)". The solar cell is a solid-phase device that directly converts solar energy into electricity through the photovoltaic effect [1-6]. The contribution of Gratzel and his team in obtaining and validating solar cells as a source of cheap electrical energy [3,5,6]. The authors successfully used the large surface area of mesoporous TiO_2 films [5]. In recent decades, various nanostructures have been successfully used as photovoltaics [4]. A layer of dye is applied to the surface of TiO_2 , and the photovoltaics based on nanomaterials obtained in this way are referred to in the literature as DSCS - dye sensitized solar cells. The nanomaterials obtained in this way are characterized by a very high specific surface area and the sensitizer is adsorbed very well. Under the influence of sunlight, a process of photoexcitation of the dye molecules takes place, with electron transfer in the conduction zone of TiO_2 , as the oxidation state of the dye changes [6,7]. The formed monolayer of the dye on TiO_2 suppresses the recombination of the injected electrons with the oxidized particles in the electrolyte. The mesoporous TiO_2 electrode used by Gratzel turns out to be very important for the effective application of DSCS as a photovoltaic [5,6]. To the first quote from the abstract - TiO_2 is used as a building block for obtaining photoelectrode thin films, which are the basis of photovoltaic devices (third generation). This includes surface sensitized solar cells, as well as quantum dots, solar cells based on perovskites. Photoanodes based on mesoporous and micro TiO_2 nanostructures help to increase the absorption of visible light. Mesoporous TiO_2 films should have an average pore size of less than 10 nm [8-10].

Polymer-inorganic hybrid solar cells combine the advantages of inorganic semiconductors (having high electronic mobility and stability) with the flexibility of attached polymers. Characteristic of these devices is that the absorption of light is carried out by the polymer by forming excitons [7,8].

In recent decades, intensive work has been done on devices based on nanorods and nanotubes. Characteristic of these

devices is that the attached polymers are embedded in the free space of the ordered nanostructures, forming hybrid active layers. Thus, direct charge transfer channels are realized [11,12].

Application of oxide layers in the form of quantum dots. In this direction, mainly work is done on compounds such as CdS , $CdSe$, Bi_2S_3 [13,14].

Inorganic solid-state solar cells have an advantage over conventional solar cells by increasing sunlight collection and eliminating unwanted sealing and breakdown processes.

Looking back over time regarding the acquisition and research of solar cells, we notice 3 periods. First period - then the first generation of solar cells appears - mono and polycrystalline silicon is mainly present, which is an indirect semiconductor material with a band gap of 1.12 eV [15].

The second generation of solar cells includes amorphous silicon, thin layers of compounds such as $CdTe$, $GaSe$, etc., obtained by deposition on glasses and flexible substrates. Second generation - includes solar cells based on thin films of amorphous silicon, microcrystalline silicon, $CdTe/CdS$. Advantages of these materials - can be deposited over large areas and at low temperatures using cheap and widely available methods of preparation [16]. With these thin layers, the presence of photoactive materials is assumed when the thickness of the films is less than 1 micrometer. They are also characterized by a high absorption coefficient, which allows to adsorb even incidental sunlight [17].

Third generation solar cells - includes dye-sensitized solar cells, as well as organic and inorganic molecules used as sensitizers. The conducting polymers used act as acceptors and donors. Of the compounds used to produce photovoltaic solar cells, ZnO occupies a special place. It is an n-semiconductor with a wide band gap. It is characterized by easy crystallization, high charge mobility and technological flexibility in its preparation. It combines very well with Cu_2O [18, 19].

In solar cells, SnO_2 also occupies an important place. It is characteristic for it that it adsorbs maximally in the ultraviolet region of the spectrum, but then this adsorption moves to the visible region. It has a maximum permeability of -70-80%. It can form an electron-hole pair in photoactive layers [20]. CdO is also used to make solar cells. It has high transmittance in the visible region and excellent conductivity at room temperature. WO_3 is also characterized by interesting properties. It is used as a transport layer in different types of solar cells - organic, or polymer, heterojunction. It has been established that it can be used as a window layer in solar cells [21]. There are 4 generations of solar cells: First generation - includes the technologies for obtaining mono and polycrystalline silicon, $GaAs$.

In the first generation, thick layers (mostly silicon) are used. Advantages of Si- it is not toxic, it is stable. Through these qualities, the processes related to environmental pollution are delayed. Silicon solar cells are compatible with Si devices used in the microelectronics industry – integrated circuits, transistors, etc. [22]. This is how well-known and developed technologies are implemented

Second generation - includes solar cells based on thin films of amorphous silicon, microcrystalline silicon, CdTe/CdS.

Third generation – includes nanocrystal line layers, active quantum dots, compounds such as GaAs/GaInP, organic, polymer solar cells, dye-sensitized solar cells, etc.

The fourth generation, known as inorganics in organics, combines the low cost and flexibility of polymer thin films with the stability of inorganic nanostructures (metal nanoparticles and metal oxides), or organic nanomaterials such as carbon nanotubes, graphene, etc. [11,12].

In the first generation, thick layers (mostly silicon) are used. Advantages of Si- it is not toxic, it is stable. Through these qualities, the processes related to environmental pollution are delayed. Silicon solar cells are compatible with Si devices used in the microelectronics industry – integrated circuits, transistors, etc. [22]. This is how well-known and developed technologies are implemented.

Al_2O_3 is particularly interesting as a material applied to photovoltaic solar cells. Recently, it has been successfully used as a passivator on the surface of crystalline silicon (c-Si). Thus, recombination losses are reduced. A number of positive physicochemical properties lead to its successful application as a passivator: the high stability of aluminum oxide to the technological processes used, the flexibility that allows it to be applied in ultra-thin films, the negative charge. Effective passivation strongly depends on doping as well as on good cleaning on the surface. As a result of applying the passivation layer, the efficiency of photovoltaic solar cells is higher than 20% [23]. This very high efficiency rate after Al_2O_3 passivation of photovoltaic solar cells has attracted the attention of many researchers nowadays. One of the best methods of applying the passivation film is considered Radio Frequency (RF) sputtering. This method is characterized by a high rate of deposition of the passivation layer, as well as by its low cost.

In the current study, the team focused on glass-based photovoltaic coatings ZrO_2 .

2. Experimental procedures

All compounds were supplied as analytical grades and were used without further modification. Thin film coatings are performed on glass slides from AGC Glass Europe.

I. A stabilized zirconia sol is initially obtained. The starting substance is $\text{ZrOCl}_2 \cdot 8\text{H}_2\text{O}$ – zirconium oxychloride. It is dissolved in absolute ethyl alcohol, so as to obtain a sol with a low molarity – less than 1. Thus, the synthesis of a stable sol is guaranteed by avoiding unwanted pre-gelations, or obtaining of sediments. Weighed amount of $\text{ZrOCl}_2 \cdot 8\text{H}_2\text{O}$ – 5.944 grams. Dissolve in 75 milliliters of absolute ethyl alcohol. Very strong hydrolysis was obtained, which necessitated the rapid addition of 1 milliliter of concentrated HNO_3 . After vigorous stirring, the sol became clear. Nitric acid also acts as an acid catalyst and chelating agent.

II. Applying the layers to the glass substrate. It is done by dipping it into the clear sol and pulling it out at a rate of 4.28 millimeters per minute. Before withdrawing, the pad rests in the ash for 10 seconds.

III. Drying It is carried out at: a) 60°C , b) 100°C and c) 150°C . The application of step drying prevents possible cracking of the layers as well as a more accurate establishment of the selected temperatures.

GLS_Z1-B, GLS_Z2-B are the number of layers, respectively. GLS4_TEL4 is placed under atmospheric conditions.

3. Results and Discussion

An X-ray diffractometer with a Bragg-Brentano θ - 2θ focusing system was used. The samples were examined at room temperature with Cu-K α radiation (monochromatic radiation with wavelength $\lambda = 1.54178\text{\AA}$) in the interval $20^\circ < 2\theta < 65^\circ$, at a step of 0.025° for 10 seconds. A graphite monochromator was used for better peak resolution (better signal-to-noise ratio).

The size of the ZrO_2 crystallites is calculated according to the Scherrer formula:

$$D = 0.9\lambda / B \cdot \cos\theta$$

D - average crystallite size /Average Crystallite size/
 λ - wavelength (in angstroms) - $1.54178\text{ \AA}$ /X-Ray wavelength/
 θ - Bragg angle (degrees) - $2\theta/2$ /Bragg angle/
 B - line broadening FWHM (2θ), /Line broadening/ must be of dimension radians ($\text{rad} = 2\theta \cdot \pi/180$)

The positions of the X-ray diffraction peaks correspond to tetragonal ZrO_2 , according to standard JCPDS card 069-1771. According to Scherer's formula, the average crystallite size corresponding to the 111 orientation (the peak with the highest intensity) was calculated. It is 30 nm /figure 1/.

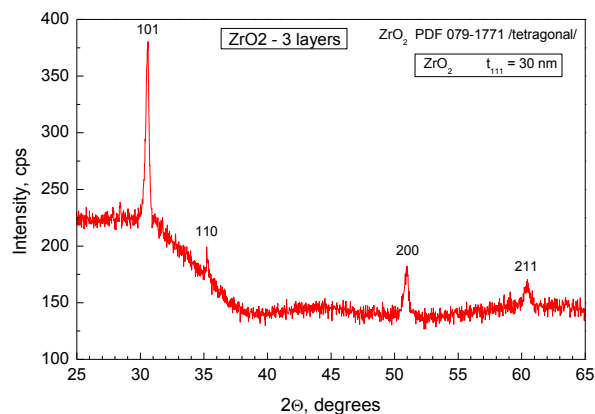


Fig. 1. X-ray diffractogram of sol gel coatings of ZrO_2 .

The optical transmittance spectra of the obtained films in the wavelength range of 200 nm to 800 nm were measured at room temperature at normal light incidence using a UV-Vis-NIR spectrophotometer (Cary 5E, Varian, Sydney, Australia).

Figure 2 show the transmittance spectra of the films, recording in the range of 200 nm to 800 nm. The transparency of reference glass is 90.9% and the transparency of all films is in the range of 65%–79.3%. As it is seen, sample GLS4_TEL4 exhibit almost a constant values in visible spectral range (75.2%–76.76%) with the highest value 78.6% at 560 nm. Up to 560nm this sample is the most transparent. Transmittance spectra of GLS_Z1-B and GLS_Z2-B show ever-increasing transparency throughout the studied spectral range. For the samples GLS4_TEL4 and GLS_Z1-B an isobestic point was found at 560nm. After that for GLS_Z1-B the transparency progresively increases and at 800nm it is about 3% higher than sample GLS4_TEL4. For sample GLS_Z1-B in visible spectral range transparency is in the range from 69.4% to 79.3%. For sample GLS_Z2-B they are respectively 65%–71.4% for the visible region.

Parallel investigation of absorption spectra (figure 3) illustrated that with the increase in absorption of the films, transparency decreases. Arising in the absorption below 370 nm is related to the intrinsic band gap absorption

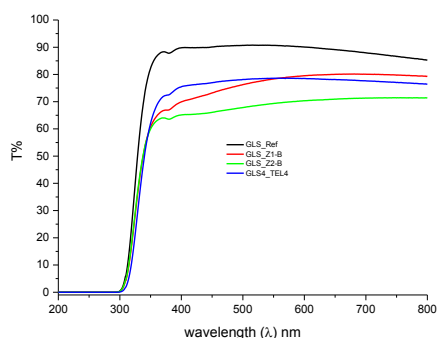


Fig. 2. Transmittance spectra of glass with one layer and two layers containing ZnO_2 .

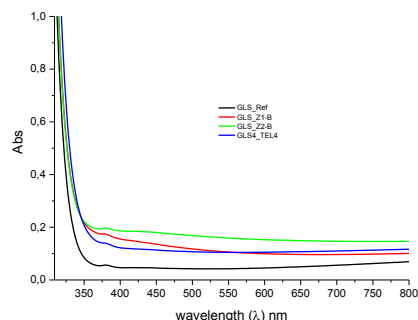


Fig. 3. Absorbance spectra of glass with one layer and two layers containing ZnO_2 .

4. Conclusions

1. Coatings are prepared by the sol-gel method using a dip coating technique. The present study characterizes self-cleaning ZrO_2 thin films for photovoltaic application.
2. The tests were carried out at different layers of the included components, speed of application of the solution on the glass substrate and different drying temperatures.
3. Research has been conducted through SEM, XRD studies and optically transparent according to UV-VIS-NIR spectra.

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Calculation of telescopic-boom bending stress capacity using fem software, in support of project logistics decisions.

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Abstract: Complex structural steel structure projects must be realized with the aid of specialized logistical technologies to meet all the design technical specifications. Selecting which equipment to employ, particularly when we need to elevate heavy structural steel components at an elevation higher than 8 meters, requires not only experience and the use of standard techniques for the logistic management of construction processes but also requires stress capacity calculations of the constituent elements of the machines that we will use for the implementation of the project. An indispensable machine for the realization of steel structures is the telescopic forklift, which serves to lift steel elements at different heights and positions, for a relatively long time, to assemble structure elements such as columns, trusses, beams, automated cranes, etc. In this paper, we have designed a telescopic forklift and calculated the stress capacity of the structural elements that compound the telescopic-boom, using the finite element software (FEM) Solid Works. Carrying out simulations with the corresponding load that we have to deal with in the realization of the project, allows us to change the section thickness of the telescopic boom or to use other logistic equipment with a higher capacity.

Keywords: TELESCOPIC-BOOM, BENDING STRESS, STRUCTURE, FEM, LOGISTICS

1. Introduction

In recent years, the construction industry has undergone a significant expansion. This expansion includes not only the construction of residential buildings but also the construction of industrial ones, such as steel sheds. Steel shed structures, commonly used for warehouses, offices, commercial centers, and military shelters, consist of reinforced concrete foundations, steel columns, trusses, beams, and cranes. Designing and constructing these structures is challenging and requires an efficient logistics system and specialized equipment. The construction of steel structures is a precise process, with structural elements being connected through welding or bolts. When assembling elements at a considerable height such as trusses, beams, or cranes, the telescopic forklift (Fig. 1) is the most commonly used tool. It provides powerful lift capacities and smart handling. Telescopic forklifts, also known as "stick" booms, are aerial work platforms that extend telescopically. Telescopic booms are the best choice for accessing hard-to-reach areas in construction, industrial, entertainment, road building, bridgework, and inspection applications [2]. The telescopic forklift is used during steel shed construction to position steel elements at different heights, allowing for the bolting or welding of elements to one another. The steel element that needs to be assembled remains unsettled for a relatively long time until it is bolted or welded to other elements. As a result, the bending stress of the telescopic forklift elements, especially the booms and their sections, poses a significant challenge.

2. Materials, sections, loads, and software used

In response to the issue highlighted in the last paragraph of the previous chapter, we will employ Solid Works, a finite element software, to design a telescopic forklift along with its components. The finite element method is extensively used these days to conduct numerical analyses of the structure of different machines, thanks to the advancements in modern computing technology. The finite element method (FEM) is extensively used these days to conduct numerical analyses of the structure of telescopic booms, thanks to the advancements in modern computing technology [3-5]. Finite elements analysis will be performed, where the software will calculate telescopic boom section stresses, a process that is part of the logistic decisions that must be made during the realization of this kind of construction work. Numerical solutions of the stress distributions could be obtained and structural optimizations could be carried out based on the stress analysis results [3-5]. The modeling parameters of all component parts of the telescopic forklift will be presented in this paper.

2.1 Design of the telescopic forklift

We have designed a telescopic forklift with the following features:

Table 1. Telescopic forklift characteristics

Self-mass	8953.2 kg
Maximum lifting height	8.25 m

The body of the forklift is compounded by the counterbalance, the wheels, the boom base, the pistons, the cabin, 1 sliding boom, the fork carriage, and the forks, as shown in the figures below:

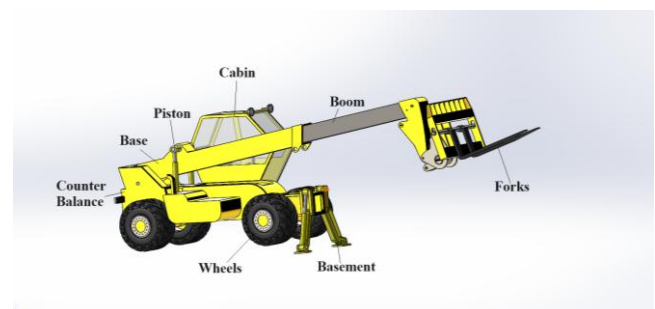


Figure 1. Telescopic forklift parts

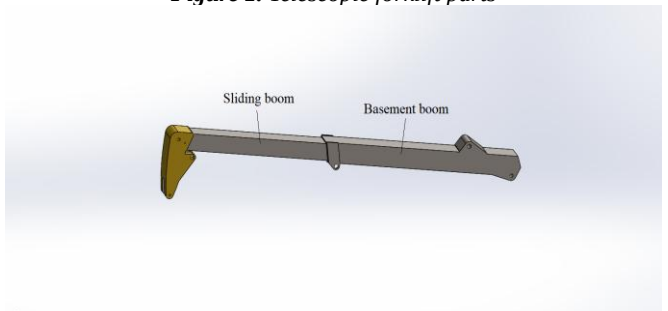


Figure 2. Structure of the telescopic boom



Figure 3. Forklift

2.2 Materials properties

All the parts of the telescopic forklift are designed with AISI 4130 Steel as shown in Table No.2

Table 2. Material properties

Name:	AISI 4130 Steel, annealed at 865C
Model type	Linear Elastic Isotropic
Yield strength:	4.6e+08 N/m ²
Tensile strength:	5.6e+08 N/m ²
Elastic modulus:	2.05e+11 N/m ²
Poisson's ratio:	0.285
Mass density:	7,850 kg/m ³
Shear modulus:	8e+10 N/m ²

2.3 Applied loads

In addition, we have applied loads on the fork (as shown in Figure 5), determined by the weight of the elements that we need to lift for constructing the military steel shed, which has a column span of L=40m and a maximum height of H=8m (as shown in Figure 5)

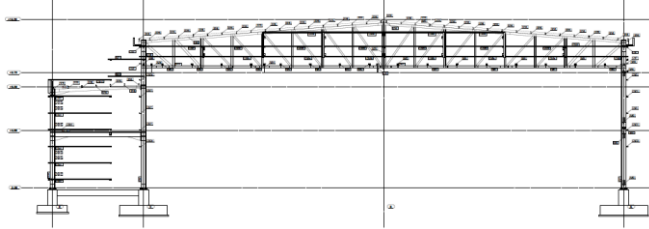


Fig 4. Steel shed structure [6]

The weight of the columns, truss, and automated crane basement beam are shown in Table No.3.

Table 3. Shed structural element weight

Element	Weight (Kg)
Columns	1,854.8
Truss	3,979.2
Crane Beam	5,000.3

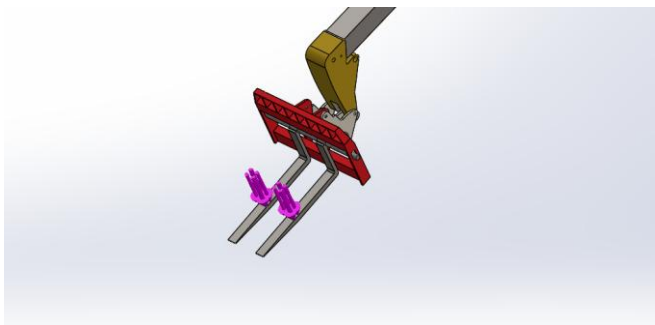


Figure 5. Applied load on the fork

2.4 Sections of the booms

The telescopic boom structure is typically made up of rectangular hollow-sectioned booms that nest inside each other [2]. The loads

transferred between the adjacent booms are realized through the sliding contacts between the sliding surfaces of the booms [2].

The final resultant stress components σ_x , σ_y , and τ_{xy} in the contact region can be calculated as the summation of the corresponding stress components of the global bending stress and the local transverse bending stress [2]. Within the regime of elastic deformation, the stress in the contact area can be considered as the superposition of two states of stress. The first part is the normal bending stress caused by the global bending deformation of the boom. The second part is the local bending stress caused by the transverse local bending deformation shown in the figures below [2]:

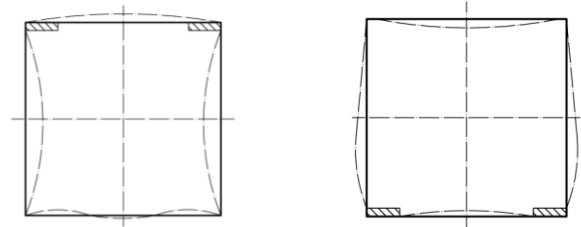


Fig 6. Local bending deformation of the cross-section of the boom- inner boom (left) and outer boom (right)

We have used Solid Works software to gather data on the bending stresses of the sections of the telescopic boom. We conducted 5 different simulations with 3 different loads to determine the appropriate section thickness required to realize the steel shed project.

3. Bending Stress Analysis and Results

In this analysis, we will present 5 simulations.

- Simulation 1

The first simulation was carried out to lift a HEA400 steel profile column, which weighs 1,854.6 kg.

Load name	Load Image	Load Details
Force-1		Entities: 2 face(s) Type: Apply normal force Value: 1,854.6 kg
Gravity-1		Reference: Top Plane Values: 0.0 -9.81 Units: m/s ²

Figure 7 Load proprieties, HEA 400 steel columns lifting

The telescopic boom base outer section dimensions were $B_b = 294\text{mm} \times 290\text{mm}$, inner section dimensions were $B_b = 246\text{mm} \times 242\text{mm}$, and plate thickness $t=24\text{mm}$. While the telescopic sliding boom outer section dimensions were $B_b = 242\text{mm} \times 238\text{mm}$, inner section dimensions were $B_b = 218\text{mm} \times 212\text{mm}$, and plate thickness $t=24\text{mm}$.

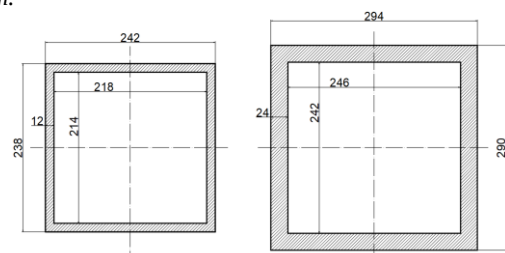


Figure 8. Section booms proprieties, first simulations

After performing analysis in SolidWorks software, and applying load and properties, the resulting data is as follows:

Table 4. Boom sections minimum and maximum bending stresses, Simulation 1

Load and section properties	Minimum section stress	Maximum section stress	Allowed yield section strength
Load 1.856-ton. Sliding boom plate thickness $t=12$ mm, boom base plate thickness $t=24$ mm.	$1.591\text{e}+03\text{N/m}^2$	$4.317\text{e}+08\text{N/m}^2$	$4.6\text{e}+08\text{N/m}^2$

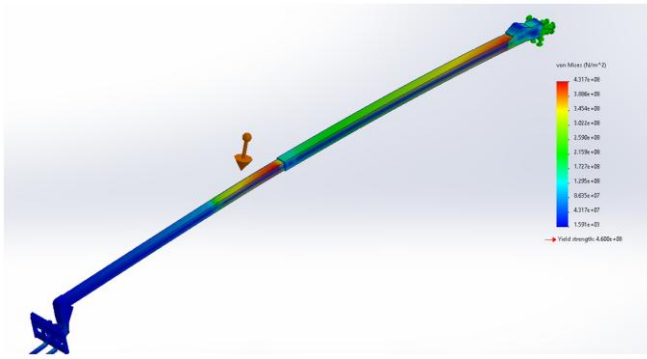


Figure 9. Telescopic booms stress distribution, Simulation 1 (Load 1.8546 ton)

Table Nr.4 results show that maximum boom section stresses are below yield limits. So, we can use a telescopic forklift with boom section dimensions according to Figure No.8 1, to lift a HEA400 column, in the function of the project we are implementing.

- Simulation 2

The second simulation was conducted to lift a single steel roof truss weighing 3,979.2 kg, using the same booms section properties as in Simulation 1.

After performing the analysis using finite element software, we obtained the following results:

Table 5. Boom sections minimum and maximum bending stresses, Simulation 2

Load and section properties	Minimum section stress	Maximum section stress	Allowed yield section strength
Load 3.9792 -ton. Sliding boom plate thickness $t=12$ mm, boom base plate thickness $t=24$ mm.	$3.689\text{e}+02\text{N/m}^2$	$6.282\text{e}+08\text{N/m}^2$	$4.6\text{e}+08\text{N/m}^2$

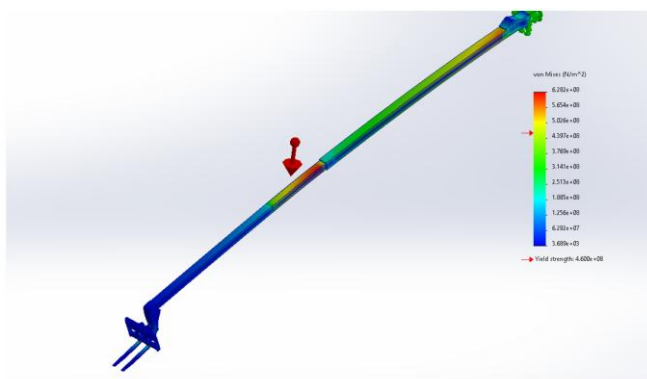


Figure 10. Telescopic booms stress distribution, Simulation 2 (Load 3.9792 ton)

Based on the results presented in Table Nr. 5, it is evident that the maximum stresses of the boom sections go beyond the permissible yield stresses. Therefore, we cannot utilize a telescopic forklift with boom section dimensions as illustrated in Figure No. 8.1 to lift on a steel truss. We need to perform additional simulations with larger section dimensions to lift the weight of the truss.

-Simulation 3

In the third simulation, we tested boom sections with different dimensions, and the one that passed the 3.9792-ton stress test had the following properties: The boom base outer section dimensions were $B_b = 306\text{mm} \times 302\text{mm}$, inner section dimensions were $B_b = 246\text{mm} \times 242\text{mm}$ and plate thickness $t=30\text{mm}$. While the sliding boom outer section dimensions were $B_b = 242\text{mm} \times 238\text{mm}$, inner section dimensions were $B_b = 206\text{mm} \times 202\text{mm}$ plate thickness $t=18\text{mm}$

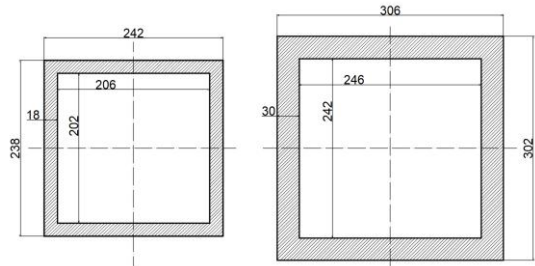


Figure 11. Section boom properties, third simulations

Following the analysis through finite element software, we have received the subsequent results:

Table 6. Boom sections minimum and maximum bending stresses, Simulation 3

Load and section properties	Minimum section stress	Maximum section stress	Allowed yield section strength
Load 3.9792 -ton. Sliding boom plate thickness $t=18$ mm, boom base plate thickness $t=30$ mm.	$3.863\text{e}+02\text{N/m}^2$	$4.6\text{e}+08\text{N/m}^2$	$4.6\text{e}+08\text{N/m}^2$

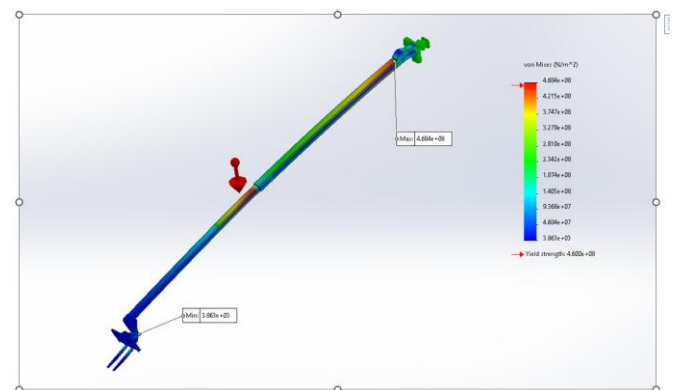


Figure 12. Telescopic booms stress distribution, Simulation 2 (Load 3.7092 ton)

Table Nr.6 results show that maximum boom section stresses are below yield limits. We can use a telescopic forklift with boom section dimensions according to Figure 11 to lift a steel roof truss for our project.

Simulation 4

The fourth simulation was carried out to lift the automated crane basement beam, which weighs **5,000.3 kg**. As per Simulation 3, the boom section properties remain unchanged. Once the analysis was completed, we obtained the following results:

Table 7 Boom sections minimum and maximum bending stresses, Simulation 4

Load and section properties	Minimum section stress	Maximum section stress	Allowed yield section strength
Load 5.003 -ton. Sliding boom plate thickness $t=18$ mm, boom base plate thickness $t=30$ mm.	$6.042\text{e}+03\text{N/m}^2$	$5.955+07\text{N/m}^2$	$4.6\text{e}+08/\text{m}^2$

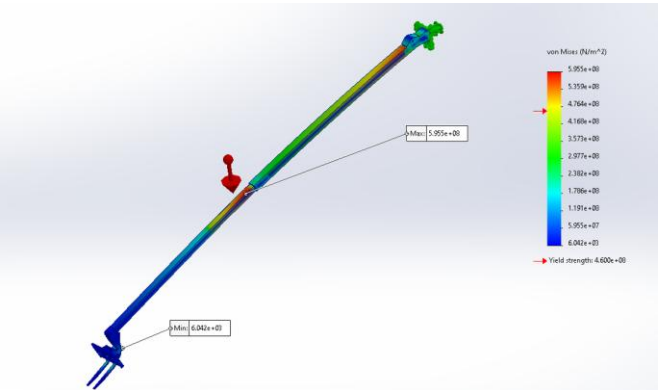


Figure 13. Telescopic booms stress distribution, Simulation 4 (Load 5.0003 kg ton)

Table Nr.7 shows that the maximum stresses of the boom sections exceed the allowed yield stress limit. We cannot use a telescopic forklift with the boom section dimensions shown in Figure 11 to lift the basement beam of the automated crane.

The maximum section dimensions allowed to apply in our telescopic boom are: Boom base outer section dimensions $Bb=310\text{mm} \times 306\text{mm}$, inner section dimensions were $Bb=246\text{mm} \times 242\text{mm}$, and plate thickness $t=32\text{mm}$. While the sliding boom outer section dimensions are $Bb=242\text{mm} \times 238\text{mm}$, the inner section dimensions are $Bb=202\text{mm} \times 198\text{mm}$ plate thickness $t=20\text{mm}$. We have conducted another simulation using these sections for the fifth time.

Simulation 5

The applied load will be **5,000.3 kg**. We used only the last boom sections available for this kind of telescope forklift.

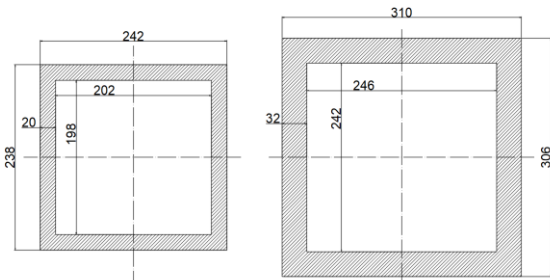


Figure 14. Section boom proprieties, fifth simulations
The results we obtained are as follows:

Table 8. Boom sections minimum and maximum bending stresses, Simulation 5

Load and section properties	Minimum section stress	Maximum section stress	Allowed yield section strength
Load 5.003 -ton. Sliding boom plate thickness $t=18$ mm, boom base plate thickness $t=30$ mm.	$6.045\text{e}+03\text{N/m}^2$	$5.586+07\text{N/m}^2$	$4.6\text{e}+08/\text{m}^2$

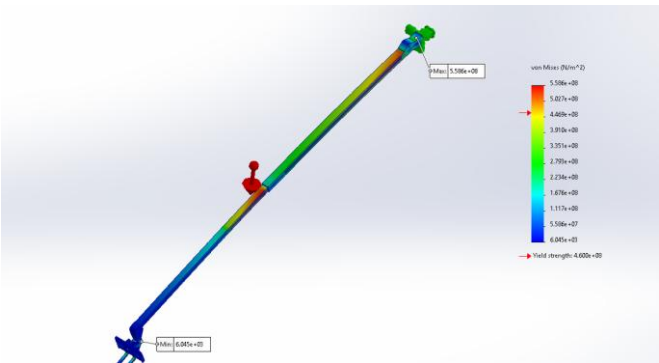


Figure 15. Telescopic booms stress distribution, Simulation 4 (Load 5 ton)

According to simulation 5, it is impossible to lift a 5-ton weight with our telescopic forklift design, no matter how much the boom sections increase. The booms of the telescopic forklift bend drastically when lifting the weight that belongs to the automated crane. This deflection reaches a value of $\delta=1.99\text{m}$. Apart from boom section bending stress issues, there are also equipment stability issues, which can lead to the overturning of our telescopic forklift.

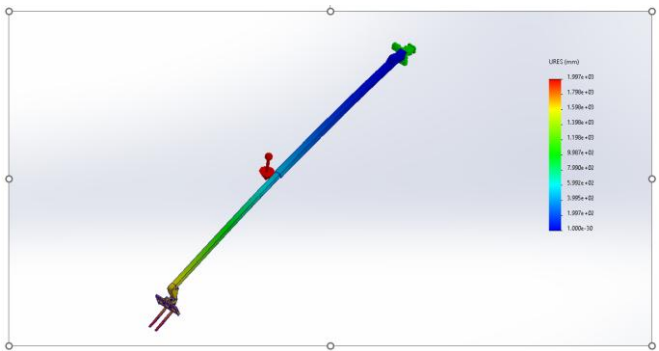


Figure 16. Telescopic boom's maximum and minimum bending values

After conducting the simulation, we found that the area of greatest stress on the boom is the support section and the connection between the basement boom and the sliding boom.

4. Conclusions

In order to successfully execute crucial projects, such as constructing steel sheds for military infrastructure, it is vital to carefully choose appropriate logistic equipment. This will ensure that the work is carried out with maximum safety and efficiency while adhering to estimated costs and timelines. The process of choosing construction equipment and machinery, should be based not only on technical manuals and experience but also on a thorough analysis of the bearing capacity and stress of the equipment's constituent elements. This can be achieved by utilizing finite element analysis. The analysis conducted in this paper enables us to determine the required thickness of the boom section for various weights lifted during the project. When the telescopic boom bending stresses exceed the allowed stresses, as the software shown during the analysis, we can increase the telescopic boom section thickness, or sometimes the right decision to complete the project works would be to use another equipment with different characteristics. By conducting finite elements, we can obtain significant insights for logistic decision-making.

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Considerations for ensuring the quality of measurement with ultrasonic gas flow meters

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Abstract: The article provides information about the factors that have major impact on the ultrasonic gas flow measurement of natural gas. Their considerations will help to the provision of reliable, high-quality and accurate measurement results, well acceptable for all parties in a custody transfer of natural gas.

Keywords: ULTRASONIC, FLOW METER, NATURAL GAS, MID

1. Introduction

Many factors need attention and serious consideration in order to ensure the reliable, high-quality and accurate custody transfer of natural gas. Nowadays, the gas operators want to have fiscal gas meters that operate with the highest reliability within specified accuracy limits, not affected by any changes in the process flow conditions.

Some of the gas operators are still using turbine meters for their natural gas applications, but the modern ultrasonic gas flow meters are able to offer a lot more - their key advantages and low measurement uncertainty covers basically all needs of every gas operator.

2. The ultrasonic gas flow meters

The operation of the ultrasonic flow measuring system is based on the principle of ultrasonic transit time difference measurement. And the determination of the gas volume flowing through is based on the current sound velocity transit time. The measurement itself is conducted using a direct path layout, where two ultrasonic transducers (forming a pair) are positioned opposite to each other in a defined angle to the gas flow. Both of them operate alternately as sender and receiver by changing their roles all the time and eliminate the impact caused by changes in the gas flow and the velocity through the flow meter.

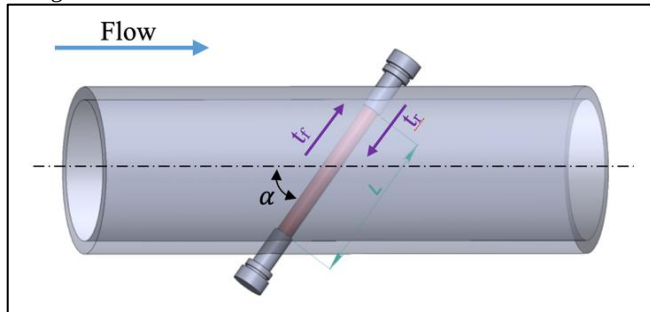


Fig. 1. Ultrasonic measuring principle

The following equations are valid:

$$(1) \quad v = \frac{L}{2 \cdot \cos \alpha} \cdot \left(\frac{1}{t_f} - \frac{1}{t_r} \right);$$

$$(2) \quad Q = v \cdot \frac{D^2 \cdot \pi}{4},$$

where:

- v – speed of gas;
- L – path length;
- α – mounting angle;
- Q – flow rate;
- D – diameter;
- t_f – transit time in direction of flow;
- t_r – transit time against direction of flow.

Every ultrasonic flow measuring system is composed of a meter body, ultrasonic transducers (forming path(s)) and a signal processing unit (SPU). Every major manufacturer has its own ultrasonic flow meter (USM) design based on know-how, used design patents for the measuring paths allocation, etc. But the USM itself is not the only important component for the reliable and

accurate measurement. Several components take place in the measurement process:

- Gas metering station / skid design;
- Ultrasonic gas flow meter configuration;
- Manufacturer's role;
- User's role.

3. Station / skid design and manufacturer's role

The station / skid design probably has the biggest impact on the measurement. The wrong design and equipment selection could lead to a lot of issues like changes in the flow profile or severe piping vibrations.

If there is a gas metering station and a gas regulating station (to measure the gas flow rate and to regulate the pressure to the consumers), there is also a flow meter and a regulating valve. The direct straight pipe between the flow meter and the regulating valve is conductor of noise, created by the regulating valve, which is always located after the flow meter. However, there is a back-wave of the noise. For this reason, an important connection must be performed – between the flow meter and the regulating valve. This connection has a form of a pipe tee and a subsequent elbow to the regulating valve, as the one section of the pipe tee (coaxial with the flow meter) is capped (closed) and the space inside of it performs the role of acoustic damper. This is a proven solution for improving the accuracy of the measurement as keeping it away from the critical values signal-noise. Otherwise, if there is no such a connection, the noise of the pressure regulator directly hits the ultrasonic measurement.

The high pressure drop during normal operating conditions is also considered as a bad influence to the ultrasonic measurement. An interesting point for the assessment purpose is which valves will be used in the station / skid, since every type of valve produces a different kind of noise.

At difficult circumstances and specific station / skid configurations, the USM's manufacturer could always help by evaluating a technical assessment by its own product development support department. The outcome is that it will avoid any possible high risk for the ultrasonic measurement to fail, no matter what type of high-frequency transducers will be used.

The metering station / skid designer with the help of the responsible metrologist must consider the operating conditions and metrology requirements to the USM. The most common information is usually stated in the instrument's operating manual and must be respected. As part of the installation conditions the straight pipe sections (both upstream and downstream of the meter) are considered as identical to the flow meter. There is a specific requirement for their difference in diameters and it must be fulfilled carefully. Sometimes a difference in just a couple of millimeters could be a matter of grave concern.

For custody transfer applications in Europe, the mandatory requirements to the gas meter and its installation conditions are stated in its EU Type-examination certificate (in accordance with Measuring Instrument Directive 2014/32/EU (MID), concerning gas meters and volume conversion devices (MI-002)) and in its OIML certificate (in accordance with Recommendation of the International Organization of Legal Metrology (OIML) R137-1 "Gas meters").

In addition, ISO 17089-1 [3] defines recommendations for ultrasonic gas flow meters and their operational requirements, including important remarks to the production of adjacent straight pipe sections (upstream / downstream of the meter) like cylindricity, internal diameter of the connecting flanges, internal surface and wall roughness, etc.

Despite the apprehensions of many, the internal wall roughness of the straight pipe sections is not of a great importance, but it should be considered. A much higher influence originates in the geometrical deviations. Once the measuring system is calibrated, the pipe roughness is not an issue anymore. There is an interesting study [2] about the influence of deposits or changes in wall roughness on the validity of the calibration and long-term accuracy of ultrasonic gas flow meters.

4. Ultrasonic flow meter configuraiton

The proper USM configuration is normally selected during the instrument delivery process and none of the below listed must be underestimated:

- Application / type of gas;
- Requested meter variant / path layout;
- Applicable metrological approval;
- Expected gas composition;
- Operating conditions and design parameters, incl. flow ranges, pressure, temperature, ambient temperature, etc.;
- Requested meter body, incl. information about nominal size of the meter, material of the meter, flange pressure rating, pipe connection diameter, should it be tapered bore or full bore, etc;
- Type of SPU and sensors, incl. I/O configuration setup and explosion protection type of the enclosure;
- Meter body testing during production phase, incl. pressure leakage test, pressure hydrostatic test;
- Flow calibration (unidirectional or bidirectional) that could be low pressure calibration or high-pressure calibration, with the choice of test points, adjustment method (linear, polynomial or piecewise correction) and calibration setup.

If the USM will operate in combination with a flow conditioner (FC) located upstream the meter, it is mandatory to calibrate the complete package (FC, inlet pipe, USM, outlet pipe). If the measuring line contains not one, but two ultrasonic meters in series, the FC selection must comply to the first USM in the line.

Regular steps to ensure the USM accuracy are:

- 1) **Manufacturing process**
- 2) **3D-measurement**
- 3) **Base line**
- 4) **Configuration, Speed of Sound Check and Zero Flow Test** (Dry calibrated meter, without gas flow, i.e. typ. uncertainty $\pm 0.5\%$);
- 5) **Ambient Air Calibration** (Wet calibrated meter, with gas flow, i.e. typ. uncertainty $\pm 0.35\%$);
- 6) **High pressure calibration, linear correction** (Wet calibrated meter, with gas flow, i.e. typ. uncertainty $\pm 0.2\%$);
- 7) **High pressure calibration, polynomial correction** (Wet calibrated meter, with gas flow, i.e. typ. uncertainty $\pm 0.1\%$).

5. Modern USM Add-ons and User's role

In addition to the hardware design and proven measurement technology, the modern USM must have variety of features that will bring the measurement process to the next level, where easy operation and access to diagnostics data are available anytime. The user-friendly software is a key feature for this purpose and it must support the commissioning and meter management, as well as the real-time performance monitoring and further diagnostic parameters and values.

An irrevocable option of modern USM is the use of parameter Speed of Sound (SOS) that shows the distribution of components on the flow profile. It is used for diagnostic purposes. Monitoring and evaluation of the instrument diagnostic information can provide key information on changes in the system status before they affect the measuring results. And a comparison of diagnostics data from different periods of the USM's operation could help to diagnose whether the device has to be maintained to even calibrated.

In a study [1] have been reviewed the types of diagnostic data and its further handling and interpretation.

Three types of flow meters have been reviewed in it:

- 4-path USM with direct path layout – Figure 2;
- 8-path USM with direct path layout – Figure 3;
- 4+1-path USM with direct path layout – Figure 4.

USM with 6-path (3-path vs. 3-path in "X" orientation) is a great addition to the above listed solutions and it gives absolutely different perspective to the changes in the flow profile, when it is combined with a 4- or 8-path meter. Nevertheless, the 6-path meter is not a subject of review in [1].

The relevant diagnostic indicators include minimum the following:

- Signal-to-Noise Ratio (SNR);
- Average Gain Control (AGC);
- Turbulence.

As per [1] "Diagnostic values derived from the individual path velocities are helpful to identify changes in the flow profile. In a 4- or 8-direct path layout, they include the following examples:

- Profile factor (quotient of the path speeds of the middle to outer paths);
- Symmetry (quotient of the path speeds of the two upper to the two lower paths);
- Swirl (quotient of the path speeds of crossing path planes)."

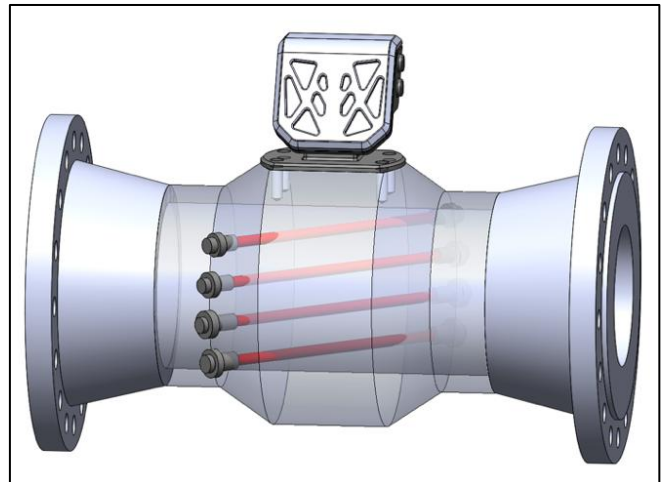


Fig. 2. Ultrasonic gas flow meter, 4-path, direct path layout

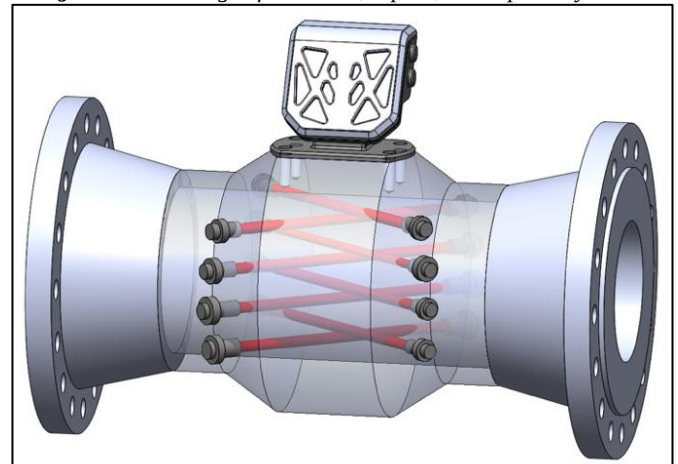


Fig. 3. Ultrasonic gas flow meter, 8-path, direct path layout

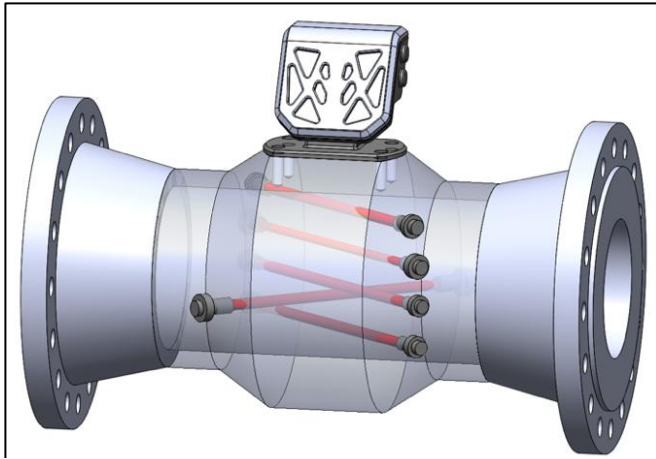


Fig. 4. Ultrasonic gas flow meter, 4-path + 1-path, direct path layout

If we consider the design on Figure 2 as “default”, and if we add just 1-path system in the center of the meter body (in the middle of the pipe), the result will become like the one shown on Figure 4. This 1-path system gives different perspective than the “default” design and it will react differently if any changes of the flow profile occur.

When we talk about diagnostics, there is another “hardware” solution that could provide additional key diagnostics data – it is the use of two USMs with different technologies in series. For instance, if a metering run is a combination of a six-path meter plus a four-path (or eight-path) meter installed in series, both of them will have different reaction of the flow profile changes, which might help identifying pollution in the metering package. If different technologies come from different manufacturers, the end user will have different sources of diagnostics data for the very same process. That would be helpful for the end user to analyse the condition of both process and assets condition.

6. Conclusion

Consideration of above-described pre-requisites is the key for reliability and quality of the measurement results which will not be affected by changes in density, flow velocity or speed of sound. The modern user-friendly software solutions are mandatory addition to the equipment. The data collection, evaluation and analysis of diagnostic indicators is a rigid part of USM technology.

The supportive manufacturer with know-how is always an advantage to every new gas project. And if the gas operator, EPC or end-customer has the chance to coordinate and assess the delivery of new equipment as per the installation design, that will contribute to the reliable ultrasonic gas flow measurement.

The reliable ultrasonic measurement of natural gas is equal to a proper project design plus a good meter plus a supportive manufacturer(s) with technology and know-how.

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Innovative mill complex for processing glass waste, applicable to the production of foam glass and composite materials

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Abstract: An innovative mill complex has been developed for the processing of glass waste applicable to the production of granular foam glass and fire-resistant, energy-saving, acoustic and thermal insulation composite building elements. The presented design solution is in accordance with the necessary technological characteristics of the ground vitreous raw material for use in the production process. It is envisaged that the grinding will be carried out in two stages and will be combined with homogenization of the batch being prepared. The first stage is the initial grinding of the raw material in a vibrating mill with metal grinding bodies, allowing grinding for a shorter period of time to a certain size of the particles with minimal contamination. In the second stage, the final grinding (up to a technological size of the particles) and homogenization is carried out in a ball mill with non-metallic grinding bodies. The main production equipment necessary for the realization of the presented technological process was considered.

Keywords: WASTE GLASS, MILL COMPLEX

1. Introduction

The technological processing of raw materials by means of milling equipment is a fundamental stage of the production process in various industries. The mechanical processing of the primary raw materials by crushing, grinding and mixing to the required optimal technological state [1-3], ensures the effective participation of the obtained fractions (from the materials) in the following production stages. Different structural types of mills have been developed [3-9], characterized by various exploitation characteristics (working mode, productivity, reparability, energy efficiency, etc.), specialized for processing certain categories of raw materials. Standard mill facilities with a classic construction are the main part of the necessary specialized machine park for the equipment and construction of various production technological lines. The main problems in the intensive operation of mill facilities are the duration of the technological process, the consumption of electricity [10], the depreciation of the used equipment [11], the risk of contamination of the processed raw materials and a number of others.

The significant increase in the scale of industrial production, the accelerated development of various economic sectors and the effect of the consumer activity of households are accompanied by an increase in the generated quantities of various waste products [12]. This determines the tendency to develop and implement technological solutions for the utilization of waste materials [13], in the role of raw materials for ecological production of semi-finished products or finished products [14,15]. Production technologies have been developed for efficient recycling of waste silicate glass [16-18] and production of various foamed glass materials (planes, profiles, granules, gravel and others). The creation of innovative equipment with higher efficiency (compared to previous generations of equipment) ensures increased productivity [19] of technological lines. A significant part of the obtained foam glass products are mainly used for thermal insulation of buildings [20], equipment, installations or for the construction of drainage systems.

At the same time, innovative composite materials have been developed based on granular foam glass (obtained from glass household waste) and inorganic binders [21-24]. An experimental process line was designed and a conceptual model of a workshop was prepared for the production of a diverse assortment of massive composite products [24,25] for construction. The used technological approach provides for mechanical processing by grinding the provided amounts of waste glass to a powdery mass and preparing homogenized batches with the participation of a foaming agent. In the course of the production process, primary granulation of the compositions and thermal foaming to foam glass aggregates with a cellular structure and different granulometric composition takes place. The prepared fractions of granular foam glass represent a predominant component for the production of composite materials with the participation of hydraulic binders and other components. The forming of the semi-finished products, the demoulding and the final processing of the final products is carried out in a separate technological section, equipped with a specialized set of formwork

forms. On the other hand, the optimization of some energy-intensive stages of the technological cycle is considered as an expedient opportunity to increase the productivity of the used methodological approach for preparing composites. For the rational implementation of the process, a number of experimental data in a wide research spectrum [26-44], obtained by different author groups, have been analyzed. In this aspect, a promising direction is the implementation of adequate changes in the implementation of the primary mechanical processing, grinding and homogenization of the raw materials.

The aim of the present work is the presentation of an original approach to the construction of an innovative mill complex for the processing of waste glass, applicable to the production of granular foam glass for the preparation of fire-resistant, acoustic and thermal insulation composite materials. The development ensures shortening of time for mill processing of materials, reduction of electricity consumption, lower depreciation of equipment (within one production cycle) and minimization of the risk of raw material contamination.

2. Experimental procedures

The main grinding facility for non-metallic materials is a ball mill with non-metallic grinding bodies to avoid contamination of the ground material. In the experienced technological line and technology for the production of fire-resistant, energy-saving, noise and heat-insulating composite building elements based on glass waste, the use of a ball mill for grinding and homogenization of the incoming charge to obtain the mixtures from which the foam glass granules are made as a component is provided of the composite material. The composition of the charge when grinding the glass crumb should not contain impurities from the grinding metal bodies. If only a ball mill with non-metallic grinding bodies is used to grind the glass powder, the process takes days and consumes a lot of energy. With the vibration mill, the grinding time is reduced many times (by times) than with grinding only with a ball mill, but the contamination with metal inclusions, mainly iron filings, released in the vibration mill are harmful to the normally proceeding technological process of foaming the glass powder with the glycerin and water glass foamer. The design of the vibrating mills, intended for the initial grinding of the particles with metal grinding bodies, allows grinding in a short time to a certain size of the particles with minimal contamination with iron filings, and the final grinding to the technological size - 85% of particles around 65 microns and the subsequent homogenization to is carried out in a ball mill with non-metallic grinding bodies - spherical balls of corundum, high-strength electro porcelain or balls of natural material - flint, which do not contaminate the glass dust. No experience has been gathered on the fabrication of non-metallic grinding cylinders for the vibratory mill involved in the construction of the vibratory mill. Thus, it is suggested that grinding be carried out in two stages and be combined with homogenization of the batch being prepared. For

this reason, it is necessary to optimize the grinding process of the output glass powder after the vibrating mill. Optimization involves the selection of such parameters of the grinding process, described in the theory of grinding in ball mills, which lead to maximum efficiency in order to reduce the energy of grinding and to minimize contamination of the prepared charge.

Research time for grinding non-metallic glass material in a grinding system with a vibration mill Fig. 1 with metal grinding cylindrical bodies, implemented under a patent.

A milling system with a vibrating mill intended for use in the experimental technological line and technology for the production of composite material based on foam glass granules and products thereof.

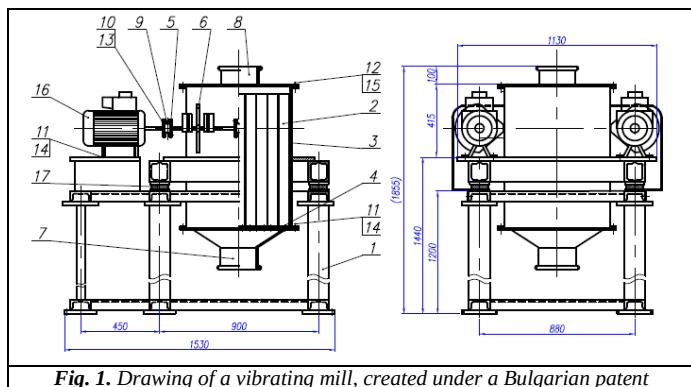


Fig. 1. Drawing of a vibrating mill, created under a Bulgarian patent

The main facility - the vibrating mill itself has been tested and works successfully for grinding non-metallic materials that are not affected by the metal shavings produced during grinding by the metal grinding cylinders made of high strength bleached cast iron. But despite its qualities, metal shavings are still released, which are harmful to the technological process for the starting material of the foam glass granules

An experimental vibratory mill with different grinding times was used for the experiments, and the amount of chips separated was measured. Grinding time to optimal size of glass crumb particles up to 1 cm in size and drum diameter $D=600$ mm, diameter of grinding bodies $d=60$ mm, number of grinding bodies 47 pcs. is shown in table 1.

Table 1. Grinding time to optimal size of glass particles.

No sample	Size of input particles in a vibrating mill 85 %	Residual iron dust from grinding	Grinding time in a vibrating mill a	Revolutions of electric motor (oscillation frequency)	Particle size
	mm	g/dm ³	min	RPM	μm
1	10 - 5	2	12	3000	440
2		4	24		380
3		8	36		320
4		20	80		160
4		50	180		90
5		60	240		60

From the conducted foaming experiments, it has been proven that the amount of harmless content of iron powder is up to 10 g/dm³, which corresponds to the first 3 samples from table 1. The grinding time for these samples is up to 36 - 40 minutes, and 85% of the bulk of glass particles is from 440 to 300 microns. The size of the particles was evaluated with a laser analyzer - granulometer brand FRITSCH, fig. 2. for sample 3, which shows under-grinding of the glass powder, and for which the need for further grinding in a ball mill with non-metallic grinding bodies is determined.

3. Results and Discussion

The laser granulometer has two modes of operation - dry and wet. For this study, the wet mode was used, where the sample was placed in a fluid (water), after which three consecutive measurements were made. Uniformity of the three measurements is obtained, which is an indicator of correctly reported values. The table below the graph shows the distribution of the particles, with

90% in the Q3(x)[%] column of the sample content having an average size of 354.23 μm. Average size is based on three sample measurements.

An experiment was also carried out for grinding in such a ball mill. A grinding system shown in Fig. 2 was used.

The time for grinding the glass powder in the ball mill to the required size of particles of glass powder 85% with a size of 65 microns, with a diameter of the grinding drum $D=1200$ mm is shown in the table. 2.

Table 2. The time for grinding the glass powder.

No sample	Size of input particles in the ball mill a	Diameter of grinding ball	Number of grinding balls (fill level)	Revolutions of the grinding drum (rotation frequency)	Grinding time	Homogenization time	Average particle size 85%
	mm	mm	-	RPM	h	min	μm
1	0,005 - 0,003	30	200	60	6	20	70
		20	300		5,5	30	80
		10	400		5,5	20	90
2		50	300	60	2	30	65
3		50	300	35	4	20	95
4		30	500	60	2,5	30	65
5		30	500	40	7	30	75

Mode No. 2 with a ball diameter of 50 mm at 60 mm and reaching the required size after 2 hours of grinding, with the foaming agents added in the last 10 minutes and then another 30 minutes of homogenization, turned out to be the most economical. The result of mode No. 4 is similar, the difference is minimal and can be further optimized in the process of work and determining the degree of wear of the balls and their cost, as well as the grinding efficiency.

A laser grain size was re-examined under the same conditions with the same analyzer. The result is 90% milled particles with an average size of 69 μm.

The data for optimizing the grinding process with minimal energy consumption from both mills and minimal contamination with harmful impurities have been determined. It is as follows: Vibration Mill Data in table 3:

Table 3. Vibration Mill Data.

No sample	Size of input particles in a vibrating mill 85 %	Residual iron dust from grinding	Grinding time in a vibrating mill	Revolutions of electric motor (oscillation frequency)	Particle size
	mm	g/dm ³	min	RPM	μm
3	10 - 5	8	36	3000	320

Ball mill data in table 4:

Table 4. Ball mill data.

No sample	Size of input particles in the ball mill	Diameter of grinding balls	Number of grinding balls (fill level)	Revolutions of the grinding drum (rotation frequency)	Grinding time	Homogenization time	Particle size 85%
	mm	mm	-	RPM	h	min	μm
2	0,005 - 0,003	50	300	60	2	30	65
4		30	500	60	2,5	30	65

The data for the two ball mill modes differ in diameter and number of balls. In a correctly conducted experiment, a result was obtained, as close as possible to a real combination of minimum grinding time, both in the vibration and ball mills, minimum grinding energy also from both mills and optimally residual iron powder, which does not interfere with the technological process for foaming of the granules.

For the coarse grinding in the vibrating mill with incoming raw material - pieces of glass crumb 0.5 - 0.6 cm after hammer crusher, the grinding time is 30 - 40 min with the outgoing particle size - 300 - 400 microns and 8 - 10 g/dm³ of iron shavings that do not interfere with the technological process. A cascade mode is used for fine grinding in the ball mill.

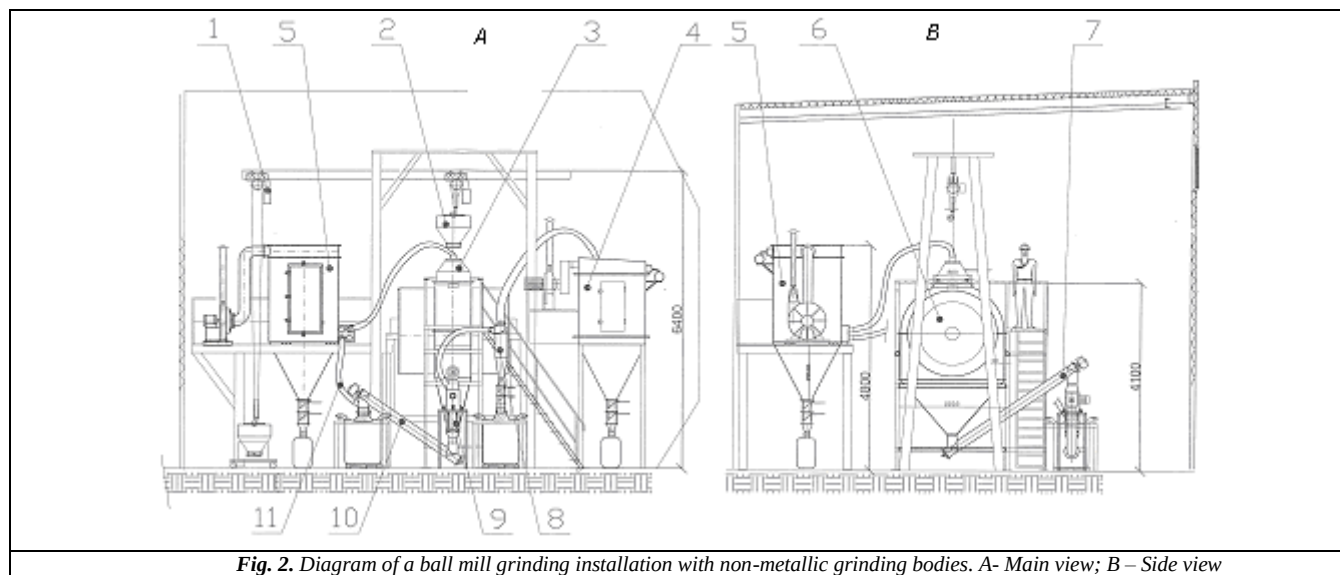


Fig. 2. Diagram of a ball mill grinding installation with non-metallic grinding bodies. A- Main view; B – Side view

When operating ball mills in this mode, in order to obtain a finer fraction, the smallest possible diameter, in the case $d = 30$ mm, grinding bodies, tailored to the desired fraction of the starting product, are used. In this mode of operation, the defragmentation of the material itself occurs during grinding. The revolutions of the ball mill required to obtain this regime depend on the diameter of the mill - $D = 1200$ mm, $n = 60$ rpm and the material of the grinding bodies - corundum. With a productivity from both mills of 150 kg/hour, the total power for 4 motors - 1 for the hammer crusher, 2 for the vibrating mill and 1 for the ball mill averages 2.5 kW/hour = 10 kW/hour. As a result, 60-70 Watts of energy is used for 1 kg of ground and homogenized raw material. There is an opportunity to make improvements in the vibrating mill - making grinding cylinders from corundum and in the ball mill - making balls with a special, more efficient pyramidal shape with rounded.

4. Conclusions

An innovative approach is presented: the construction of a mill complex for the processing of glass waste raw materials, applicable to the production of granular foam glass for the production of composite acoustic and thermal insulation composite materials (cladding boards, profiles and fire-resistant elements) for construction. Two technological stages are envisaged for mill processing of the vitreous raw material to form a fractional composition with optimal target characteristics for effective application in the production process. By applying primary grinding of the raw material in a vibrating mill (with metal grinding bodies) for a short period, basic mechanical processing is carried out until a satisfactory technological consistency of the vitreous mass and minimal contamination. The final grinding of the raw material is carried out in a ball mill (with non-metallic grinding bodies) combined with homogenization of the components and preparation of batch compositions.

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Morphology and structure of oxide thin films obtained by the sol-gel method: a review

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Abstract: One-component CeO_2 coatings and bi-component $\text{CeO}_2/\text{ZrO}_2$ multilayer coatings were obtained by a sol gel process. The phase composition, surface morphology and roughness of the samples were studied by means of X-ray diffraction (XRD), scanning electron microscopy (SEM), Atomic force microscopy (AFM) and X-ray scanning electron microscopy (XPS). The corrosion resistance and protective ability were characterized by using salty solution of 3.5% NaCl at 25 °C. The multilayer configuration of CeO_2 and ZrO_2 ensure enhanced protection of the steel in comparison to the single CeO_2 coatings and uncoated steel. The surface morphology and anticorrosion properties depend significantly on the treatment temperature of both CeO_2 underlayer and ZrO_2 top layer. At lower treatment temperatures, they are relatively dense and smooth. The corrosion resistance of the multilayers slows down, when ZrO_2 coatings were heated above 500°C. This probably is due to the more pronounced crystallization of cubic zirconium dioxide, resulting in deeper boundaries between the individual grains. The protective properties of a $\text{CeO}_2/\text{ZrO}_2$ multilayers could be attributed to the low crystallized structure with very fine crystallites.

Keywords: SOL-GEL METHOD, COATINGS, CeO_2 , $\text{CeO}_2/\text{ZrO}_2$

1. Introduction

The course of various corrosion processes significantly limits the exploitation period and has an extremely adverse effect on the condition and workability of different facilities, production installations, metal constructions, machine park, transport fleet and other. Corrosion reactions are accompanied with various processes related to gradual change the composition, micromorphology, structure, chemical resistance, mechanical properties and functional properties of the metal contact surface. One of the widely applied approaches to protect the metal products from the effects of corrosion factors is the use of a variety types of organic or inorganic protective coatings [1]. Diversity protective thin coatings with specific characteristics can be deposited on the metal surface by various methods, including thermal oxidation [2], electrochemical deposition [3], chemical vapor deposition (CVD) [4], plasma spraying [5], physical vapor deposition (PVD) [6], electron-beam evaporation [7], pulsed laser deposition [8], thermal annealing [9], atomic layer deposition [10], spray pyrolysis [11], pressing techniques [12], sputtering [13] and a sol-gel technique [14-16].

Different non-toxic nanostructured, homogeneous, oxides coating are investigated in the role of appropriate barrier layers, increasing the corrosion resistance of the metals [15-28].

Considerable interest is the preparation of innovative, competitive and long-lasting coatings with optimized complex indicators, suitable for operation in a variety of corrosive environments. A current trend is the application of environmentally friendly and economically viable technologies for manufacturing products at lower consumption of energy carriers. The sol-gel method is an alternative ecological, low cost and low temperature technological approach for obtaining nanoscale materials with different functional properties, applicable [29-33] in optics, electronics, medicine and other fields. The sol-gel technology allows the obtaining of materials and products in different forms (powders, layers, fibers, nanocomposites, net-like structures, monoliths etc.) and offers a number of advantages compare to other standard classical high temperature techniques used to make similar products. The method provides a number of significant technological possibilities: accessible precursors, use of basic laboratory equipment, work in a standard environment, effective control the reaction conditions of synthesis, relatively low temperature of synthesis, obtaining diverse of materials with good homogeneity, desired chemical composition, high purity, controlled porosity and other specified target properties. The sol-gel technique involving several consistent main stages [34-36]: hydrolysis and polycondensation reactions, gelation, aging, period of drying, densification and crystallization processes. Usually introduce of appropriate catalysts increases the rate of hydrolysis. The pH value of the prepared reaction system, which is dependent on the specifics of the applied catalyst, essential impact of the ongoing hydrolysis

and condensation processes and of the structure and properties of the resulting final phases.

A number of authors report [15, 37-42] on the application of sol gel method to produce appropriate anti-corrosion coatings for effective protecting various materials and products in aggressive environments. For the preparation by sol-gel method of different type's thin or thick coatings [43-45] with effective controlled uniform thickness is applying of single and multi-deposition techniques. The use of dip coating or spin coating [46, 47] modus is an important major factor determining the the characteristics of the resulting layers. In this technique, some technological parameters have a significant impact: amount of the components, viscosity, surface tension, humidity, duration of the rotation, speed of the rotation, temperature of the surrounding atmosphere and so on [45]. Spin-coating method provides the more technological possibilities for precise obtain of thin films with finer structure and different properties than dip-coating method [44]. In the formation of the structure of the prepared sol-gel coatings, the used heat treatment regime has a significant role, the maximum temperature used being of major importance.

The ceria and zirconia protective coatings are characterized with prezenze of excellent wear resistance, good chemical stability, low thermal conductivity, non-toxic properties, appropriate corrosion resistance and high thermal expansion coefficient close to that of many metals [48], which reduce the formation of cracks during high-temperature impacts. At the same time the high dielectric constant and unique mechanical indicators (fracture toughness, high hardness) of ZrO_2 determine it's the essential importance in different areas of practice [37, 38, 49-53].

Anti-corrosion and thermal protection abilities of zirconia sol-gel based [38, 50, 51, 52, 54] coatings deposited on stainless steel, ferritic steel 9Cr1Mo, aluminum and glass substrates was studied [37]. Laboratory tests have been performed to investigate of anticorrosive characteristics of zirconia coatings at immersion chiefly in acid or salt media [55].

A particularly promising technological approach is the preparation of multilayer coatings formed of 2 or 3 types of oxides, deposited over the other. Currently, the development of various multilayer anti-corrosive coatings for protection of metals is perceived as especially perspective approach, since they provide higher degree of protection than to monolayer coatings [56]. The multilayer coatings combine the specific physic-chemical characteristics of the various oxide layers, which significantly increases the functional performance of the finished products and expands the prospects for their application. The experimentally anti-corrosion behavior of ZrN/ZrO_2 multilayers coatings on stainless steel, deposited by ion plating have been investigated [57]. In laboratory conditions it has been established that the bi-layer structure is distinguished by a higher corrosion resistance, than at sample with single layer with of the same thickness, without this

does reduce the resistance of the coating to the surface of the test specimen [58]. On the other hand it is observed anticorrosive properties are enhance of the anticorrosion of ceria doped ZrO_2 coatings [59].

The developed various nano-hybrid coatings demonstrated high mechanical, physic-chemical and anticorrosion properties [41, 42], depends of the content and activation of the introduced nanoparticles.

Experimental modified silane-based hybrid coatings [60, 61] with different content of CeO_2 and ZrO_2 nanoparticles were prepared. The introduced CeO_2 and ZrO_2 nanoparticles were represent suitable fillers, determining the increase the anti-corrosion properties of the hybrid coatings [62, 63].

In the volume of the layer deposited by sol-gel technology are incorporated amorphous ZrO_2 or crystalline CeO_2 nanoparticles, with various sizes from 5 nm up to 10 nm.

It has been found that the presence in compositions of nanoparticles CeO_2 improve of corrosion protection characteristics, whereas the content of ZrO_2 simultaneously enhance corrosion and wear resistance [40]. The corrosion behavior of the obtained hybrid nanocomposite coatings and the possibilities for their use in the role of protective coatings for electro-galvanized steel [63], AA2024-alloy [41] and Mg-alloys [40] have been investigated.

A number of authors report [64-66] cerium is an appropriate inhibitor of different metals and alloys corrosion: aluminum, aluminum alloys, steel, magnesium, magnesium alloys, tin and others. The introduction of appropriate corrosion inhibitors in the composition of coatings can provide effective corrosion protection performance, as the presence of inhibitors can considerably limits the appearance of local corrosion [67,68]. The protective CeO_2 coatings suppress the cathode processes [69] by inhibiting the corrosion reactions and are especially suitable for the passivation of metal materials in the role of an active barrier layer [59].

Experimental cerium-based anti-corrosion coatings were prepared by sol gel technology [70]. The effect of introduced various concentrations of cerium ions on the characteristics of sol-gel derived protective coatings were studied [71]. The possibilities for preparation and characteristics of TiO_2 - CeO_2 coatings by using the sol-gel method by dip-coating the technique were investigated. It is proven that the corrosion resistance indicators is enhancement with increment of the content CeO_2 in resulting nanocomposite coatings. The evidently presence of cerium ions have a beneficial effect on the corrosion resistance of the investigated coatings [71]. This result showed the essential importance of introduced CeO_2 in the oxides coatings, intended for effective corrosion protection of someone metal materials.

The present paper reports the experimental results from the performed the investigations of the corrosion resistance of CeO_2 coatings and bi-component $\text{CeO}_2/\text{ZrO}_2$ multilayer protective coatings, obtained by the sol-gel method (dip coating technique) [72-80].

2. Experimental procedures

For CeO_2 coatings obtained by the sol-gel method, $\text{Ce}(\text{NO}_3)_3 \cdot 6\text{H}_2\text{O}$ (0.4M) dissolved in isopropanol was used as a precursor solution. After immersing the pads in the solution and holding for 10 seconds, they are withdrawn at a speed of 30 mm/min. After each application, the samples were air-dried in two stages: first at 100°C for 1 hour, then the temperature was increased to 300°C for 1 hour. The procedure was repeated 3 times. The samples were divided into 2 groups - in the first group (code C1) - 2 more layers are applied in the procedure described above. In the case of the second group of samples (code C2) - 2 applications followed, each of the layers being processed at 500°C.

For $\text{CeO}_2/\text{ZrO}_2$ multilayer coatings obtained by sol gel method, $\text{ZrOCl}_2 \cdot 8\text{H}_2\text{O}$ (p.a) dissolved in ethanol was used as a precursor solution and nitric acid was added to prevent hydrolysis. 1.6 ml of acetylacetone was added to the mixture as a complexing agent, the solution was stirred for 2 hours. After immersing the pads in the solution and holding for 10 seconds, they are withdrawn at a speed

of 30 mm/min. After each application, the samples were air-dried in two stages: first at 100°C for 1 hour, then the temperature was increased to 300°C for 1 hour. The procedure was repeated 2 times.

Multilayer coatings consisting of 3 layers of CeO_2 and two layers of ZrO_2 were deposited and characterized.

The layers of CeO_2 were deposited under the conditions of obtaining samples C2. After their heat treatment, 2 layers of ZrO_2 , treated at different temperatures, were successively deposited on them.

In this study, nanosized TiO_2 coatings donated with samarium were obtained by the sol-gel method to increase the corrosion resistance of 316L steel. Two organic titanium precursors were used to prepare the solution for TiO_2 deposition donated with samarium: Titanium Isopropoxide (TTIP) and Titanium Butoxide. Acetylacetone (AcAc) was used as a stabilizing agent.

Titanium isopropoxide (TTIP); titanium butoxide and AcAc were dissolved in 2-propanol. The resulting solution is clear and orange, which is typical for the formation of a chelated complex. After stirring vigorously at room temperature, a mixed solution of distilled water and i-propanol (iPrOH) was added drop wise to the above solution with stirring. The molar ratio of the components is TTIP: iPrOH: H_2O : AcAc = 1:30:1:1. The solution of the Titanium butoxide was prepared by the same method.

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3. Results and Discussion

X-ray phase analysis data showed that a nanocrystal line phase of cubic CeO_2 was formed after isothermal heating (according to powder diffraction file PDF 43-1002) (Fig. 1). The size of the crystallites for both types /C1 and C2/ of samples is 7 nm.

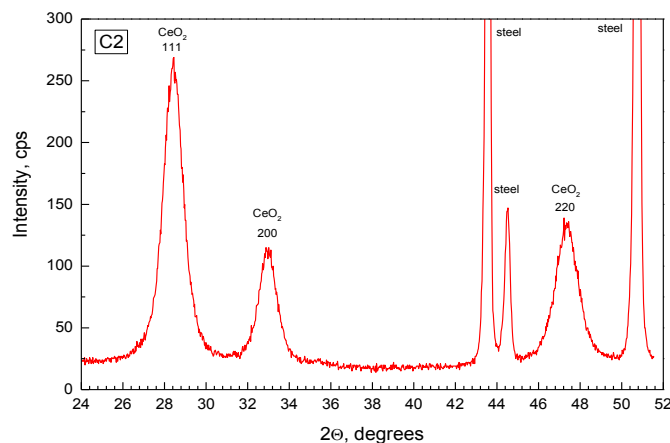


Fig. 1. X-ray diffractogram of sol gel coatings of CeO_2 .

Figure 2 shows the SEM images of the surface of the samples before and after the corrosion test. Sample C1 has a relatively smooth surface with the presence of microcracks, while the morphology of sample C2 is smoother and with much fewer microcracks. After conducting the corrosion test, the surface retains its characteristics, pits, holes and other characteristic signs of corrosion are not observed.

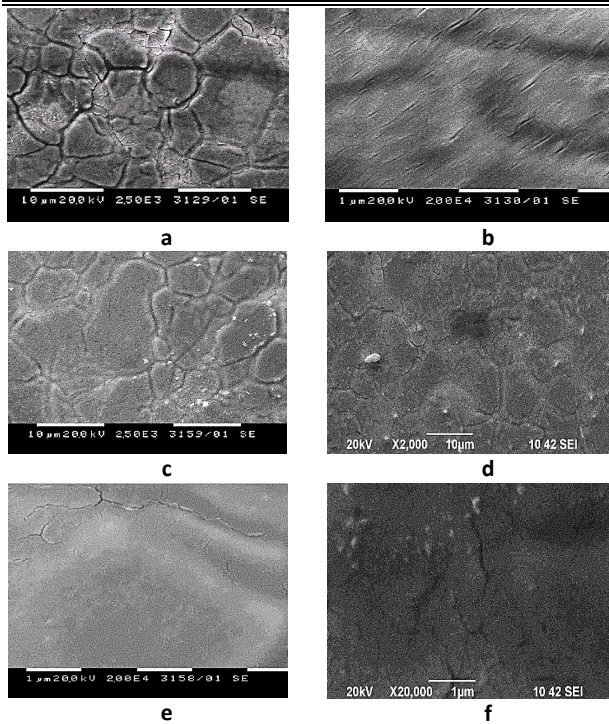


Fig. 2. Morphology of freshly prepared CeO_2 sol gel coatings – C1 (a,b) and C2 (c,d) and C2 after corrosion test (e,f).

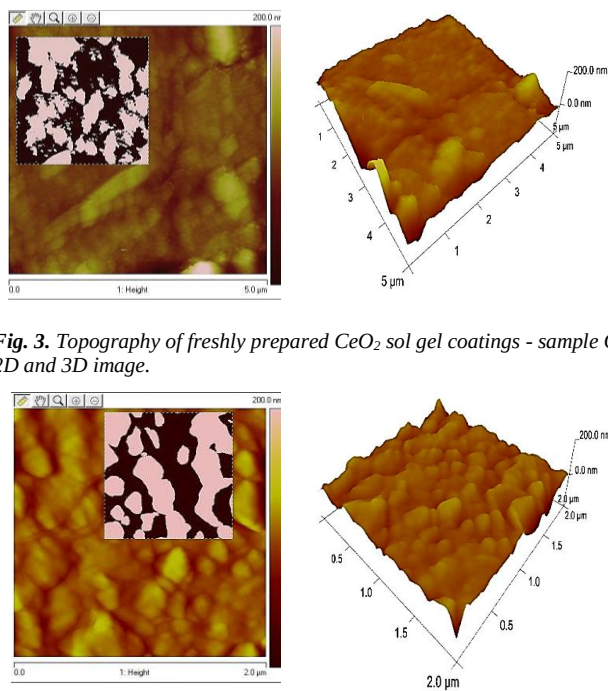


Fig. 3. Topography of freshly prepared CeO_2 sol gel coatings - sample C2 in 2D and 3D image.

Fig. 4. Topography of CeO_2 sol gel coatings - sample C2 after corrosion test in 2D and 3D image.

Figure 3 shows the topography of the CeO_2 coating after the heat treatment. It can be seen that the coating is dense, without visible pores and with good adhesion, and the surface is composed of numerous nano-sized crystals. The roughness was calculated using an AFM software program - R_q is 15 nm ($R_a=10$ nm). Figure 4 shows the topography of a coating after a corrosion test. The surface roughness of the sample is also very close: R_q is 14 nm ($R_a=10$ nm), which is another evidence (besides the morphology shown in the SEM photographs) that the sample exhibits good barrier properties under the influence of NaCl environment.

Presents the analysis of the chemical composition of the coatings before and after the corrosion test; it can be seen that the composition does not change significantly - Table 1.

Table 1. EDX analysis of CeO_2 /C2/ coatings obtained by the sol-gel method.

At %	Freshly received sample	After corrosion attack
O	36,39	34,24
Cr	11,89	12,42
Mn	0,7	0,77
Fe	39,57	40,81
Ni	4,03	4,32
Zr	-	-
Ce	7,42	7,45

The conditions of the final thermal treatment of multilayer coatings of $\text{CeO}_2/\text{ZrO}_2$ obtained by the sol-gel method for each of the coatings are presented in Table 2.

Table 2. The thermal treatment of multilayer coatings of $\text{CeO}_2/\text{ZrO}_2$.

Code pattern	First layer T (°C)	2nd layer T (°C)	3rd layer T (°C)	4th layer T (°C)	5th layer T (°C);
C3	$\text{CeO}_2/300$	$\text{CeO}_2/300$	$\text{CeO}_2/300$	$\text{ZrO}_2/500$	$\text{ZrO}_2/500$
C4	$\text{CeO}_2/500$	$\text{CeO}_2/500$	$\text{CeO}_2/500$	$\text{ZrO}_2/500$	$\text{ZrO}_2/500$
C5	$\text{CeO}_2/300$	$\text{CeO}_2/300$	$\text{CeO}_2/300$	$\text{ZrO}_2/600$	$\text{ZrO}_2/600$
C6	$\text{CeO}_2/500$	$\text{CeO}_2/500$	$\text{CeO}_2/500$	$\text{ZrO}_2/600$	$\text{ZrO}_2/600$
C7	$\text{CeO}_2/300$	$\text{CeO}_2/300$	$\text{CeO}_2/300$	$\text{ZrO}_2/700$	$\text{ZrO}_2/700$
C8	$\text{CeO}_2/500$	$\text{CeO}_2/500$	$\text{CeO}_2/500$	$\text{ZrO}_2/700$	$\text{ZrO}_2/700$

X-ray phase analysis data (Fig. 5) showed that after isothermal heating, a nanocrystalline phase of cubic CeO_2 was formed, according to powder diffraction file PDF 43-1002, and cubic ZrO_2 according to powder diffraction file PDF 49-1642. From the presented radiographs, enhanced crystallization of cubic ZrO_2 is observed with an increase in the annealing temperature of CeO_2 - 500°C and ZrO_2 - over 600°C. The crystallinity of the CeO_2 phase does not change significantly.

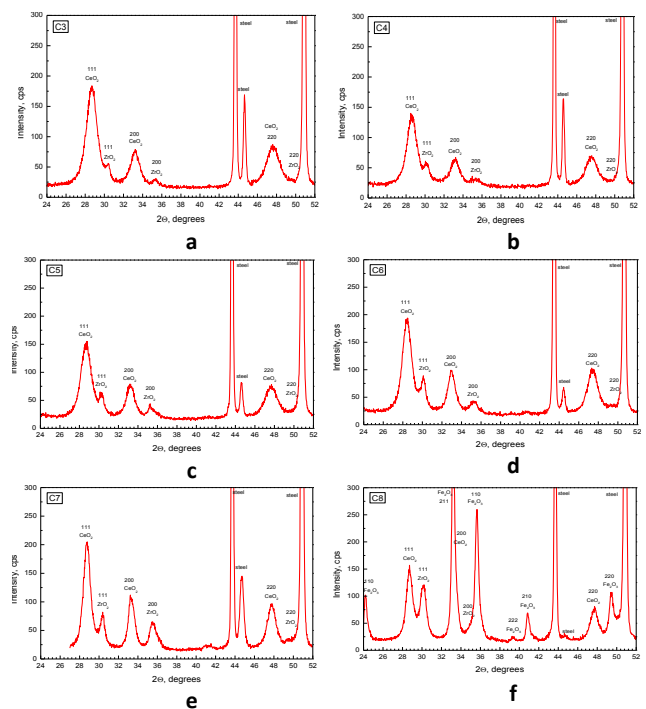


Fig. 5. X-ray diffractogram of sol gel coatings of $\text{CeO}_2/\text{ZrO}_2$.

Figure 6 shows the SEM images of the surface of the multi-grain samples after heat treatment. C3 and C4 coatings have a relatively smooth surface with the presence of microcracks (in C4 slightly more cracks due to the increased temperature of CeO_2 processing). The morphology of C5 and C6 coatings is similar. As the heat treatment temperature of the zirconia layers increased above 600°C, the morphology was seen to change and visible deep cracks formed for the ZrO_2 samples heat treated at 700°C. The sample consisting of cerium dioxide treated at 500°C and a top layer of ZrO_2 heat treated at 700°C (C8) even has areas where the coating has begun to separate from the substrate.

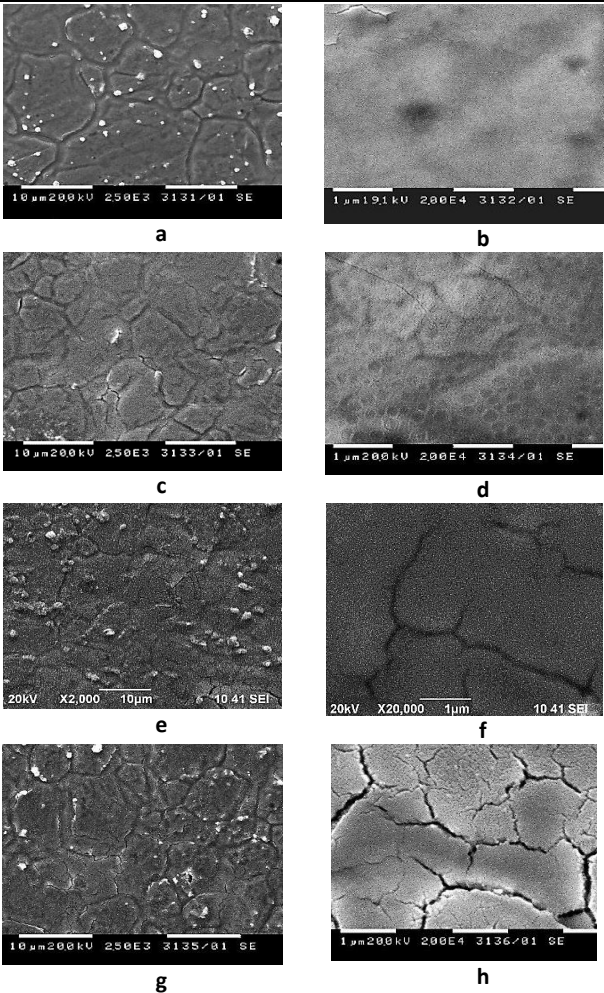


Fig. 6. Morphology of sol gel coatings from $\text{CeO}_2/\text{ZrO}_2$ – C3 (a,b); C5 (c,d); C6 (e,f) and C7 (g, h) fresh coatings.

Figure 7 shows the SEM photographs of multilayer coatings C3, C5 and C6 after 200 hours of residence in a corrosion environment of sodium chloride. From them, it can be seen that the coatings retain their characteristic surface morphology, pitting and other damaged areas as a result of corrosion not being observed.

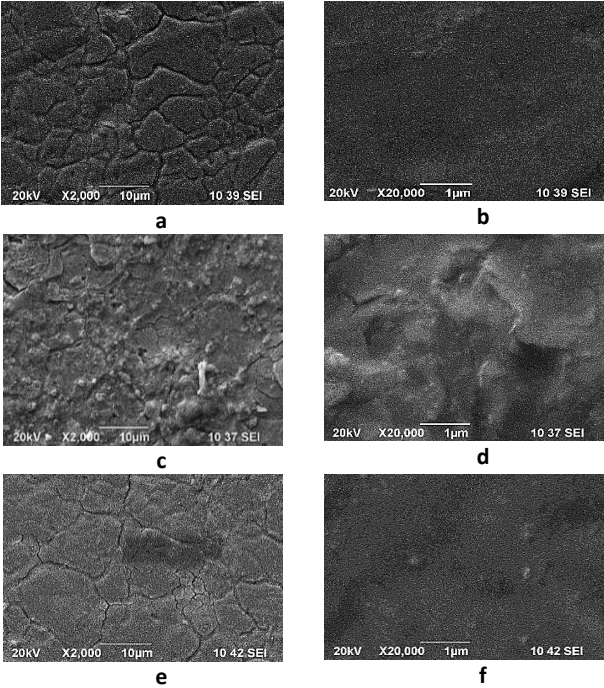


Fig. 7. Morphology of sol gel coatings of $\text{CeO}_2/\text{ZrO}_2$ – C3 (a, b) C5 (c, d) and C6 (e, f) after corrosion test.

Figure 8 shows the topography of a fresh C3 coating after heat treatment. It can be seen that the coating is dense with good adhesion, the surface is composed of many nano-sized crystals. The roughness calculated by AFM software program R_q is 9.5 nm ($R_a=7.2$ nm). After conducting a corrosion test, the sample shows a morphology with a roughness R_q is 10 nm ($R_a = 7.7$ nm) (fig. 9). Figure 10 shows the topography of coating C6, which is similar to sample C3. The surface roughness of the sample is also close: R_q is 5.4 nm ($R_a=3.7$ nm). After conducting the corrosion test, the roughness remains at the same values: R_q is 5 nm ($R_a=3.5$ nm). (fig. 11) which proves the good resistance of the coating under the influence of the corrosive environment.

Table 3 presents the data on the crystallite sizes of the two phases calculated according to Scherer's formula.

Table 3. Crystallite sizes data of the two phases (ZrO_2 and CeO_2).

Sample	Size of crystallites (nm) - phase ZrO_2	Size of crystallites (nm) - phase CeO_2
C3	16	6
C4	12	7
C5	14	6
C6	13	7
C7	15	10
C8	11	10

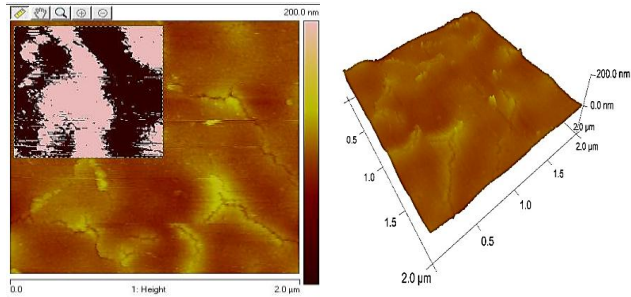


Fig. 8. Topography of $\text{ZrO}_2/\text{CeO}_2$ sol gel coatings freshly obtained - sample C3 in 2D and 3D image.

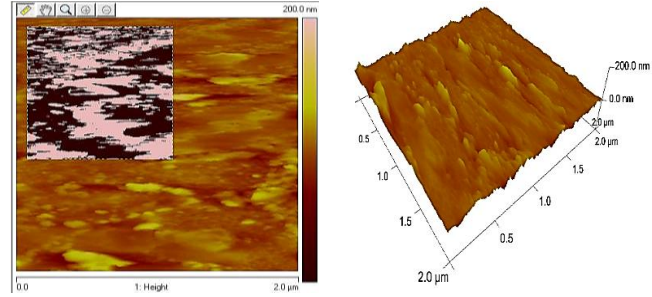


Fig. 9. Topography of sol gel coatings $\text{CeO}_2/\text{ZrO}_2$ - sample C3 after corrosion test in 2D and 3D image.

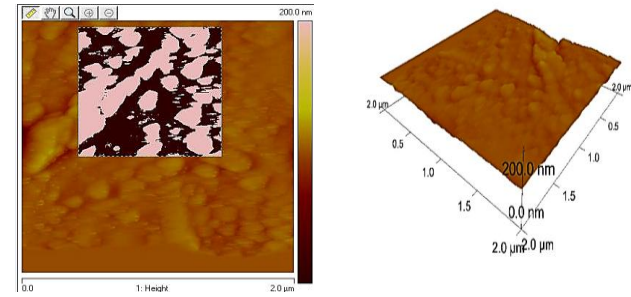


Fig. 10. Topography of sol gel coatings $\text{CeO}_2/\text{ZrO}_2$ – sample C6 freshly obtained in 2D and 3D image.

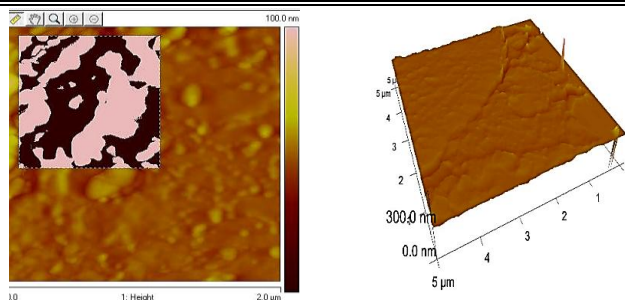


Fig. 11. Topography of sol gel coatings $\text{CeO}_2/\text{ZrO}_2$ - specimen C6 after corrosion test in 2D and 3D image.

The results of the corrosion test showed that the heat treatment of the $\text{CeO}_2/\text{ZrO}_2$ multilayer coatings definitely affects their corrosion resistance as evaluated by the weight loss.

At a lower heating temperature of the ZrO_2 layer (up to 500°C), the resistance is higher. Above this processing temperature, it decreases, which is probably due to the more pronounced crystallization of cubic zirconia. Enhanced crystallization leads to deeper and more pronounced boundaries between individual grains. This type of morphology accelerates corrosion that occurs between grains (intergranular corrosion). It is important to note that the best corrosion resistance is shown by the multilayer coating of CeO_2 heated at 300°C and ZrO_2 coating heated at 500°C . The sublayer of CeO_2 , which crystallizes in a cubic phase, influences the layer of ZrO_2 deposited on it - it is also cubic. However, the cubic phase is not characteristic of this oxide at the applied heating temperatures (up to and including 700°C , when the monoclinic phase is stable). It is known that the cubic phase has much fewer defects and is characterized by better mechanical properties than the monoclinic phase - it can be assumed that the corrosion resistance of cubic ZrO_2 is better than that of monoclinic ZrO_2 .

4. Conclusions

They have been researched - one-component coatings of CeO_2 , multilayer coatings of $\text{CeO}_2/\text{ZrO}_2$ and $\text{TiO}_2/\text{Sm}_2\text{O}_3$ by sol-gel method.

It has been proven that the surface structure strongly depends on the treatment temperature of the CeO_2 sublayer as well as the ZrO_2 coating. At lower temperatures, they are dense, with good adhesion and relatively smooth.

At a processing temperature of 500 and above 500°C of ZrO_2 coatings, the resistance in a corrosive environment decreases, which is probably due to the more pronounced crystallization of cubic zirconia, which leads to deeper boundaries between individual grains.

The protective ability of a sample with a multilayer coating of $\text{CeO}_2/\text{ZrO}_2$ is significantly better than that of a sample with only CeO_2 coating.

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Wetting coatings on TiO₂ based glasses for photovoltaic application and contact angle measurements

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Abstract: They have been conducted on ellipsometry and contact angles. The contact angles of a surface coating on glasses applied in photovoltaics were measured. This study used a DSA 100-Expert (Krüss GmbH, Germany) to measure contact angles on glass substrates. Contact angles were measured using the DSA 100-Expert tilt table accessory to identify both advancing and receding contact angles. A drop of deionized water is deposited on the glass substrate and then the table is tilted at a constant rate of 5 degrees per minute, to a tilt angle of 90 degrees.

Keywords: WETTING COATINGS, PHOTOVOLTAIC, GLASS, TIO₂

1. Introduction

The construction of solar systems with different power (for domestic and business customers) and large photovoltaic parks is a current energy alternative, in line with the trends for the use of ecological renewable energy sources [1-6]. At the same time, due to the drastic change in the geopolitical situation and the unsustainable prospects for access to conventional energy carriers, traditionally provided by large international suppliers, the role of the solar energetics is significantly increasing.

Regarding the final consumers of the generated electricity, photovoltaic plants are classified into three main categories [1,3,7]: stand-alone installations (providing power only to individual sites), solar systems connected to the National Electricity Distribution Network and combined (hybrid) installations combining the characteristics of the previous ones two.

The productivity of solar installations is determined by a variety of factors [3,7]: orientation of photovoltaic panels, impact of cyclic diurnal and seasonal weather changes, climatic specifics of the region, contamination of solar modules, etc. Main pollutants are heterogeneous local deposits, diverse fractions of dust particles [8,9] (of natural or industrial origin), products of the biological cycle of different populations, and others.

Different construction types of cleaning systems [7,8,9] (manual, automated and robotic) are used for the individual categories of photovoltaic systems. In this aspect, the use of a self-cleaning coating is considered as a promising and cost-effective approach for maintaining the solar panels in a highly efficient state [10]. Of significant interest is the development of innovative nano-sized, self-cleaning coatings [11-16], obtained by technological methods providing a long-lasting effect and high atmospheric resistance.

A self-cleaning mechanism has been discussed, which is defined as the capability to expel the contamination particles by the action of spherical water droplets [17-19]. It's proved that water contact angle is one of the significant factors to obtain self-cleaning coatings and strong anti pollution effect [20]. There are two main functional types of self-cleaning coatings: hydrophobic and hydrophilic. The main difference between hydrophobic and hydrophilic was based on the movement of water droplets. Self-cleaning hydrophobic coatings repels the present various contaminants by sliding away or rolling off the particles from its surface [21].

Hydrophobic coatings can be further classified as hydrophobic and superhydrophobic surfaces differentiated by the motion of droplets. Self-cleaning is expressed by the capability of a hydrophobic surface to wash out dust particles by the action of water droplets [17-19].

On the superhydrophobic coatings, the spherical droplets will be carrying the various contaminants away in a rolling motion, while on a hydrophobic surface, the half-spherical droplets carry the

contaminants away by sliding motion. It has been experimentally found that the rolling motion of droplets is significantly more effective to clean of the coatings than the sliding motion [11]. The hydrophobic coatings must be characterized a very high static wettability contact angle and a very low roll-off angle to obtain an effective self-cleaning mechanism [21].

Silicon dioxide SiO₂ is commonly used in the development of various hydrophobic self-cleaning functional coating for the cover glass materials. Research team [22] have obtained silica coating composed of base-catalyzed silica sol and acid-catalyzed silica sol by using dip-coating method and adequate laboratory regime of thermal treatment. The mixed silica coating exhibits suitable superhydrophobic and self-cleaning characteristics with the water contact angle of 162°. As the coating possess strong Si-OH bond, it gives strong adhesion to glass surface [21].

The existing micro and nanotextures on the hydrophobic coatings halt the expanding motion of liquid, substantially increasing the liquid droplet's contact angle [21]. Thus, the liquid droplet can immediately roll off at a higher speed for the superhydrophobic surface. Different from a hydrophilic coatings which holds back the contracting motion of the liquid and provokes the lowering in contact angle of the liquid droplet [21].

The self-cleaning mechanism of superhydrophilic coating can be initiated with or without UV light. At the same time, a self-cleaning hydrophilic coating is assisted by a photocatalysis mechanism to lowers the presence the various pollutants on the super hydrophilic surface under UV-light exposure [21]. The photocatalysis process is initiated by photocatalysts such as titanium dioxide TiO₂ (or other semiconductor materials) to generate electrons and holes and formed electron-hole pairs by absorption of UV-radiation in photocatalyst coating. In the further development of the process the electron-hole pairs then oxidize the adsorbed species on the photocatalyst [21,23,24].

The photocatalysis reaction of the obtained coating is based on the TiO₂ band where the bandgap is enough to generate more hydroxyl groups and superoxide anion for photocatalysis process [21]. The titanium dioxide is mostly applied as photocatalyst component, but its band gap energy is high which can absorb UV-radiation only. In relation to this, various modifiers such as silicon dioxide, iron, tungsten and nitrogen have been doped into the titanium dioxide materials to increase its photo-response to visible range of light.

Whereas self-cleaning mechanism without the influence of UV-light is denoted as non-photocatalyst. Superhydrophilic coating spreads the water droplet into thin-film layer of water and flow the contaminants down the water stream [25]. The superhydrophilic polymers consists of various polar functional groups such as hydroxyl, carboxyl, and carbonyl-chains. The different polar functional groups are characterized by significant attraction to water which provides the solid surface completely wetting [21].

In the present article, the results of the performed laboratory studies of experimental self-cleaning TiO_2 thin films, deposited by the sol-gel method on the glass plates are presented. Obtaining transparent self-cleaning coatings for solar panels is considered as a major possibility for potential application of the development.

2. Experimental

2.1. Materials

All compounds were supplied as analytical grades and were used without further modification. Thin film coatings are performed on glass slides from AGC Glass Europe. TiO_2 precursors and solvents were 99% titanium isopropoxide, also commonly referred to as **titanium** tetraisopropoxide or TTIP, is a chemical compound with the formula $\text{Ti}\{\text{OCH}(\text{CH}_3)_2\}_4$ /TTIP/ and 99.9% ethanol ($\text{C}_2\text{H}_5\text{OH}$), all purchased from Alfa Aesar Germany. The hydrolyzing agent is distilled water, and the stabilizer is nitric acid / HNO_3 /. Preparation of the glass substrate. Before being cleaned, the slides were cut to size (20 mm x 70 mm x 2 mm). Substrate cleaning is important prior to the deposition process, as this allows the cleaning and removal of submicron particles from the substrate surface. This is decisive for the quality of the bonding film on the substrate. The glass substrates were cleaned/washed/ in 99.9% ethyl alcohol for 15 minutes and acetone for 15 minutes and then dried for 30 minutes at 100°C . Cleaning the glass substrates improves the adhesion of the coating material to the substrate and prevents contamination on the formed coating.

Preparation of TiO_2 sol. The aim of the synthesis is to obtain coatings of TiO_2 on glass substrates applying sol-gel method. Mixture of precursor – 5 ml of 99 % TTIP and 5 ml of DEA / $\text{C}_4\text{H}_{11}\text{NO}_2$ /– was added dropwise to the acid solution, made of ethanol, water and nitric acid in a ratio of 1:1:0.5 for prevent gel formation. To ensure adequate hydrolysis, the mixture was continuously stirred at 500 rpm with a magnetic stirrer for 2 hours under air pressure to produce a pink translucent solution. Schematics of the process of obtaining a thin film of sol gel with TiO_2 . Depiction of the chemical synthesis of TiO_2 -based sol. A dip coating machine (Dip Coating technology) at a speed of 42.8 mm/min was used to deposit thin layers of TiO_2 on the substrates. A lower speed of the applied solution on the glass substrate helps the coating to be uniform, while a higher rate helps the solution to become thinner. The deposited films were then heated at a temperature of 500°C for 15 min /schema 1/.

Schema 1: Schematics of the process of obtaining a thin film of sol gel with TiO_2

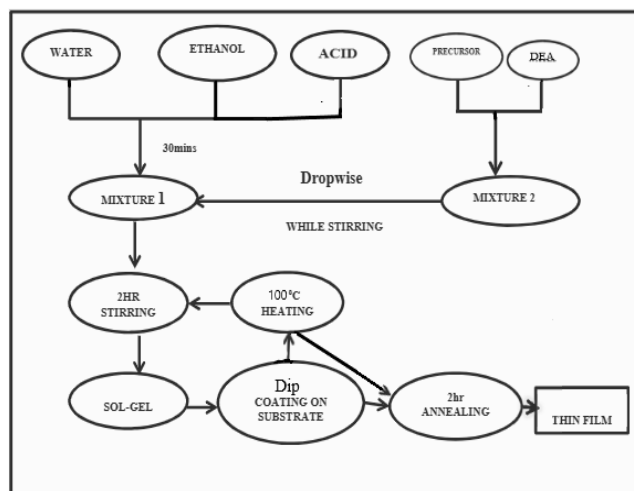


Table 1. Table for samples:

samples:	Main composition:	Drying time	T°C-treatment	Number of layers
GLS-11	TTIP	30 min	500°C- 15 min	1
GLS-12	TTIP	30 min	500°C-15 min	1

3. Result and Discussion

3.1 Contact Angle Measurements

This study utilised the DSA 100-Expert (Krüss GmbH, Germany) to measure contact angles on glass substrates. Contact angles were measured using the tilting table accessory of the DSA 100-Expert to identify both the advancing and receding contact angles. A droplet of deionised water was deposited onto the glass substrate, and the table was then tilted at a consistent rate of 5 degrees per minute, up to an angle of inclination of 90 degrees.

Each contact angle measurement was performed three times on each substrate to ensure the accuracy of the results. The advancing and receding contact angles were measured as the substrate tilted from 0 to 90 degrees. The images of the droplet at each degree of tilt were captured and subsequently processed using the DSA 100-Expert's built-in software.

Contact angle hysteresis, defined as the difference between the advancing and receding angles, was also evaluated in this study.

Sample Preparation

The glass substrates were cleaned before the experiments. The cleaning procedure involved wiping the substrates with a cloth soaked in 95% ethanol and rinse with deionised water. The substrates were then left to dry in a clean, dust-free environment. The cleanliness of the samples was confirmed through a preliminary contact angle measurement of a bare glass sample ($\theta < 10^\circ$).

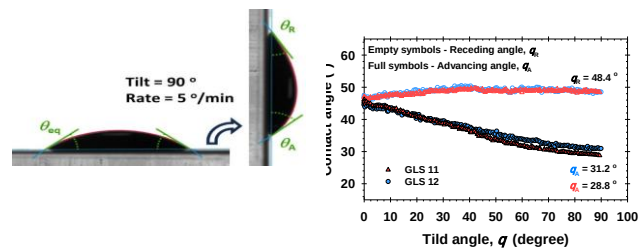


Fig. 1 . Contact angle measurements on modified glass surfaces: A) Represents the procedure of determining dynamic contact angles by tilting the optical table of the apparatus to 90 degrees. B) Illustrates the advancing and receding contact angles of a water droplet on samples GLS 11 and GLS 12. The values are calculated by taking the 2D profile of the droplet and applying the tangential method to both sides of the droplet concerning its midpoint

The receding angle of the droplet on both modifications is $\theta_R = 48.4^\circ$. The advancing angles, however, show slight differences: GLS 11 has $\theta_A = 31.2^\circ$, and GLS 12 has $\theta_A = 28.8^\circ$. Generally, differences within a 5% deviation are considered negligible in such experiments. However, the difference between the advancing angles of the modified glass surfaces approaches this value. Hence, in terms of hysteresis, it can be inferred that GLS 12 exhibits slightly higher resistance to droplet movement than GLS 11.

3.2. Ellipsometry Measurements

Ellipsometry measurements were employed in this study to determine the refractive index and thickness of the adsorbed layers on modified glass substrates. The Accurion EP4 Ellipsometer was utilised for these measurements due to its precision, accuracy, and non-destructive principle. The ellipsometer was operated in two distinct modes: Null-ellipsometry and Rotating Compensator Ellipsometry (RCE).

The measurements were made at an angle of incidence of 60 degrees, spanning a spectral range from 360 to 1000 nm. Initially, Null-ellipsometry was performed to determine the accurate refractive index of the substrate (glass) and the adsorbed layers. This mode measures the phase shift between *p*- and *s*-polarized light, providing high precision in refractive index determination.

Following the null-ellipsometry, the RCE mode was utilised to generate a thickness map of the adsorbed layers on the substrate. The rotating compensator technique allows for high-resolution measurements of amplitude and phase changes, making it particularly suitable for mapping the spatial variation in the thickness of thin films over large areas (500x500 μm).

All data obtained from these measurements were fitted using the Cauchy equation, a standard model for analysing transparent layers. The fitting process was performed using EP4's built-in software, which allows for the adjustment of multiple layers and substrates, thereby ensuring the precision and reliability of the thickness map.

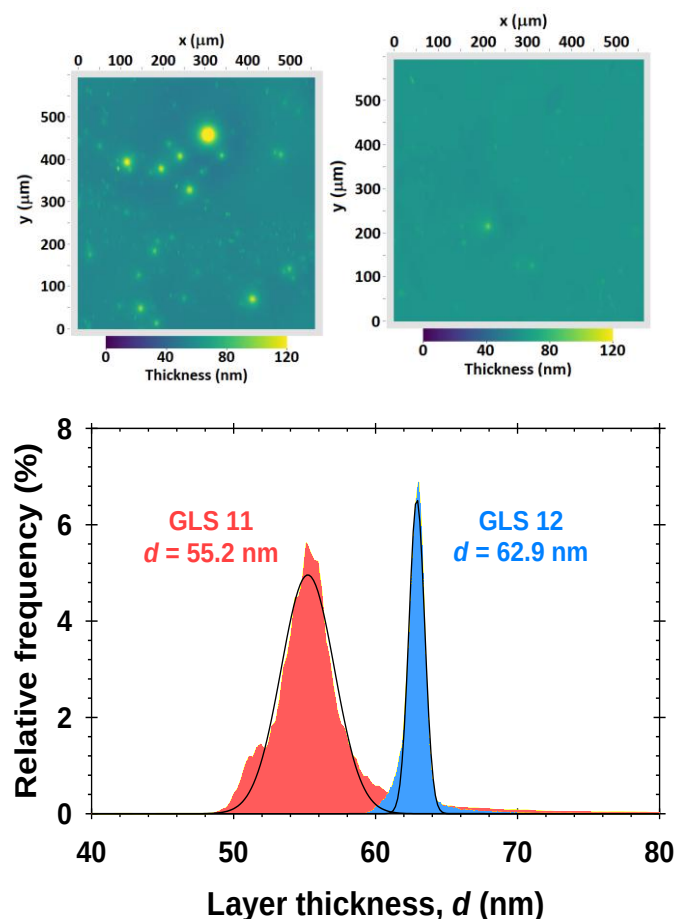


Fig. 2. Ellipsometry map images of samples: A) GLS 11 and B) GLS 12. The colour scale, ranging from 0 to 120 nm, visually represents the samples' thickness and is displayed below the images. The histogram presents the thickness distribution across the entirety of the observed area, modelled with a Gaussian fit (depicted as a solid line). The maximum point of this Gaussian fit is used to derive the thickness values displayed in the graph.

Figure 2. A displays an ellipsometry map image illustrating the thickness of the modified glass sample GLS 11. The image reveals that the procedure used to create GLS 11 results in a dense layer interspersed with hemispherical spots. The analysis of the accompanying histogram indicates a monomodal distribution of layer thickness, with a high-frequency value of 55.2 nm. The areas visible on the surface, represented in yellow, correspond to thicknesses around 100-120 nm, suggesting they are initial states for forming a double layer.

In contrast, the procedure used to produce the GLS 12 modified glass results in a uniformly dense layer with a thickness of 62.9 nm covering the entire surface (see Fig. 3B). The histogram shows that this layer displays a narrower distribution centred around the 62.9 nm mark. Additionally, the surface of GLS 12 has fewer spot inclusions than GLS 11.

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Engineered nanomaterials based on graphene oxide and their potentials for combined cancer therapies

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Abstract: Graphene oxide, owing to its unique physicochemical properties, has established itself as a versatile platform with applications ranging from drug delivery to medical imaging. The modification of graphene oxide has the potential to enhance crucial properties such as near-infrared (NIR) adsorption capacity, water dispersity, and cytotoxicity. This paper aims to discuss the potential of unmodified graphene oxide and polyethylene glycol (PEG)-modified graphene oxide nanoparticles as responsive systems to NIR in the context of combined photothermal and chemotherapy. The focus is on their application for treating colorectal and hepatocellular cancer cells, highlighting their promise in integrated cancer therapies.

Keywords: MODIFIED GRAPHENE OXIDE, PEGYLATED GRAPHENE OXIDE, PHOTOTHERAPIES, CHEMOTHERAPY, COLON 26 CELLS, HEPG2 CELLS

1. Introduction

Engineered nanomaterials (ENMs) have recently garnered significant attention for many applications, ranging from optoelectronic, electronic, cosmetic, dental bonding, and imaging to drug delivery systems [1-3]. The central focus is on certain nanomaterials like graphene oxide (GO), an oxidized form of graphene, known for its cost-effectiveness, abundance, and ease of processing [4-6]. The interest in GO is immense and comes from its unique one-atom thin sheet structure [7, 8], which ensures a high specific surface area with de-localized electrons, facilitating efficient drug loading. The heightened interest in GO is further attributed to its high content of oxygen-containing functional groups. These groups located on the edge or basal planes of the GO sheets offer high reactivity and can be easily modified for biomolecule attachment. The modifications improve the physicochemical properties of GO, such as NIR adsorption capacity, water dispersity, and drug loading/delivery capacity [9, 10]. Current literature supports that PEGylation is pivotal in mitigating the cytotoxicity of various graphene oxide derivatives while enhancing their physiological stability and pharmacokinetic properties [11-13]. Notably, GO-PEG serves a dual purpose as a photosensitizer (photothermal absorbent) in photothermal therapy (PTT) and as a drug carrier. This dual functionality positions GO-PEG as a promising candidate for the development of intelligent nanoplateforms, offering synergistic anti-cancer therapies [14].

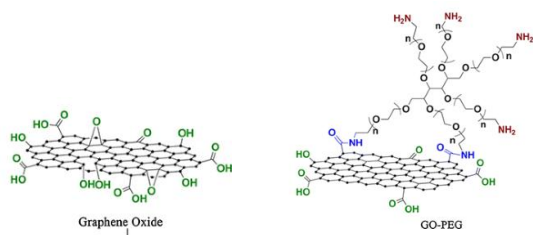


Fig. 1. Schematic illustration of graphene oxide(GO)and PEGylated graphene oxide (GO-PEG)

Consequently, we have subjected graphene oxide (GO) nanoparticles to modification using polyethylene glycol (PEG) and evaluated their biological efficacy against two different cancer cell lines: HepG2, representing hepatocellular cancer, and Colon26, representative of colorectal cancer. This evaluation was conducted following near-infrared (NIR) irradiation.

2. Experimentals

2.1 Synthesis of GOs nanoparticles

The synthesis of nano-graphene oxide (nGO) and nGO-PEG nanoparticles (NPs) followed a well-established protocol, as detailed previously [14-16]. In brief, a water solution containing GO (Graphenea, Spain) at a concentration of 1 mg/ml underwent sonication for 2 hrs at 500 W (VCX 500, Sonics and Materials, Inc., Newtown, CT, USA) in order to achieve nanosized GO.

For the preparation of nGO-PEG NPs, mPEG-NH₂ (Abbexa Ltd., Cambridge, UK) was added to nGO solution. The resulting mixture was sonicated at the same conditions for 5 min and was subsequently incubated for 22 hrs in a water bath at 70⁰ C. The resultant nGO-PEG was centrifuged to remove unbounded PEG and was then stored at 4⁰ C.

2.2. Physico-chemical characterization of GOs Nanoparticles

The average size, size distribution and zeta potential of the nanoparticles were characterized by Zetasizer, following a previously described methodology [14].

2.3. Cell culture

The mouse colorectal cancer cell line, Colon 26 and HepG2, a hepatocellular cancer cell line, were purchased from American Tissue Culture Collection (ATCC) and was maintained in DMEM medium supplemented with 10% foetal calf serum and antibiotic/antimicotic solution at 37°C in a fully humidified atmosphere at 5% CO₂.

2.4 Assessment of biological activity of GOs nanoparticles

The cells were seeded at a density of 1x10⁴ cell in 96-well plates for cell viability assessment, 1x10⁴ cell in 24-well plate for overall cell morphology evaluation, and 1x10⁵ cell in 6-well plates for cell motility assessment. The cells were allowed to incubated for 24 hrs before exposure to nanoparticles with a concentration of 100 µg/ml. At the next day the cells underwent irradiation for 5 or 15 minutes at 808 nm depending on the cell culture plate, and were subsequently stained with fluorescein diacetate (FDA) to evaluate the alteration in cell morphology as previously described [15].

Cell viability after 24 hours of incubation with nanoparticles was assessed using the WST-1 kit from Takara, following the manufacturers' instructions. For the evaluation of cell motility, a wound healing assay was conducted at the 24-hour of incubation of cells with NPs coupled with a 5 minute laser irradiation at 808 nm.



Fig. 2. A single 808 nm near-infrared light (NIR) laser system used for irradiation of cancer cells

2.5. Statistical analysis

The data presented in this article are expressed as means $\pm$ standard deviation (SD). Statistical differences between groups were determined using analysis of variance (ANOVA), and probability levels of 0.05 and 0.01 were considered to indicate statistical significance.

3. Results and Discussion

3.1. Physico-chemical properties of GOs nanoparticles

Zetasizer measurements revealed that the unmodified graphene oxide (GO) NPs exhibited a negative charge, characterized by a zeta potential value of -32.9 mV, and an average particle size of 252.7 nm (as shown in Table 1). Conversely, upon PEGylation GO NPs displayed increased dimensions of 324.6 nm, accompanied by a reduced negative charge of -21.6 mV. The observed size variations in both types of GO nanoparticles are attributed to the introduction of a larger PEG moiety (0.35 kDa). Additionally, the substitution of the negatively charged -COOH group in GO molecules with neutral PEG molecules probably contributed to the decrease in negative zeta potential

Table 1. Zeta potential and average particle size of GO and GO-PEG NPs in water solution

Type of NPs	Surface charge [mV]	Average particle size [nm]
nGO	-32.9	252.7
nGO-PEG	-21.6	324

The particle size distribution analysis indicated an increase after PEGylation, with the size distribution of nanographene oxide (nGO) particles ranging from 43.82 nm to 458.7 nm. In contrast, nGO-PEG particles exhibited a broader size range from 164.2 nm to 615.1 nm. This observation suggests that the PEGylation process led to a dispersion of sizes in the graphene oxide nanoparticles, contributing to a broader range in the distribution of particle sizes.

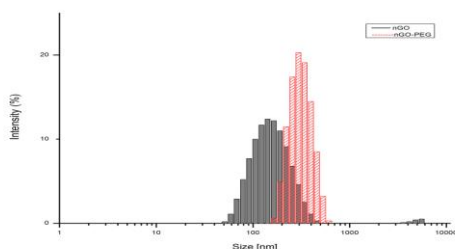


Fig. 3. Particle size distribution of nGO and nGO-PEG NPs

3.2. Biological activity of GOs Nanoparticles

The FDA staining and WST-1 assay results (see Fig.3 and Fig.4) illustrated a distinct impact of both nanoparticles, alone and in conjunction with near-infrared (NIR) irradiation, on both cell lines. In Colon 26 cells, NIR irradiation suppressed the viability of untreated and graphene oxide (GO)-treated Colon 26 cells but stimulates viability in cells treated with GO-PEG. Conversely, a slight stimulation of cell viability was observed after irradiation of control and GO-treated HepG2 cells while no noticeable effect was observed in GO-PEG-treated cells. These findings highlight the differential responses of Colon 26 and HepG2 cells to the combined influence of NPs and NIR irradiation.

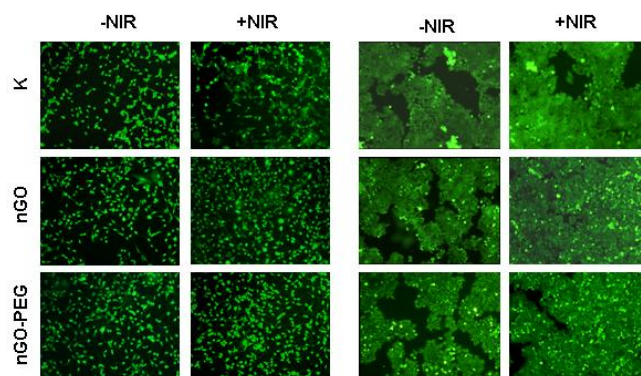


Fig. 4. FDA micrographs of Colon 26 cells (left panel) and HepG2 cells (right panel) incubated for 24 hrs with nGO and nGO-PEG NPs, and irradiated for 5 min at 808 nm; magnification 10x

An intriguing observation is that in Colon 26 cells the synergic effect of both types of GO nanoparticles and NIR irradiation closely resembles the impact observed in irradiated controls. In contrast, in HepG2 cells, the most significant inhibitory effect on cell viability was observed in non-irradiated GO-treated cells. This suggests cell-type-specific responses, indicating that the combined influence of GO and NIR irradiation may vary in its effectiveness across different cancer cell lines. Understanding these distinct responses is crucial for tailoring nanoparticle-based therapies for specific cancer types.

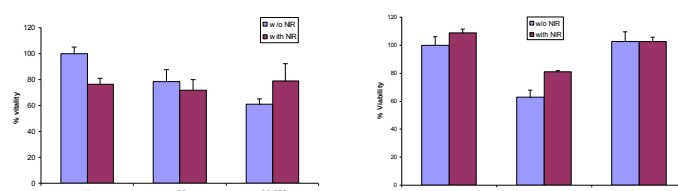


Fig. 5. Viability of Colon 26 cells (left) and HepG2 cells (right) after 24 hrs incubation with nGO and nGO-PEG NPs, followed by 5 min irradiation with 808 nm

Recognizing the crucial role of cellular migration in tumor invasion and metastasis [16], our objective was to investigate the impact of nGO and nGO-PEG, with and without near-infrared irradiation, on cell migration using the *in vitro* wound-healing assay. Both cell lines were exposed to 100 μ g/mL of nGO and nGO-PEG, incubated for 24 hrs and then subjected to 15 minutes of NIR irradiation with 808 nm. The results depicted in Fig. 5. showed the effects on cancer cell migratory capacity resulting from nanoparticle treatment alone and in combination with NIR irradiation, with evaluations conducted 24 hours after cellular incubation.

Upon assessing the combined effects of nanoparticles (NPs) and near-infrared (NIR) irradiation on Colon26 motility, the most pronounced inhibitory effect was observed in cells treated with nGO-PEG and subjected to NIR irradiation. In the case of HepG2

cells, the analysis of wound healing results unveiled a more robust inhibitory effect of both NPs compared to the untreated control.

These findings underscore the differential impact of NPs and NIR irradiation on the motility of Colon26 and HepG2 cells, emphasizing the importance of considering cell-type-specific responses in therapeutic applications.

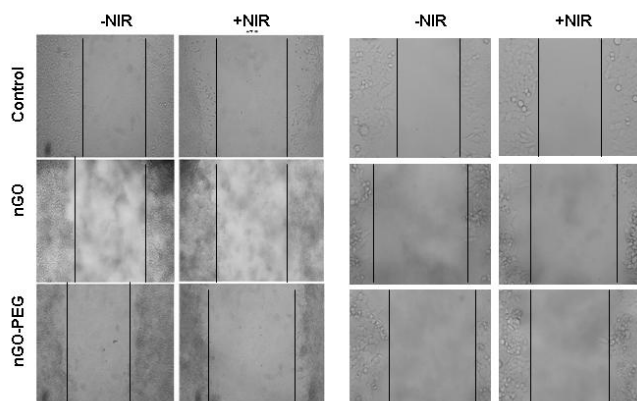


Fig. 5. Wound closure of Colon 26 cells (left panel) and HepG2 cells (right panel), after 24 hrs incubation with nGO and nGO-PEG NPs, followed by 15 min irradiation with 808 nm, magnification 10x

4. Conclusions

In summary, our findings indicate that unmodified (nGO) and PEGylated nano-graphene oxide (nGO-PEG) nanoparticles exhibit varying potential for cancer treatment, depending on the specific type of cancer cells under consideration. The differential responses observed underscore the importance of tailoring nanoparticle-based therapies according to different cancer cell types' distinct characteristics and behaviors. This insight contributes to a nuanced understanding of the applicability and effectiveness of nGO nanoparticles in the context of cancer treatment strategies.

5. Acknowledgements

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Investigation of Tribological Parameters of 3D Printed Samples

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Abstract: The present paper focuses on the investigation of the tribological processes of EasyFil HIPS (Dark Blue) in interaction with other materials used for 3D printing. A comparative analysis was made of the interaction with other widely used materials for 3D printing - PLA, PETG, CARBON, Steel Fil, TPU, Flex, Vero white. The interaction of rolling friction, sliding friction and restitution is investigated.

Keywords: 3D PRINTING, 3D MODELING, SLIDING FRICTION, RESITUTION COEFFICIENT, ROLLING FRICTION.

1. Въведение

Нарастването на интереса в индустрията към използването на 3D печата като средство за изработване на множество елементи и части, кара изследователите да проучват надеждността на своите продукти, включително запазване на културното наследство в многобройни реализации [1, 2, 3]. Износоустойчивостта е от изключително значение за производството, затова се налага анализ на трибологичните процеси, настъпващи в 3D отпечатани проби и детайли. Въпреки това, трибологията на 3D отпечатаните обекти досега не е била широко разглеждана. Настоящото изследване е сред първите, които разглеждат как трибологичните качества на 3D отпечатани полимери се влияят при взаимодействие помежду им. За тази цел се използва технология за моделиране на отлагане (FDM) за производство на трибологични образци за изпитване [4, 5, 6].

2. Материали

Моделирането и отлагането на разтопена нишка материал (FDM) е процес, базиран на екструзия, при която материалът се насочва селективно през дюза [4, 6]. Процесът започва от 3D цифров дизайн, който може да бъде получен от CAD софтуер. Тази 3D геометрия се трансформира в команди за движение, идентифицирани като G-код. Командите са съвместими с електрониката за управление на машината. Чрез използването на екструдер върху печатната платформа се отлага термопластична нишка. Двумерен слой се създава върху друг, произвеждайки осезаем триизмерен елемент. 3D принтерите, базирани на FDM техниката, понастоящем са най-разпространените принтери за отпечатване на полимери и полимерни композити на потребителско ниво [7, 8]. Материалите използвани в изследването са HIPS и взаимодействащите му в изследването - PLA, PETG, CARBON, Steel Fil, Steel, Flex, Vero white, TPU.

HIPS е удароустойчив полистирол, който е широко признат като лек и универсален материал, който служи за съпорт с цел да бъде разтворима поддържаща структура за модели, изработени от ABS. HIPS е много популярен материал в областта на 3D печата поради своята гъвкава природа и уникални свойства. Материалът е направен от полистирол, синтетичен полимер, използван в много домакински предмети. HIPS се произвежда чрез екструзия, при която нишката се нагрява и разтопява, екструдира се през дюза, за да се създаде желаната форма слой по слой. HIPS е твърд, издръжлив и устойчив на удар [10,11]. За да се принтира успешно EasyFil HIPS, съгласно инструкциите на производителя, е необходимо да се загрее печатащата глава до 220-260°C и печатното легло до 90-110°C с охлаждане 0-30%. Проучването установи оптималните параметри, необходими за отпечатване на материала и произведе отпечатани проби като плочка 120x60x10, плочка 60x60x10 и сфера 9 mm.

3. Коефициент на триене при търкаляне

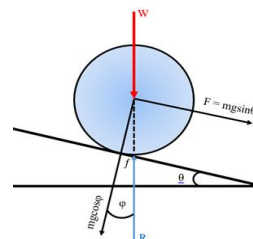
Триенето е вид съпротивление от механична гледна точка, което възниква, когато едно тяло се преобърне по повърхност. Това явление не може да бъде обяснено с абсолютния твърд модел, който разглежда контакта между сфера и повърхност като точка, т.е. изключва деформации в контактът. Трибологията разглежда контакта не в една точка, а наличието на контактна зона с разпределение на нормалните напрежения по посока на движението [5, 11]. Когато сфера е върху наклонена повърхност, нормалната сила варира в зависимост от косинуса на ъгъла между масата и посоката, перпендикулярна на повърхността, както е записано в (1):

$$Fr\theta = fW\cos\theta \quad (1)$$

Където:

F_г е силата на триене при ъгъл θ;

θ е ъгълът на наклона;



Фиг. 1 Диаграма на триене при търкаляне



Фиг. 2 Снимки от експеримента по намиране на коефициент на триене при търкаляне

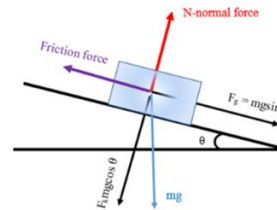
В хода на изследването се поставиха (9mm) сфери от 6 различни материала върху повърхността на плочка (120x60x10) EasyFil HIPS. На фиг. 2 са показани снимки от експеримента с всеки отделен материал - PLA, PETG, Carbon, Steel fill, Vero white и Steel. В таблица 1 са изложени резултатите от изследването, където са осъществени по 3 опита с всеки един материал и е представена средната стойност на коефициент на триене при търкаляне. Установява се, че при взаимодействието на HIPS с PETG имаме най-висок коефициент на триене при търкаляне (0,31344), а най-малък със Steel (0,179604).

Таблица 1: Резултати от коефициент на триене при търкаляне.

Материал	Ъгъл на триене, θ°	Ъгъл на триене, θ rad	Коефициент на триене при търкаляне, $\sin \theta^\circ$
Hips 1	6,33	0,110479	0,110255
Hips 2	7,94	0,138579	0,138136
Hips 3	17,21	0,300371	0,295875
avg	10,49333	0,183143	0,182121
PLA 1	11,95	0,208567	0,207058
PLA 2	15,51	0,270701	0,267407
PLA 3	18,04	0,314857	0,309681
avg	15,16667	0,264708	0,261628
PETG 1	16,53	0,288503	0,284517
PETG 2	18,29	0,319221	0,313827
PETG 3	19,98	0,348717	0,341692
avg	18,26667	0,318813	0,31344
Carbon 1	10,59	0,18483	0,18378
Carbon 2	15,19	0,265116	0,262021
Carbon 3	17,63	0,307702	0,302869
avg	14,47	0,252549	0,249873
Steel fill 1	13,74	0,239808	0,237516
Steel fill 2	21,64	0,377689	0,368774
Steel fill 3	10,45	0,182387	0,181377
avg	15,27667	0,266628	0,26348
Vero white 1	14,06	0,245393	0,242938
Vero white 2	6,99	0,121999	0,121696
Vero white 3	12,15	0,212058	0,210472
avg	11,06667	0,19315	0,191951
Steel 1	8,16	0,142419	0,141938
Steel 2	9,21	0,160745	0,160053
Steel 3	13,67	0,238587	0,236329
avg	10,34667	0,180583	0,179604

4. Коефициент на триене при търкаляне

В трибологията триенето се разграничава в три кинетични състояния на трибосистемата "тяло-антитяло": триене в покой (статично триене), триене при прехода от покой към движение и триене в движение. Многобройни изследвания през 30-те години на миналия век показват, че в преходното състояние на системата от почивка до движение, възниква сила на триене, придружена от микроизмествания в контактните петна. Тя може да се каже категорично, че статичното триене е сложно гранично условие на трибосистемата, която се характеризира със статична сила на триене, статичен коефициент на триене, непълен ъгъл на триене и контакт микроразмествания. Феноменът на предварително изместване на контактното тяло беше първо създадена през 1926 г. едновременно и независимо от двама учени А. Верховски (СССР) и Ранкин (Англия). Предразположението е от голямо значение не само за разкриване на същността на явление на триене, но също и в техниката в случаите, когато се използва външно триене за предаване движение, например, режимът, в който работят задвижващите колела на превозните средства. Предварителното движение е от съществено значение за точното позициониране на инструменти, габарити и елементи. За метални повърхности тя варира от 0,1 до 40 μm в зависимост от грапавостта им, физичните им свойства и продължителността на стационарния контакт. Оповърхност, наклонена под ъгъл θ (водач), който е в състояние на видим покой (фигура 1). Силите, действащи на трибосистемата образуват статична нула и равновесните условия са представени от уравненията: [11 - 21]

**Фиг. 3** Диаграма на свободно тяло, подложено на триене, докато се плъзга по наклонена повърхност

- Силата на кинетичното триене се определя от формулата:
- $$F_k = \mu_k \cdot N \quad (2)$$

Където:

- F_k , е силата на кинетичното триене;
- μ_k е коефициентът на кинетично триене;
- N е нормалната сила.

Когато към тяло се приложи външна сила, неговото ускорение надолу по наклонена повърхност се определя чрез сравняването му със силата на кинетичното триене, действаща върху блока. Ако външната сила надвишава силата на триене, тялото ще се ускори надолу, докато ако силата на триене е по-голяма, тялото ще се забави и в крайна сметка ще спре. Това основно правило е в съответствие с първия закон на Нютон за движението (инерцията), който гласи, че обект с ненулева нетна сила, действаща върху него, ще изпита ускорение. В случаите, когато няма налична обща сила, като например когато силата на кинетичното триене е равна на външната сила, блокът ще поддържа постоянна скорост и ще продължи да се движи надолу по наклонената повърхност без ускорение. Тези принципи могат да бъдат визуализирани чрез диаграмата на свободното тяло на фигура 3.

Компонентът на силата на гравитацията в посоката на наклона се дава от [11]:

$$F_g = mgsin\theta \quad (3)$$

Където:

- m е масата на блока,
- g е гравитационното ускорение,
- θ е ъгълът на наклона.

Нормалната сила (перпендикулярна на повърхността) се дава от:

$$N = mgcos\theta \quad (4)$$

Следователно, тъй като силата на триене се противопоставя на движението на блока:

$$F_k = \mu_k \cdot mgcos\theta \quad (5)$$

За да се изчисли коефициента на кинетично триене върху наклонена равнина, трябва да се установи точката, в която успоредната сила, упражнена върху блока, е еквивалентна на перпендикулярната сила. Това се случва, когато блокът е под фиксиран ъгъл θ и се движи с постоянна постоянна скорост:

$$\Sigma F = ma = 0 \quad (6)$$

$$F_k = F_g \text{ or } \mu_k mgcos\theta = mgsin\theta \quad (7)$$

От горните уравнения следва:

$$\Sigma \mu_k = mgsin\theta / mgcos\theta = \tan\theta \quad (8)$$

където θ е ъгълът, под който блокът започва да се движи с постоянна скорост [12].

На фиг.4 са показани снимки от проведения експеримент за намиране коефициент на триене при плъзгане. Използвани са 8 проби 60x60x10 от различни материали (Hips, PLA, PETG, Carbon, Steel fill, Vero white, Flex, TPU), плъзгани по плочка 120x60x10 Hips.



Фиг. 4 Снимки от експеримента за намиране коефициент на триене при плъзгане

Таблица 2: Резултати от експеримента за намиране коефициент на триене при плъзгане.

Материал	Ъгъл на триене, θ°	Ъгъл на триене, θ rad	Коефициент на триене при плъзгане, $\tan \theta^\circ$
Hips 1	25,61	0,446979	0,479334
Hips 2	24,91	0,434762	0,464397
Hips 3	23,01	0,4016	0,424681
avg	24,51	0,42778	0,455937
PLA 1	26,04	0,454484	0,488597
PLA 2	28,2	0,492183	0,536195
PLA 3	31,41	0,548208	0,610642
avg	28,55	0,498292	0,544086
PETG 1	24,07	0,420101	0,446693
PETG 2	21,78	0,380133	0,399567
PETG 3	20,92	0,365123	0,382263
avg	22,25667	0,388452	0,409247
Carbon 1	25,38	0,442965	0,474407
Carbon 2	28,41	0,495848	0,540924
Carbon 3	26,48	0,462163	0,498146
avg	26,75667	0,466992	0,504187
Steel fill 1	21,98	0,383623	0,40362
Steel fill 2	27,79	0,485027	0,527017
Steel fill 3	31,28	0,545939	0,607532
avg	27,01667	0,47153	0,509892
Vero white 1	30,35	0,529707	0,585524
Vero white 2	31,01	0,541227	0,601098
Vero white 3	29,03	0,506669	0,554994
avg	30,13	0,525868	0,580379
Flex 1	46,49	0,811404	1,053412
Flex 2	47,27	0,825017	1,082552
Flex 3	50,38	0,879297	1,207934
avg	48,04667	0,838573	1,112433
TPU 20% 1	24,43	0,426384	0,454252
TPU 20% 2	25,63	0,447328	0,479764
TPU 20% 3	25,57	0,446281	0,478476
avg	25,21	0,439998	0,470777

5. Реституция

Коефициентът на възстановяване (реституция) се използва, за да се демонстрира скоростта на разсейване на енергия, включваща сблъсъци на повърхности, най-често сфера. Степента на възстановяване зависи от много елементи, като например геометрия на телата в контакт, скоростта на приближаване, свойствата на материала, продължителността на контакта, и всяко триене. Коефициентът се определя, като се вземат предвид височините преди и след въздействието. Свободно падаща сфера се освобождава от височина 650 mm (фиг.5).

Сферата на HIPS, която е 9 mm, пада върху плоча на HIPS с размери 60x60x10 mm, след което отскокът се записва с помощта на високоскоростна камера NAC MEMRECAM HX-6 [21], [23]. По същия начин се извършват и експериментите за взаимодействие с останалите материали където сфери (9 mm) от тях падат над плочка HIPS(60x60x10 mm).

За намирането на коефициента на възстановяване се извършват по 3 експеримента с всеки отделен материал и е взета средната стойност. Получените резултати от

коефициентът на реституция се използва формулата [18], [24], [26]:

$$e = \frac{v_2}{v_1} = \left(\frac{h_2}{h_1} \right)^{\frac{1}{2}} \quad (9)$$

където:

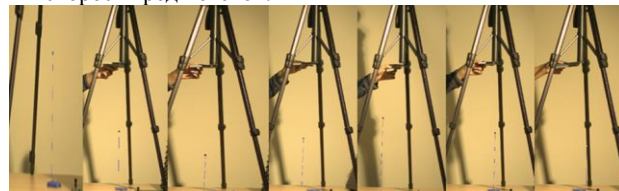
e - коефициент на възстановяване;

v_2 - скорост след отскок;

v_1 - скорост преди отскок;

h_1 - височина преди отскок;

h_2 - скорост преди отскок.



Фиг. 5 Снимки от експеримента за намиране коефициент на реституция

Таблица 3: Резултати от коефициент на възстановяване SQRT D/C.

Материал (Основа/Сфера)	№	Начална височина [mm]	Височина на отскока [mm]	D/C	е-Коефициент възстановяване SQRT D/C
Hips/Hips	1	650	320,41	0,492938	0,702096
	2	650	94,47	0,145338	0,381233
	3	650	67,65	0,104077	0,32261
	avg	650	160,8433	0,247451	0,497445
Hips/Carbon	1	650	281,9	0,433692	0,658553
	2	650	250,34	0,385138	0,620595
	3	650	238,13	0,366354	0,605272
	avg	650	256,79	0,395062	0,628539
Hips/PETG	1	650	180,97	0,278415	0,527651
	2	650	234,41	0,360631	0,600525
	3	650	369,51	0,568477	0,753974
	avg	650	261,63	0,402508	0,634435
Hips/PLA	1	650	255,67	0,393338	0,627167
	2	650	293,08	0,450892	0,671485
	3	650	315,73	0,485738	0,696949
	avg	650	288,16	0,443323	0,665825
Hips/Steel	1	650	354,57	0,545492	0,738575
	2	650	313,39	0,482138	0,694362
	3	650	339,75	0,522692	0,722975
	avg	650	335,9033	0,516774	0,71887
Hips/Steel fill	1	650	277,17	0,426415	0,653005
	2	650	313,43	0,4822	0,694406
	3	650	248,4	0,382154	0,618186
	avg	650	279,6667	0,430256	0,655939
Hips/Vero White	1	650	208,98	0,321508	0,567016
	2	650	268,56	0,413169	0,642782
	3	650	171,42	0,263723	0,51354
	avg	650	216,32	0,3328	0,576888

5. Бъдещи стъпки

Получените данни от лабораторните експерименти могат да бъдат използвани за моделирането на симулационни модели, с които да се получат точни резултати при симулациите [26]. Друг аспект, в който могат да бъдат използвани тези данни е теоретично и експериментално определяне обороти на мелници, включително изследване на иновативни мелещи среди, [27, 28].

6. Заключение

От направеното изследване на коефициента на триене при търкаляне, плъзгане и реституция. Изследването на образците установи, че при взаимодействие за намиране на коефициента на триене при търкаляне върху проба EasyFil Hips (120x60x10) с PETG (сфера, 9mm) има най- висок коефициент на триене при търкаляне (0,31344), а най-малък със Steel (0,179604). От проведените експерименти значително по-висок коефициент на триене при плъзгане има между Hips и Flex (1,112433), а най-нисък коефициент имаме във взаимодействието на Hips с PETG (0,409247). Данните от изследването на реституция при взаимодействие на Hips с други 3D отпечатващи материали показва основа Hips и сфера Steel (0,71887), което показва най-голям коефициент на възвръщаемост спрямо останалите материали, а най-малък коефициент има при основа Hips и сфера Hips (0,497445).

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Innovative Construction Methods Based on 3D-Printing Smart Home Technologies

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Abstract: This article describes the advent of 3D-printed buildings in combination with smart technologies technologies involving the integration of artificial intelligence (AI) and the Internet of Things (IoT). The building construction progress over the years determines human development. The evolution of living spaces through the ages has changed homes from shelters to comfortable living areas called homes. The specialized 3D printer designed for building construction at an affordable price serves as an engine of this change, introducing humanity into a revolutionary phase. This wide-ranging experiment creates the intersection of smart technologies and 3D printing, revealing their potential for reconciliation and redefining the concept of home.

Keywords: 3D-PRINTING, SMART HOME, INTERNET OF THINGS, ARTIFICIAL INTELLIGENCE

1. Въведение

Преходът към тези технологии е доказателство за човешкия стремеж към непрекъснато усъвършенстване и адаптиране. В исторически план, от глинени колиби до тухлени къщи, стремежът винаги е клонял към оптимизираме условията на живот. Сега, на прага на ера, доминирана от технологичния напредък, е ясно, че домовете ще бъдат нещо повече от жилищни пространства. Те се създават да бъдат взаимосвързани екосистеми, проектирани прецизно и съобразени с индивидуалните нужди. Тази симбиоза между традиционното строителство и най-съвременните технологии предвещава бъдеще, в което домовете са ефективни, устойчиви и преди всичко интелигентно интегрирани.

Преди няколко десетилетия 3D принтирането се появява като нова концепция, обещаваща да бъде едно от най-трансформиращите технологични постижения в производството, културното наследство, производство на детайли и др. [1-3]. Първоначално използвано за прототипи в малък мащаб, приложенията му бързо набират широка популярност. С разпространението на нови материали и усъвършенстването на техниките за печат, неговият потенциал вече е ясен [4]. Днес това не е просто нова технология за производство, а революционен метод, позволяващ създаването на цели структури (Фигура. 1).



Фигура 1. 3D – принтиране на сграда

Бързото строителство, значителното намаляване на разходите и несравнимата свобода на проектиране са основните предимства на 3D-технология в сравнение с традиционните строителни методи. Освен това тези домове могат да бъдат персонализирани до най-малкия детайл, като се гарантира, че всяка сграда отговаря на индивидуалните предпочитания.

Някога считани за недостижима цел, интелигентните домове сега са неизбежна част от модерното строителство. Това е факт благодарение на бързия напредък в новите производствени технологии. Вдъхновени от най-новите тенденции в строителството, тези домове са символ на модерността. От

автоматизирани системи за осветление, които се настройват според времето, до адаптивен климатичен контрол и от интелигентни решения за сигурност до удобства, активирани с глас – тези домове предефинират лукса и функционалността. Освен непосредствената привлекателност на удобството, те също предлагат подобрена енергийна ефективност, оптимизиране на използването на ресурсите и намаляване на въглеродният отпечатък върху околната среда. Тъй като технологията продължава да се развива, интегрирането на изкуствен интелект (AI) и интернет на нещата (IoT) гарантира, че тези домове не само отговарят на команди, но учат и предвиждат нуждите на своите обитатели, оформяйки бъдеще на интуитивен живот.

2. Информация за технологията и материалите за 3D печат

Началото на всеки проект, свързан с 3D - печат е 3D цифров модел, който може да бъде създаден с помощта на различни 3D - софтуерни програми. След това моделът се трансформира слоеве, като по този начин дизайнът се преобразува във файл, който може да се чете от 3D принтер. Материалът, обработен от 3D - принтера, след това се наслоява според зададения дизайн. Съществуват редица различни видове технологии за 3D - принтиране, които използват разнообразни материали по различни начини за създаване на крайния обект., такива са:

- пластмаси
- метали
- керамика
- пясък.

Всеки от различните видове 3D принтери използва различна технология, която обработва различни материали по различни начини. Подобна техника за 3D печат е селективното лазерно синтероване (SLS) - този лазер се използва за стопяване на частици прах заедно, за да се създаде обект. Материали използвани в SLS технологията обикновено имат висока якост и гъвкавост. Най-популярните са найлон или полистирен [4]. Наличните материали за 3D печат са изминали са се усъвършенствали с течение на времето. Вече има голямо разнообразие от различни видове материали, които се доставят в различни състояния (прах, нишка, пелети, гранули, смола и т.н.). За специфичните платформи се разработват материали със свойства, подходящи за конкретните приложения. Найлонът или полиамидът обикновено се използва в прахообразна форма в комбинация с процеса на синтероване (термична обработка, използван за превръщане на прахообразни материали в твърда маса, без да се достига до точката на пълно топене) или под формата на нишка в комбинация с процеса на моделиране на разтопено отлагане-FDM (нишката обикновено се нагрява до разтопено състояние и след това се екструдира през дюзата на 3D принтер). Това е здрав, гъвкав и издръжлив пластмасов материал, който се оказва надежден за 3D печат. Акрилонитрил бутадиен стирен (ABS) е друга често срещана пластмаса, използвана за 3D печат, и се

използва широко в базовите FDM 3D принтери под формата на нишка. Това е здрава пластмаса и се предлага в широка гама от цветове.

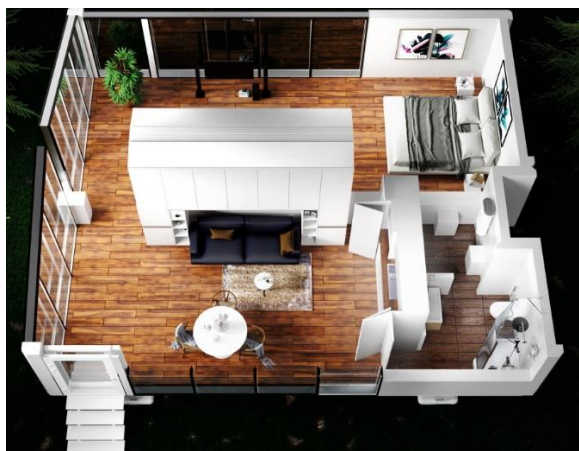
Полимлечната киселина или полилактидът (PLA) е биоразградим пластмасов материал, който е популярен в 3D принтирането поради тази причина. Може да се използва във формата на смола за процеси на лазерна стереолитография (SLA) и цифрова обработка на светлината (DLP), както и под формата на нишка за FDM процеса. Предлага се в различни цветове, включително прозрачни, което се оказва полезна опция за някои приложения на 3D печат. Той обаче не е толкова издръжлив или толкова гъвкав като ABS. LayWood е специално разработен материал за 3D печат за начално ниво на екструдирание от 3D принтери. Предлага се под формата на нишка и е композит от дърво/полимер [6].

2. Интегриране на интелигентни технологии в 3D-отпечатани домове

Задълбочавайки се в примери за производствена технология, става очевидно, че ефективността се увеличава чрез цялостна интеграция. 3D - принтирането улеснява строителния процес. Вместо конвенционалния метод за изграждане на структура и след това монтиране на технологични компоненти, 3D - отпечатаните домове интегрират технологии от етапа на планиране.

Такъв синергичен подход елиминира излишните стъпки, рационализира процеса на изграждане и осигурява хармония между физическата структура и вградените в нея технологии. Всеки ъгъл, всяка стена и всяка част от къщата могат да бъдат в обща концепция с мисълта за технологията. Това води до подобрена производителност, намалени системни сблъсъци и гарантира безпроблемна дългогодишна експлоатация. С навлизането на усъвършенстваните материали, които служат за двойни цели като стени или подове, абсорбиращи слънчева светлина, с вградени отоплителни системи, бъдещият дом се превръща в иновативно решение.

В световен мащаб симбиотичната комбинация от 3D - принтиране и интелигентни технологии в жилищното строителство не е просто теория, а реалност. Примери могат да се намерят вече в редица места по света. Всяка къща, построена с помощта на достъпен широкоформатен 3D принтер, може да се похвали с интегрирани сензори за оптимално използване на енергията, гласово управлявани комунални услуги и интуитивни системи за сигурност. Това не са просто къщи, а интерактивни жилищни пространства, които се адаптират и отговарят на нуждите на своите обитатели (Фигура 2).



Фигура 2. Интелигентно оборудван 3D – принтиран дом

Разработени са обществени проекти, използващи 3D - печат за създаване на устойчиви, интелигентни достъпни домове, с цел да се покаже, че иновациите могат да бъдат както авангардни, така и приобщаващи, обслужващи различни демографски и

икономически слоеве. Тази глобална тенденция подчертава трансформиращата сила и обхвата на комбинирания технологичен напредък (Фигура 3).



Фигура 3. 3D – принтирана къща

3. Екологични и икономически ползи

Комбинацията от 3D - печат и интелигентна технология води до устойчиво бъдеще. Изграждането на домове с широкоформатен 3D - принтер минимизира отпадъците, тъй като материалите се използват с висока прецизност. Когато това се съчетае с възможностите на интелигентните технологии за пестене на енергия, се създава решение за екологичен живот. Освен това, модулният характер на 3D отпечатаните компоненти означава по-малко емисии, свързани с транспорта, тъй като големи части могат да бъдат отпечатани на място, вместо да бъдат изработени предварително на друго място и в последствие изпратени с помощта на допълнителна транспортна техника. Намаленото време за изграждане също се изразява в по-малко работни часове, намалявайки разходите. Освен това, с новите технологии в производството, които се развиват с бързи темпове, общите разходи се очаква да намалят. Тази комбинация от опазване на ресурсите и финансова жизнеспособност показва, че иновациите не трябва да бъдат компромис. В резултат на това авангардният и устойчив начин на живот може скоро да стане икономически достъпен за по-широк кръг от хора. [7]

4. Перспективи в 3D – технологии в жилищното строителство

Възможностите в бъдещото жилищно строителство нарастват с напредъка в производствените технологии. Скоро може да се видят домове, които автономно откриват и ремонтират износването на стени с материали, които адаптират цвета си според настроените на обитателите, или дори свръхэффективни енергийни системи, които преразпределят мощността въз основа на нуждите в реално време или самоподдържащи се домове, които използват възобновяема енергия, съхраняват излишната енергия и дори я споделят със съседни структури, създавайки една наистина взаимосвързана общност. Усъвършенстваните сензори могат да наблюдават качеството на въздуха в помещенията и да го коригират за постигане на подходящ микроклимат (Фигура 4).



Фигура 4. Иновативен дизайн на 3D – принтиран дом [8]

Тъй като 3D - печатът се съвместява добре с интелигентните технологии, можем да очакваме промяна в начина, по който възприемаме градското развитие, проправяйки пътя за градове, които са не само умни, но адаптивни и футуристични.

5. Бъдещи предизвикателства

Както при всяка нова технология съществуват известни предизвикателства. Едно от тях е сложното комбиниране на фундаментна конструкция с високотехнологични технологии, осигуряващи издръжливост и функционалност. Съществува и евентуален риск за поверителността на данните във взаимосвързани домове. Интелигентният дом, въпреки цялата си привлекателност, трябва да даде приоритет на защитата на потребителските данни. Освен това от решаващо значение е тези домове да останат приобщаващи, като се гарантира, че дизайнът им е интуитивен и удобен за потребителя през поколенията.

6. Заключение

Сливането на 3D - печат и интелигентни технологии не е просто еволюция, а революция. Докато технологията на производство води към бъдеще, изпълнено с възможности, тя привлича строители, любители на технологиите и потенциални собственици на жилища да бъдат активни участници в оформянето на тази трансформираща ера. Домовете на бъдещето няма да бъдат просто направени от тухли и хоросан, но ще бъдат изградени от интелигентност и иновация.

Тези решения обещават не само естетически и функционални подобрения, но и по-широки ползи за обществото като екологичност, достъпност и приобщаване. Освен това, тези иновации стоят като свидетелство за човешката изобретателност и желанието да подобрим живота си. Тъй като технологичните граници продължават да се разширяват и приоритетите се променят, можем да очакваме създаване на изцяло нова екосистема.

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Classification of variants of suspended ropeways lines

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Abstract: In the present work, a classification of the suspended ropeways has been made according to purpose and structural composition feature. They are mainly chair and cabin aerial ropeways. The structure of passenger ropeway structures and the standards they must meet are described in more detail. The chemical composition of the ropes, the types of tangles and the standards for their production, maintenance and operation are specified. The classification made gives a multi-criteria optimization, which aims to support the choice in the design of ropeways.

Keywords: ROPEWAY, SEAT LINES, CABIN LINES, ROPES

1. Introduction

Suspended ropeways lines (SRL) are increasingly used for transporting passengers and cargo. It's no longer just skiers and snowboarders who rely on the gear to transport them from place to place. Ropeways are increasingly being used and are individually in demand for other purposes as well, including transporting people to tourist attractions, transporting bicycles and other cargo, and transporting passengers in cities. Each suspended ropeway is individual and unique and meets the individual requirements according to its purpose [1]. They are used for: our amusement parks, fairs, sports and tourism events, but they are above all a mountain facility for overcoming great distances and heights. They offer excellent conditions for winter sports such as local and national competitions, European and world Olympics. Winter sports are: alpine skiing, snowboarding, cross-country skiing, ski jumping and other ski sports, as well as for hiking, with provided joint sports-tourist bases, complexes, rest stations, hotels, resorts, etc. Excellently built and maintained are ski slopes and other ski facilities providing exceptional opportunities with extreme riding. Ski seasons usually run from mid-December to early April in the mountain resorts in Bulgaria. The climate is moderate, the winter is mild with a lot of snowfall. The average monthly temperature in January is about 4.8 degrees. Mountain routes for extreme cycling during the warmer months of the year have been developing more and more lately.

The purpose of the present work is to make an attempt to classify the types of suspended ropeway lines according to their purpose and according to their structural composition.

2. Classification of types of suspended ropeways

2.1. By purpose

A wide range of metal powders (from light alloys through steels to super-alloys and composites) is currently available for DMLS process and other new materials are under development [2-4]. Table 1 lists mechanical properties of selected powder materials, fig. 1. After summarizing the exploratory bibliographic reference and analysis, a great variety of ropeway lines (RL) used in industrial production and sports-tourist events was established. At the same time, in all observations and analyses, common features are noticeable, which can be used in the development of general or generalized classifications according to basic, additional and auxiliary signs. They are useful for studying the purpose and characteristics of ropeways. Essentially facilitating the analysis of the properties of existing and development of new innovative ropeways.

Generally speaking, cableways are divided into two main groups:

a) Cargo cableways

Most manufacturers offer varieties of material transport and sports equipment - mountain carts and many others, which are transported safely and comfortably from point A to point B - on the mountain in summer and in winter or in the city. Only a few cableway modifications are required for the chairlifts to readjust

between summer and winter operation. It is for this reason that the mountain routes for extreme cycling during the warm months of the year have been increasingly developed recently, Fig. 2.



Fig. 1 Cargo cableways, [5]



Fig. 2 Cargo lift for mountain bikes, [2]

b) Passenger suspended ropeways lines (PSRL).

These are lifts transporting passengers with open (seat) or closed (cabin) facilities (up to 6 passengers, up to 35 passengers and up to 230 passengers) and combined (seat and cabin). Due to the great interest in mountain biking, many manufacturers are reconstructing chairlifts and gondolas with the possibility of combined transportation of people and bicycles, fig. 3.

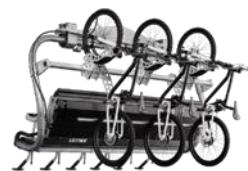


Fig. 3 Combined lifts for the transport of people and bicycles [2]

2.2. By constructive composition feature

The main classification sign in the presented classification of SRL is the sign of the probability of the structural composition of the vehicles, divided into two classes, fig. 4:

a) saddle- single-rope line;

b) cabin - single-rope, double-rope or multi-rope line.

Depending on the mutual connection of the transportation of the vehicles (seats or cabins), carried out structurally with the rope, the ropeways are: (fix-fi) or pluggable (kuppelbate), detachable means in the stations (driving and reversing). The type of vehicles (seats, cabins) is determined by: the purpose, legal capacity, speed, type of RL, the nature of the profile, basic parameters (functional, geometric, structural), mass (kg), compatibility of number of passengers and symbols.

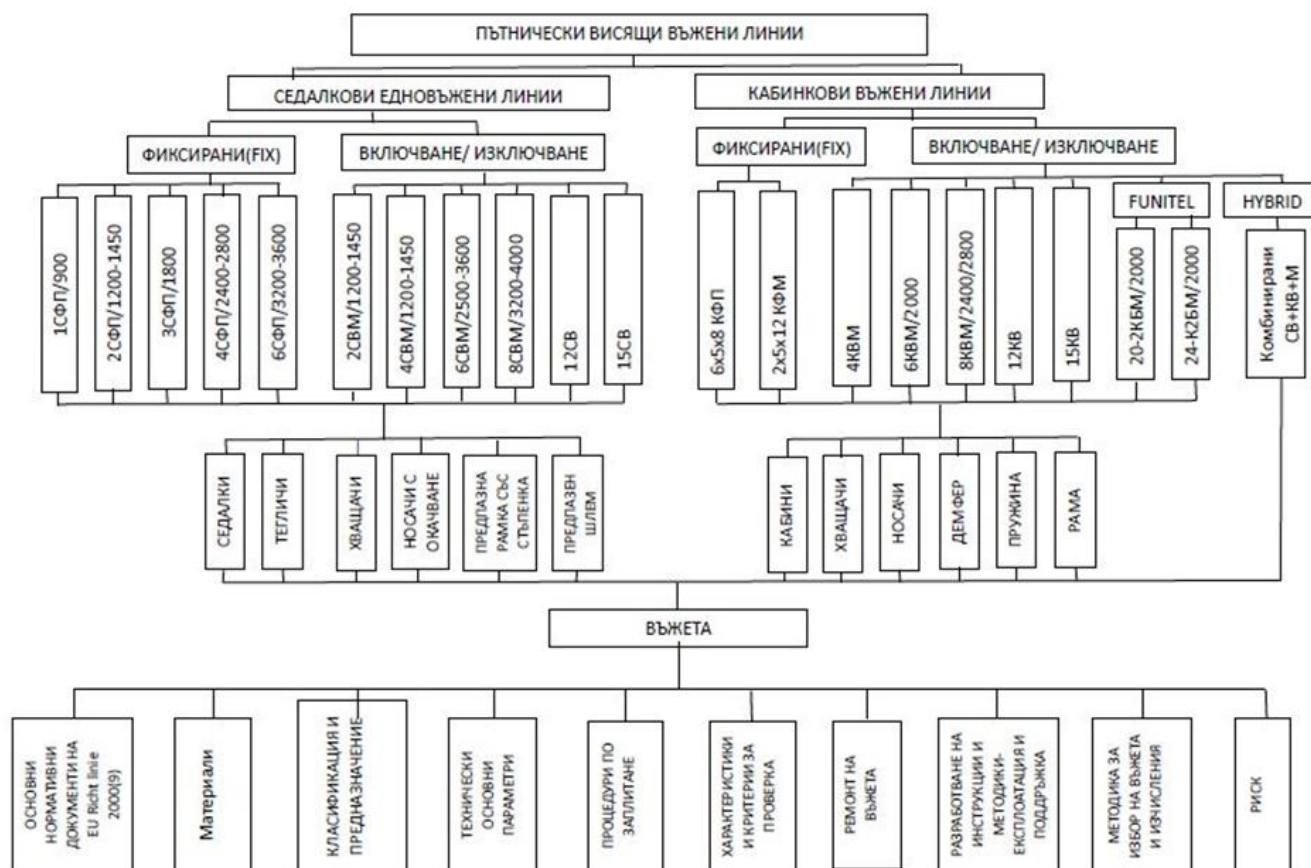


Fig. 4 Classification of variants of passenger suspended ropeways according to structural composition feature

For the classification of PSRL, one of the most famous methods of [6], used by a number of authors, is used. It is carried out depending on the technological purpose and the different execution of AL [7-9]. The Directive of the European Parliament and composition of 20.03.2000 on ropeways for passenger transport (Richt linie 2000 (9) EU standard on technical safety of passenger ropeways and ski lifts adopted as BDS. EN. It is approved was also used with the adopted ordinance on the safe operation and technical supervision of ropeways, Council of Ministers and decree No. 1860-04.07.2014.

3. Analysis and discussion of the compiled classification

A general approach is summarized and formed on the basis of common and additional signs used for research, design, construction of facilities and components (modules), construction, installation, implementation, operation, maintenance, repair activities, service, conducting inspections, tests, analyzes that can be used in their classification, including and the human factor risk (knowledge, habits, skills).

The presented in fig. 4 classification of variants of passenger suspended ropeways lines according to structural composition features makes it possible to systematize the areas of application and to find the necessary constructive normalized, standardized, innovative building units (modules), building different variants of overhead lines used in industry, production and in sports tourism events. PSRL have structural and constructive compositions with interconnected functional components for chair ropeways lines (SRL) of: seats, crucibles, grippers, carriers with suspensions, safety frames with glass and safety helmet, and for cabin ropeways lines (CRL) - single-rope, double-rope, multi-rope, funitel (Funitel) and mixed (HyBrid) from: cabins, grips, carriers, dampers and springs.

- Single-rope SRL with circular motion are of three types:

- with fixed/non-detachable seats for the rope - passengers get on and off during movement. The movement of the rope does not stop when passengers board and disembark;
- with an acceleration lane - a pulsating movement that reduces their speed when the vehicle enters the passenger boarding and disembarking stations;
- with detachable seats for the rope – the seats are detached from the rope, which reduces their speed when entering the stations

➤ Single-rope CRL are built less with a pulsating and more with a pendulum (reciprocating - reciprocating) movement.

➤ Double-rope passenger suspended ropeway lines (DPSRL) have two parallel supporting ropes on which the cabins move. Between the two end stations - driving and turning, the two carrying ropes are stretched with a certain force and locked, and between the stations they are supported by the poles. In PVVL with two parallel carrying ropes, the cabins are attached to the transport rope with two grippers. At DPSRL with circular movement, duplication of the towing (transport) rope is provided with a special braking device, which, when the towing rope breaks, catches the carrier. The productivity of passenger ropeway lines is between 300 and 400 passengers per hour P/h [10]. The passenger double-rope line is composed of the following components: feeding station (platform), suspended track, reverse pulley, guide rollers, gripping (gripper) and on (off) device, diverting saddle, carrying rope, cabin with passengers, release device, seat of anchoring (gripper with inclusion), drive pulley, cabin without load (passenger unloading), towing rope, posts, deflecting pulley, tension rope, stumbling weights. Double-rope and multi-rope lines are built with pendulum motion only.

The maximum speed of movement of the passenger suspended ropeways must be considered and determined on the basis of (regulation-bibliography) according to the number of ropes used, the type of lift and its purpose.

4. Types of ropes for ropeways

The construction of the ropes and the types of entanglements that are applied depend on: the type of overhead line, the loads, the climatic conditions. They must meet the requirements for wire and core coatings such as: confined core (FC) steel bundle (WSC), independent steel rope (IWRC), [5], [12-14].

The chemical composition of the material from which the steel rope is made is essential to withstand certain factors according to (Richtlince 2000). They are manufactured from alloy steel with the chemical composition listed in Table 1.

Table 1: Chemical composition of the ropeway material

% C	%Si _{max}	%Mn	% S _{max}	%P _{max}	% Cr max
0,06-0,75	0.30	0.35-0.70	0.045	0.045	0.25

The wires produced have a high tensile strength achieved by the special drawing technology. The safety requirements of ropeways for transporting people must meet the following standards:

- BDS EN 12927:(2019)- Safety requirements for ropes
- BDS EN 12397:(2004)- Requirements for the operation of ropes
- BDS EN 12927-1:(2004)- Criteria for selecting ropes and securing their ends
- BDS EN 13243:(2015)- Electrical equipment, other than that of drive systems
- BDS EN 12927-3:(2005)- Entanglement of towing and transport ropes of 6 bundles (strands)
- BDS EN 12927-7:(2004)- The criteria for control, repair and maintenance of ropes
- BDS EN 1909:(2004)- Requirements for emergency and rescue operations

In addition to the standards that ropeways must meet, technical supervision [15, 16] of freight and passenger ropeways lines is also extremely important. There are several types of technical inspections, the first of which is mandatory when registering a SRL. Periodicals are carried out once a year and once every 4 years with testing. Extraordinary pre-ices are carried out when the facility has not been operated for more than 12 months, has been moved to a new location, after reconstruction, replacement or repair of elements and at the request of the user.

5. Conclusion

By means of the classification of aerial ropeways, their purpose and structural layout are indicated. Aerial ropeways can be used both for transporting people via chairlifts and cabin lifts, as well as cargo of various types, incl. materials, sports equipment and mountain bikes. Passenger aerial cableways must meet multiple standards and undergo regular technical inspections to be safe for operation.

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Types, Properties and Applications of Phase Variable Materials

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Abstract: Energy from fossil fuels that decreases and is harmful to the environment, requires a reduction in its use. The development of industrial production and the growth of the population lead to an increasing need for electricity. To meet these needs, it is necessary to apply new technologies using renewable energy. Phase change materials are the base of a more energy-efficient future, as they are best suited to efficiently store thermal energy from renewable energy sources. Increasing the efficiency of thermal energy storage systems requires a more detailed study of phase change materials. This document describes the types of phase change materials, their properties, and their field of application.

Keywords: ORGANIC PCM, INORGANIC PCM, EUTECTIC PCM, THERMAL ENERGY SAVING

1. Въведение

Енергията е ключов фактор за развитието на човечеството от различни гледни точки, като технологично подобрене, опазване на околната среда и икономически растеж. Повишаването на стандарта на живот и технологичният прогрес предизвикват увеличаване на търсенето на електроенергия. Според доклада на Международната агенция по енергетика, глобалното търсене на енергия се очаква да нарасне с около 30% между 2017 г. и 2040 г. [1]. Нарастващото търсене на енергия в световен мащаб и стъпките за намаляване на потреблението на изкопаеми горива с оглед на опазване на околната среда водят до използването на алтернативни енергийни източници. Слънчевата енергия е най-често използваният вид енергия сред възобновяемите енергийни източници поради широката си област на приложение [2]. Основен проблем за възобновяемите енергийни източници като слънчевата и вятърната енергия е необходимостта от ефективно съхранение, поради техният периодичен характер. Съхранение на енергия може да се постигне чрез различни системи, като в зависимост от видовете съхранявана енергия се използват различни методи за улавяне и събиране на енергията. Методите за съхранение на енергия могат да бъдат класифицирани като магнитни, механични, химични и термични методи. Топлинната енергия може да се съхранява във всички видове материали благодарение на техния топлинен капацитет. От инженерна гледна точка това явление е известно като „съхранение на осезаема топлинна енергия“. С топлинния капацитет на използвания материал и промяната в температурата, осезаемата топлина може да се съхранява в процесите на зареждане и разреждане. В процеса на зареждане температурата на материала за съхранение се повишава, тъй като енергията се улавя и намалява по време на фазата на разреждане. При този тип съхранение обаче са необходими големи количества материали за съхранение на топлина.

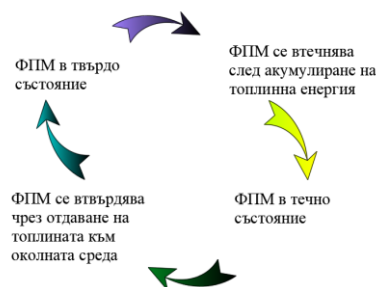
Термохимичното съхранение е друг начин за съхранение на топлинна енергия. В процеса на термохимично съхранение топлинната енергия се съхранява под формата на химичен потенциал и може да се използва в обратима ендотермична химична реакция. Топлинната енергия се съхранява в химическите връзки чрез реакция, която консумира енергия. При метода на термохимично съхранение необходимостта от енергия се набавя чрез обратни реакции, при които се освобождава енергията в химичните връзки.

Друг метод за съхранение е съхранението на латентна топлина. При този метод съхранението на латентна топлинна енергия възниква, когато се осъществи фазов преход в диапазона на работната температура. При този тип съхранение, с по-малко

количество фазово променящ се материал се съхранява повече енергия в сравнение със системите за съхранение на осезаема енергия [3].

2. Фазово променящи се материали. Видове.

Фазово променящите се материали са материали, улавящи и съхраняващи големи количества топлинна енергия по време на фазов преход. Едно от критичните свойства на ФПМ е опазването и съхранението на топлинна енергия при състояние на топлинно равновесие, което настъпва след няколко фазови цикъла. Докато ФПМ обменят топлина в постоянни цикли на промяна на фазата, те също осигуряват по-стабилна температура на околната среда [4]. Материалите съществуват в природата под формата на твърди, течни или газообразни фази. Когато настъпи фазова промяна в дадено вещество, то съхранява или освобождава топлина. Тази съхранена или отделена топлина се нарича латентна топлина. Когато температурата на твърдо вещество се повиши до температурата му на топене, това твърдо вещество се топи чрез улавяне на голямо количество топлина и фазата му се трансформира от твърда в течна (Фигура 1). Фазовите състояния на ФПМ могат да се променят в определен температурен диапазон.



Фигура 1. Фазов преход на ФПМ от твърдо в течно състояние

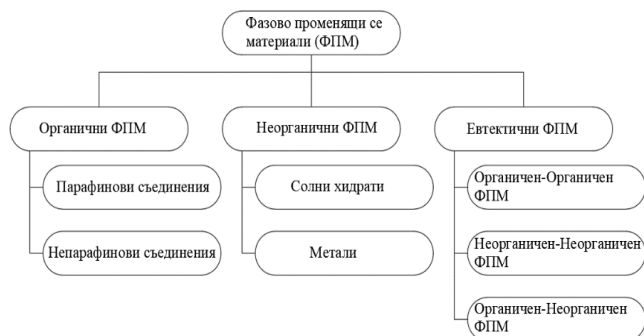
Фазовият преход може да възникне и между неklasически състояния на материята, като кристално съответствие, при което материалът преминава от една кристална структура към друга, която може да има по-високо или по-ниско енергийно състояние.

По отношение на химичния състав, ФПМ могат да бъдат категоризирани в три основни категории: органични, неорганични и евтектичен тип, комбиниращ органични и неорганични ФПМ (Фигура 2).

2.1. Органични ФПМ

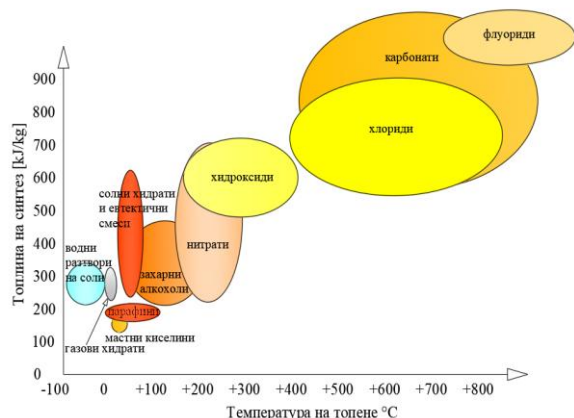
Органичните ФПМ, които се класифицират на парафинови и непарафинови съединения, са един от най-предпочитаните

видове ФПМ, използвани в системите за съхранение на топлинна енергия. Парафините могат да се използват отделно или да се използват в комбинация един с друг при желани температурни диапазони. Непарафиновите материали се произвеждат от различни органични вещества, съдържащи естери, мастни киселини, гликоли и алкохоли. Сред органичните видове ФПМ, мастните киселини претяляват най-голям интерес, защото включват много полезни характеристики, като: ниски разходи, липса на необходимост от допълнително капсулиране, по-лесно регулиране на размера и стабилна форма [6].



Фигура 2. Видове ФПМ

В допълнение, точката на топене и топлината на синтез на някои видове ФПМ са илюстрирани на фигура 3.



Фигура 3. Точка на топене и топлина на синтез на ФПМ [5]

ФПМ на био основа са вещества, произхождащи от възобновяеми и естествени източници, продукция на хранително-вкусовата промишленост, съдържащи хранителни продукти като палмово масло, масло от палмови ядки, соево масло и кокосово масло. Екологичността на търговските материали става все по-важна във всички сектори на индустрията за минимизиране на въздействието върху околната среда и въглеродния отпечатък. Парафинът е вещество на петролна основа и следователно материалите, използвани за производството му, допринасят за глобалното затопляне. Непарафиновите материали се получават предимно от растително масло и са щадящи природата. Въпреки че производството на мастните киселини от растително масло е щадящо за околната среда, няма достатъчно данни за използването на устойчиви, произведени от биоресурси вещества, които биха могли потенциално да се използват като ФПМ. [7]

2.2. Неорганични ФПМ

За разлика от органичните, неорганичните ФПМ не са запалими и са много по-евтини. Неорганичните ФПМ съдържат

метали, соли, солни хидрати и метални сплави. Солните хидрати обикновено се обозначават като AB_nH_2O , където n означава броят на водните молекули в солната смес. Солта и солните хидрати са срещани в изобилие в солени езера или морска вода, което прави материалите по-евтини от органичните. Тези материали са предпочитани за съхранение на топлинна енергия, поради ниската цена и незапалимите свойства. Въпреки това, използването на неорганични материали с променлива фаза в системите за съхранение на топлинна енергия подлежи на допълнителни проучвания, тъй като основните пречки за внедряването им в такива системи, произтича от лоша стабилност и ниска топлопроводимост при дългосрочна употреба поради разделяне на фазите, дехидратация или преохлаждане [8].

2.3. Евтектични ФПМ

Въпреки че има три различни вида евтектични ФПМ, днес широко се използват два типа: органични-органични материали с фазова промяна и органични-неорганични материали с фазова промяна. Могат да се прилагат различни техники за смесване, за да се постигнат различни практически изисквания. За да се произведат органични сложни материали с променлива фаза с предпочитана точка на топене и съхранение на латентна топлина, отговарящи на ежедневните практически нужди, обичаен метод е да се смесят два или повече органични ФПМ чрез топене и смесване при различни температури на промяна на фазата. Образуването на бинарни евтектични съединения от мастни киселини и мастни алкохоли, производството на евтектични полимастни киселини от концентрирани мастни киселини и комбинацията на мастни киселини с парафини за бинарен ФПМ са някои примери за образуване на евтектични материали с променлива фаза.

Лошата топлопроводимост на органичните ФПМ е основната пречка, ограничаваща употребата на тези вещества. Следователно, производството и подобряването на органични материали с фазова промяна с по-добра топлопроводимост и по-висока плътност на съхранение на енергия е активно изследователско поле, в което се провеждат много проучвания. За да се развият термичните свойства на материалите с органична фазова промяна, комбинирането на вещества с по-добри термични свойства чрез метода на топене-смесване се прилага често при разработването на ФПМ [9].

В таблица 1 са посочени предимствата и недостатъците на материалите с променлива фаза от трите основни групи.

Таблица 1. Предимства и недостатъци на видовете ФПМ

Органични ФПМ	Неорганични ФПМ	Евтектични ФПМ
Предимства + Добра химическа съвместимост + Рениклируеми с други материали + Висока топлина на топене + Възможност за работа в широк температурен диапазон + Замръзване без голямо преохлаждане + Фазопреобразуване при ниско налягане + Химическа стабилност + Възможност за рениклиране Недостатъци - Висока запалимост - Ниска температура проводимост в твърдо състояние - Относително голяма промяна на обема - Ниска плътност - Висока цена - Ниска температурна проводимост	Предимства + Ниска цена + Малка промяна на обема + Висока температурна проводимост + Висока топлина на топене + Топене при точно определена температура + Фазопреобразуване при ниско налягане + Възможност за рениклиране + Незапалимост Недостатъци - Корозия - Нужда от преохлаждане - Ниска температурна стабилност - Възможност за несвързано разтваряне - Склонност към деградация - Химическа нестабилност - Проблемна съвместимост с някои материали - Нужда от контейнер за съхранение	Предимства + Високообемно съхранение на топлина + Висока плътност + Няма фазова сегрегация и конгруентна фазова промяна + Топене при точно определена температура Недостатъци - Липса на достатъчно достатъчно изследвания за тези материали - Силна мизия - Висока цена - Нисък капацитет за латентна топлина

3. Приложение на ФПМ

Материалите с променлива фаза намират широко приложение в различни области, като: системи за съхранение на енергия, микроелектронни приложения за управление на температурата, строителство, текстилна промишленост, телекомуникации, транспорт и фармацевтичен сектор.

Материалите с променлива фаза имат определен температурен диапазон на топене и се използват в приложения в съответствие с тези температурни стойности. ФПМ могат да бъдат групирани в 4 основни категории според техния работен температурен диапазон (Фигура 4).



Фигура 4. Температурен диапазон на топене на ФПМ. Приложения

Първият температурен диапазон е нискотемпературният диапазон (-20 °C до +5 °C), при който материалите с фазова промяна се използват в търговски и жилищни хладилни/охладителни системи. Вторият диапазон е средно-ниският температурен диапазон (+5 °C до +40 °C), при който материалите с фазова промяна се използват в процеси на отопление/охлаждане и климатизация в сгради. Третият температурен диапазон е средният температурен диапазон (+40 °C до +80 °C), при който материалите с фазова промяна се използват в системи за соларно отопление/производство на топла вода и пренос на топлина в електрониката. Крайният температурен диапазон е високотемпературният диапазон (+80 °C до +1200 °C), при който се използват материали с промяна на фазата в соларните концентратори, системите за оползотворяване на отпадна топлина и конструкции за абсорбционно охлаждане.

4. Заключение

Системите за съхранение на термална енергия, използващи фазово променящи се материали, са непрекъснато развиваща се научна област, която помага за намаляване на емисиите на парникови газове, зависимостта от изкопаеми ресурси и консумацията на енергия. В зависимост от увеличаването на новите области на приложение, обхватът на секторите, в които се използват ФПМ, също се разширява. Някои от секторите на приложение са: технологии за отопление, охлаждане и климатизация, методи за съхранение на концентрирана слънчева енергия, строителния сектор, автомобилната индустрия, текстилният сектор. Проблемите с ефективността, общите разходи, производителността и надеждността са основните предизвикателства, срещани на етапа на избор на ФПМ в много сектори. Освен това в много случаи липсват международни или национални стандарти за използването на материали с фазова промяна. Въпреки че в продължение на много години са провеждани различни изследвания в много области на ФПМ, няма стандарти в процесите на тяхното изследване и развитие. Следователно създаването на такива стандарти ще стои като една доста сериозна бъдеща задача.

Системите за съхранение на термална енергия, включващи комбинация от различни методи като пенообразуване, оребвяване и интегриране на наноматериали, осигуряват допълнителни подобрения в свойствата на топлопренос на ФПМ. Следователно изучаването и прилагането не само на

един метод, а на комбинация от методи ще доведе до повишаване на енергийната ефективност на системите за съхранение на термална енергия.

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A study on deflections of GFRP reinforced concrete beams.

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Abstract: Steel reinforcing bars have not performed well in applications where members were subject to corrosive environments. Alkaline concrete protection can provide relatively good protection of the steel reinforcement, but when these are exposed to an aggressive environment or the protection breaks down, the reinforcement starts the corrosive process and it leads to rupture and fragmentation of the protective layer of concrete.

These reasons lead to high maintenance costs, repairing or even replacing them. This problem prompted a lot of researchers to seek alternative materials with characteristics better than steel to be used in construction. GFRP bars, which are fibers with high resistance immersed in a polymer resin matrix, with a high tensile resistance and also resistant to corrosion, emerged in the 1990s as an alternative to replace steel rods. The use of GFRP is increasingly accepted by the countries, which are trying to create or adopt special codes for their use in building structures.

This paper will take a quick look over GFRP materials and their mechanical properties, but also will aim to provide some ideas on the study of concrete members reinforced with GFRP bars and their design based on SLS method as it represents the most problematic one, focusing on deflections of GFRP reinforced beams.

Keywords: GFRP, CONCRETE, SLS DESIGN, DEFLECTION, CURVATURE, MOMENT OF INERTIA.

1. Introduction

This study aims at an investigation on the new trend of using GFRP bars as internal reinforcement in concrete members. It intends to:

- Identify some of GFRP's mechanical properties, as a possible material to be used as internal reinforcement in concrete members.

- Investigate, using theoretical methods and application, through literature and codes, the flexural behavior of concrete members reinforced with GFRP bars and their design based on Service Limit States (SLS), in terms of cracks width, deformations and deflections under service and sustained loads.

Through experimental tests carried out on beams reinforced with GFRP bars, will be studied their failure modes, deflections, and cracking, and the comparison of experimental data with theoretical values based on existing codes.



Fig. 1 GFRP reinforcing bars used in a concrete slab

2. Methodology

Glass fibers (GFRP) are used as reinforcing bars as internal reinforcement, as external reinforcing sheets and structural profiles produced with pultrusion. They are sensitive to moisture, to the presence of salts and alkali and suffer the effect of cracks, resistance loss, and rupture under constant loading. They are good electrical and thermal insulation and with low cost of reinforcing fibers.

Glass fibers (GFRP), are among the most common of FRP bars and they are offered by a large number of manufacturers in the world. GFRP bars are produced in size ranging from 3/8 to 1 3/8 in. (9 – 41 mm), no.3 to no.13 bars, but ASLAN 100 produces FRP bars starting from No. 2 (6 mm) to No. 13 (41 mm).

Because the FRP mechanical properties differ from those of steel, particularly the module of elasticity that is significantly lower in FRP bars than in steel bars, the elastic behavior up to fracture, lack of ductility, etc., the SLS design, especially the cracking and deflection criterion may control the design of GFRP-RC beams. SLS design of GFRP-RC beams takes into account these major problems:

- Cracking
- Deformation and deflection
- Stresses in the material

The most problematic ones are the first two problems, as these guarantee the functionality of the structure throughout its lifetime.

The service conditions also depend on the importance of the structure and the environment. The problem that appears is similar to the already known one of concrete structures reinforced with steel bars. Because GFRP bars have a much lower modulus of elasticity than steel bars, the serviceability limit state dictates the design of concrete sections reinforced with GFRP bars. Permissible deflections for service loads in these structures are taken the same as for all other structures, so the relevant design conditions must be applied. The permitted crack widths for these elements are not the same as for conventional concrete elements reinforced with steel bars, due to the greater corrosion resistance of GFRP bars.

The methods, the models, and the restrictions used during the analysis must be different; in addition, a large number of existing materials in the field of FRP bars production, with quite different mechanical characteristics and not as unified as for steel bars, requires special ways to solve these problems.

Only some countries have implemented specific design codes:

- American Code (ACI-440R-96),
- Canadian Code (ISIS CANADA/CSA S806-02)
- Norwegian Code (EUROCRETE)
- Italian Code (CNR-DT203/2006)
- Japanese Code (JSCE)

3. Deflections of GFRP-RC beams under service loads

Similar to the case of steel-reinforced concrete members, an “effective” second moment of inertia based on the gross moment of inertia I_g , and the cracked moment of inertia I_{cr} , is used to calculate deflections of an GFRP-reinforced beam. Due to the reduction of the moment of inertia in the cracked section, and consequently as for relaxation and greater deformation in the concrete, larger deflections occur.

M_{cr}/M_a ratio also determines the effective moment of inertia of the section based on Branson equation, (1968,1977), [1]. The deflection may be calculated using elastic theory equations for uncracked sections. If M_a increases over M_{cr} , cracks start to show up in the concrete section, starting from the supports, and later in the middle span, so the moment of inertia is suddenly decreased in the section from I_g to I_{cr} .

Between cracks, tension is transferred from the reinforcement to the concrete, by bond stresses (tension stiffening phenomenon), so Branson, proposed the use of the effective moment of inertia I_e :

$$I_e = \left(\frac{M_{cr}}{M_a} \right)^3 \cdot I_g + \left[1 - \left(\frac{M_{cr}}{M_a} \right)^3 \right] \cdot I_{cr} \leq I_g \quad (1)$$

Where I_e - effective moment of inertia, M_{cr} - the moment in the section at the first cracking, I_g - gross moment of inertia, M_a - the maximum moment in the section where the deflection is calculated, I_{cr} - the cracked section moment of inertia [1].

The relationship between the acting moment and the moments of inertia are shown in Fig. 2.

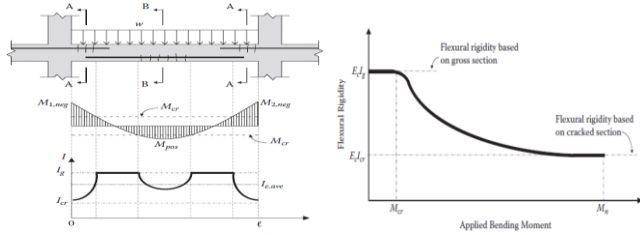


Fig. 2 Moment of inertia for a continuous beam and relationship between moments and moment of inertia

The "tension-stiffening" phenomenon affects the stiffness, deformations and cracks of the elements working in bending, so in Branson's equation, its effect depends on the ratio between the gross moment of inertia and that of the cracked section I_g/I_{cr} , and increases significantly if this ratio goes above 3. In beams reinforced with FRP bars, this ratio usually goes above 5, so Branson's equation underestimates the deformations of these beams.

Table 1: Comparison of main methods and design codes of the effective moment of inertia [13], [14].

Reference	Models for I_e
ACI 318 R -95 (1995) Branson's formula	$I_e = \left(\frac{M_{cr}}{M_a} \right)^3 \cdot I_g + \left[1 - \left(\frac{M_{cr}}{M_a} \right)^3 \right] \cdot I_{cr} \leq I_g$
Benmokrane (1996)	$I_e = \frac{I_g}{7} \cdot \left(\frac{M_{cr}}{M_{max}} \right)^3 + 0.84 \cdot I_{cr} \left[1 - \left(\frac{M_{cr}}{M_{max}} \right)^3 \right] \leq I_g$
ACI 440.1R -03 (2003)	$I_e = \frac{I_g}{\beta} \cdot \left(\frac{M_{cr}}{M_{max}} \right)^3 + \alpha \cdot I_{cr} \left[1 - \left(\frac{M_{cr}}{M_{max}} \right)^3 \right] \leq I_g$ $\frac{1}{\beta} = \alpha \cdot \left(\frac{E_{FRP}}{E_s} + 1 \right) \leq 1, \quad \alpha = 0.5 \text{ and } \alpha = 1$
Yost (2003) based on ACI	$I_e = \left(\frac{M_{cr}}{M_a} \right)^3 \cdot \beta_d \cdot I_g + \left[1 - \left(\frac{M_{cr}}{M_a} \right)^3 \right] \cdot I_{cr} \leq I_g$ $\beta_d = a_b \cdot \left(\frac{E_{FRP}}{E_s} + 1 \right) \cdot a_b = 0.064 \cdot \left(\frac{p_{FRP}}{p_b} \right) + 0.13$
ACI 440.1R -06 (2006)	$I_e = \left(\frac{M_{cr}}{M_a} \right)^3 \cdot \beta_d \cdot I_g + \left[1 - \left(\frac{M_{cr}}{M_a} \right)^3 \right] \cdot I_{cr} \leq I_g$ $\beta_d = \frac{1}{5} \cdot \left(\frac{p_{FRP}}{p_b} \right) \leq 1$
Rafi & Nadjai (2009)	$I_e = \left(\frac{M_{cr}}{M_a} \right)^3 \cdot \beta_d \cdot I_g + \left[1 - \left(\frac{M_{cr}}{M_a} \right)^3 \right] \cdot I_{cr} \leq I_g$ $\gamma = \left(0.0017 \cdot \frac{p_{FRP}}{p_b} + 0.8541 \right) \cdot \left(1 + \frac{E_{FRP}}{E_s} \right) \leq 1 \text{ or } \gamma = 0.86 \cdot \left(1 + \frac{E_f}{400} \right) \text{ in GPa}$ $\beta_d = \frac{1}{5} \cdot \left(\frac{p_{FRP}}{p_b} \right) \leq 1$
EC2-CEB, Italian Code CNR-DT 203/2006	$f = f_1 \cdot \beta_1 \cdot \beta_2 \cdot \left(\frac{M_{cr}}{M_{max}} \right)^m + f_2 \cdot \left[1 - \beta_1 \cdot \beta_2 \cdot \left(\frac{M_{cr}}{M_{max}} \right)^m \right]$ $m = 2$
Toutanji & Saafi (2000)	$I_e = \left(\frac{M_{cr}}{M_a} \right)^m \cdot I_g + \left[1 - \left(\frac{M_{cr}}{M_a} \right)^m \right] \cdot I_{cr} \leq I_g$ $m = 6 - \frac{10 \cdot E_f}{E_s} \cdot \rho_f \text{ if } \frac{E_f}{E_s} \cdot \rho_f < 0.3 \text{ so } m = 5.98$ $m = 3 \text{ if } \frac{E_f}{E_s} \cdot \rho_f \geq 0.3$
Alsayed Modeli A (2000)	$I_e = \left(\frac{M_{cr}}{M_a} \right)^m \cdot I_g + \left[1 - \left(\frac{M_{cr}}{M_a} \right)^m \right] \cdot I_{cr} \leq I_g$ $m = 5.5$
Alsayed Modeli B (2000)	$I_e = I_{cr} \text{ for } \frac{M_a}{M_{cr}} \geq 3$ $I_e = \left[1.4 - \frac{2}{15} \cdot \left(\frac{M_a}{M_{cr}} \right) \right] \cdot I_{cr} \text{ for } 1 < \frac{M_a}{M_{cr}} < 3$
Bischoff (2005,2007) & Scanlon (2007)	$I_e = \frac{I_{cr}}{1 - \left(1 - \frac{I_{cr}}{I_g} \right) \cdot \left(\frac{M_{cr}}{M_a} \right)^2}$
Abdalla based on ACI (2002)	$I_e = \frac{I_g \cdot I_{cr}}{I_{cr} \cdot \xi + 1.15 \cdot I_g \cdot (1 - \xi)}$ $\xi = \frac{0.5 M_{cr}}{M_a}$
Abdalla, Rizkalla & El Badry (EC2)	$f = \left(\frac{M_{cr}}{M_a} \right) \cdot \beta \cdot f_s + \left[1 - \beta \cdot \left(\frac{M_{cr}}{M_a} \right) \right] \cdot \alpha \cdot f_s$ $\alpha = 0.85 \text{ and } \beta = 0.5$

Deformations must be checked both for short-term and long-term loads, taking into consideration the phenomenon of fatigue. This methodology was adopted from ACI 318R-95 for calculating deformations for short-term acting loads. In these years, many researchers, based on experimental tests, proposed adjustments to Branson's equation, in order to have new approach in I_e calculations.

A summary of the main methods and design codes in calculating effective moments of inertia and deflections, without entering in details of their modifications of Branson's equation, are given in Table 1, [2], [3], [4], [5], [6], [7], [8], [9], [10], [11], [12], [16].

The deflections calculated both with the methods of the effective moment of inertia, as with the method of curvature (elastic line) of the beam, must fulfill certain conditions regarding permissible deformations in the concrete elements. It should be noted that if the deflections calculated using the moment of inertia of the cracked section satisfy the allowable values, then there is no need to use the effective moment of inertia.

4. Experimental testing of serviceability behavior of GFRP - RC beams

This paper contains experimental data derived from laboratory tests conducted on four reinforced concrete beams with GFRP bars. The purpose of these tests is the observation of deflections of the beams under the action of two concentrated loads. At the end, the results will be compared with theoretical calculations.

The cross-section of the beams is 250 X 400 mm, with 4000 mm span length, and 4200 mm total length. Because of the laboratory conditions and for not using concrete vibration, self-compacting concrete grade C30 was used. The concrete was produced with 25 mm maximum aggregate size, 0.35-0.37 water-to-cement ratio and 323 kg/m3 cement content [13], [14].

Table 2: Mechanical properties of GFRP bars

Diameter	Cross section	Weight	Modulus of elasticity	Tensile strength	Tensile strength
SI (mm)	A (mm ²)	W (g/ml)	GPa	MPa	%
15.87	197.9	181	46	620	1.42

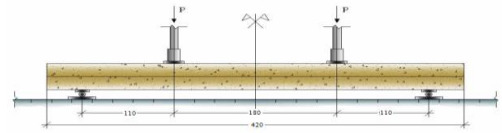


Fig. 3 Schematic view of the specimen



Fig. 4 The gaging system

Schematically, the beam specimens tested under four-points bending, are shown in Fig.5.

The tests would be carried out on four beams with different reinforcements. In the first pair of beams (beams T1 & T2), 4 Ø16 GFRP bars were used as longitudinal reinforcement, in the third beam (beam T3), 5 Ø16 GFRP bars, and in the fourth beam (beam T4), 2 Ø16 GFRP, while the upper reinforcement and staffs were not changed[13], [14].

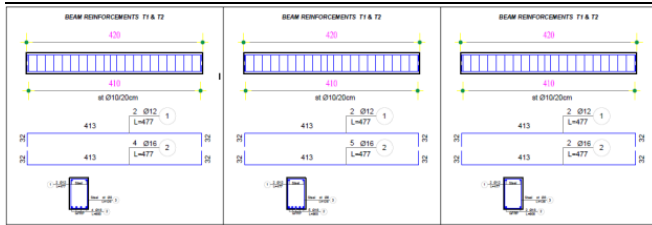


Fig. 5 The reinforcement of beams

Loading is done in cycles by scaling the electronic press at a loading rate of 300N/second. The first loading cycle was taken up to 10 kN, the second up to approximately 30 kN, the third cycle up to approximately 60 kN and the last cycle up to the failure of the beam. Only in T4 beam, this loading is done initially up to 10 kN, then up to 20 kN, up to 40 kN, and until the beam failure.



Fig. 6 Beam T1 & T2 - Concrete crushing failure, full cracked section (≈ 90 kN)



Fig. 7 Beam T3 (≈ 102 kN) & T4 (≈ 55 kN) - Concrete crushing failure, full cracked section

5. Data analysis on deflection behavior

Experimental data are analyzed and are integrated in appropriate curvatures and are compared to theoretical calculations based on American Code ACI 440.1R -06.

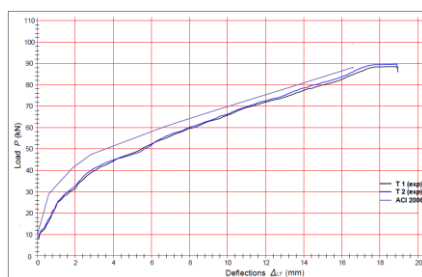


Fig. 8 Experimental vs predicted midspan deflection of T1 & T2

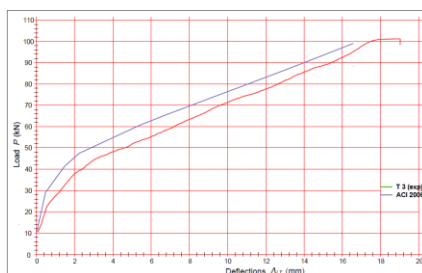


Fig. 9 Experimental vs predicted midspan deflection of T3

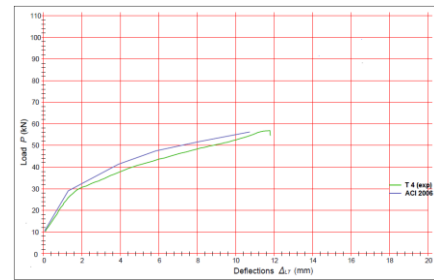


Fig. 10 Experimental vs predicted midspan deflection of T4

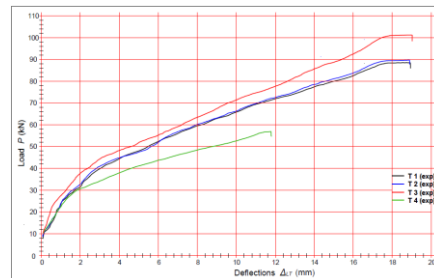


Fig. 11 Experimental midspan deflection of T1, T2, T3, T4.

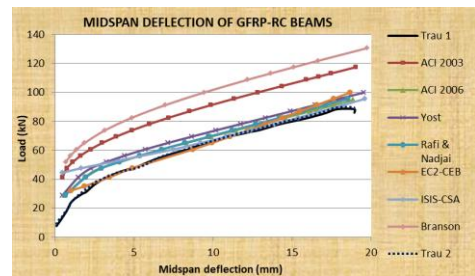


Fig. 12 Experimental vs theoretical midspan deflection of T1 & T2 for different design models

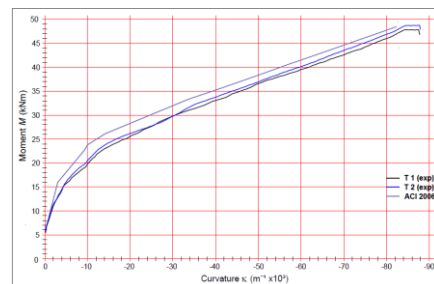


Fig. 13 Experimental vs predicted maximum curvature of T1&T2

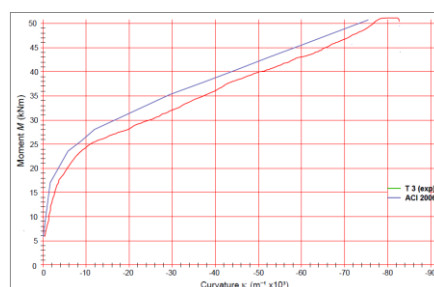


Fig. 14 Experimental vs predicted maximum curvature of T3

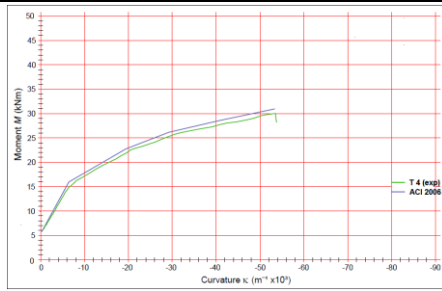


Fig. 15 Experimental vs predicted maximum curvature of T4

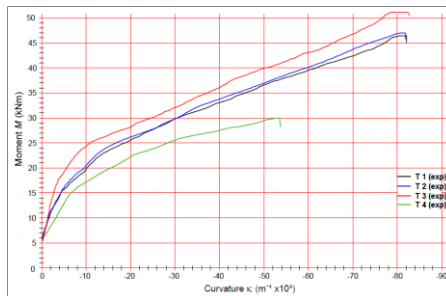


Fig. 16 Experimental maximum curvature of T1, T2, T3, T4

6. Test results and discussions

At the first pair of beams T1 & T2 (named TS1 & TS2 before test) were used 4 bars Ø16 GFRP, as longitudinal reinforcement with a theoretical balanced reinforcement ratio of $\rho_f = 0.00932 \approx \rho_{fb} = 0.0093$.

At beam T3 (named TS5 before test) were used 5 bars Ø16 GFRP, as longitudinal reinforcement, having a lightly overreinforced beam where $\rho_f = 0.0093 < \rho_f = 0.0116 < 1.4 \cdot \rho_{fb} = 0.0013$. At beam T4 (named TS5 before test) were used 2 bars Ø16 GFRP, as longitudinal reinforcement, having an underreinforced beam where $\rho_f = 0.00466 < \rho_{fb} = 0.0093$.

6.1 Results on deflection behavior

Figures 8, 9, 10, 11 and 12, show the experimental load-deflection response at midspan for all beams, compared to the theoretical calculations based on the American ACI 2006 code [14].

T3, is a slightly over-reinforced beam, so the concrete crushing occurs. The maximum deflection is slightly higher than in the case of T1 and T2, but still exceeds the allowable deflection before failure, corresponding to the ultimate load of 101.5 kN, which is about 14-15% higher than the ultimate load and for a reinforcement 25% greater than in the case of T1 and T2. The theoretical values are quite close to the experimental ones with a difference of only 5-6 kN (higher), or with a deflection of only 0.7-1mm smaller than the experimental values, so only 6-7% difference. This means that ACI 2006 gives expected good results for close to balanced and over-reinforced beams [14].

T4 is an under-reinforced beam, with half of the balanced reinforcement, that is, as much as 50% of the reinforcement of the beams T1 and T2, therefore the GFRP bars rupture occurs and after that, the concrete in the pressed area is crushed by the immediate deflection as seen in figure 16. It appears that this failure occurred for a much smaller load than in the case of T1 and T2, only 56.9 kN or 35-36% less. Also, the deflection at the failure moment is 11.8 mm, much less than the allowable deflections and also the deflections of beams T1 and T2. It can be seen that the predicted values are very close to the experimental ones with a difference of less than 3% [14].

Figure 17 shows the beam deflection–reinforcement ratio at rupture load of T4 for $P = 56.9$ kN. The greater the reinforcement, the smaller the deflections, and this go almost linearly in inverse proportion. ACI 2006 gives good results for under-reinforced or slightly over-reinforced beams, but it seems that the tendency is that error tends to increase almost proportionally with the beam reinforcement increment as shown in Figure 18, [14].

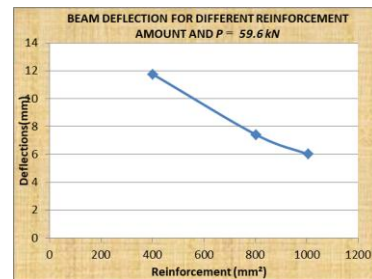


Fig. 17 Beam deflection – reinforcement ratio at rupture load of T4

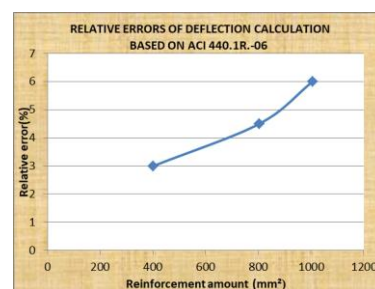


Fig. 18 Relative errors of deflection – reinforcement ratio based on ACI 440.1R-06

6.2 Results on curvature behavior

Figures 13, 14, 15, and 16 show the experimental load-curvature response at midspan for all beams, compared to the theoretical calculations based on the American ACI 2006 code.

We can see that the values obtained experimentally for T1 & T2 beams follow the same trend as deflections and are very close to each other with only a 2-3% difference. Also, the predicted values are quite close to the experimental ones with a difference of about 5%. The maximum bending moment in the section until the failure is 46.9 kNm for beam T1 and 47.8 kNm for beam T2, while the predicted ones are around 50.2 kNm. The maximum curvature value is about $90 \cdot 10^{-3} \text{ m}^{-1}$ at T1 beam [14].

For beam T3 the maximum bending moment is 51.1 kNm while the predicted one is 54.7 kNm, with a difference of 7%. The maximum curvature is $82 \cdot 10^{-3} \text{ m}^{-1}$, or about 8.5% less than for beams T1 and T2.

For beam T4 due to insufficient reinforcement and rupture of the GFRP bars, the maximum bending moment is only 30 kNm, and the predicted one is 31 kNm, having a difference of about 3%. The maximum curvature is $54 \cdot 10^{-3} \text{ m}^{-1}$, around 40% smaller than for beams T1 and T2 [14].

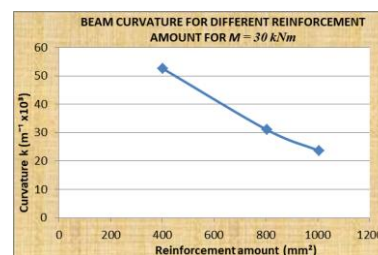


Fig. 19 Beam curvature – reinforcement ratio at rupture moment of T4

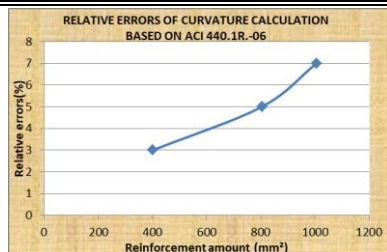


Fig. 20 Relative errors of curvature – reinforcement ratio based on ACI 440.1R-06

Figure 19 shows the beam curvature – reinforcement ratio at rupture moment of T4 for $M = 30$ kNm, the greater the reinforcement, the smaller the curvature, and this goes almost linearly, in inverse proportion. ACI 2006 gives good results for under-reinforced or slightly over-reinforced beams, but it seems that the tendency is that the error tends to increase almost proportionally with the beam reinforcement increment as shown in Figure 20, slightly more pronounced than the one for the deflections [14].

7. Conclusions

After the experimental results analysis and their comparison with the theoretical predictions based on ACI 440.1R-06, we can summarize the most relevant conclusions as follows:

1. The failure of GFRP reinforced concrete beams, when they have a balanced reinforcement ratio, or when they are slightly over-reinforced (around 40% more than the balanced one), occurs in a similar way as the failure of steel-reinforced beams, due to concrete crushing in the compression zone.

2. The failure of under-reinforced GFRP reinforced concrete beams, occurs in a different way from the failure of steel-reinforced beams, due to GFRP bar rupture in the tension zone, since the FRP reinforcement will not yield.

3. The prevailing problem of the tested beams seems to be cracking and deflections, and not the flexural capacity, except for the under-reinforced beam.

4. During the deflection and curvature analysis, is noted their trend increases with the decrease of the reinforcement ratio. The limit of theoretical prediction of deflections is achieved before the beam failure, except for the under-reinforced beam, when the failure occurs for rupture before having large deflections [14], [15], [17].

5. During the comparison between theoretical predictions based on ACI 440.1R-06 and experimental results, was noted that this design code is quite accurate for calculating the deflections and beam curvature with slightly differences of 4-7% [14].

6. Also other methods and design codes such as Yost, Rafi & Nadjai, ISIS Canada, EC2 – CEB & Italian Code CNR, give good theoretical predictions regardless of the method used. The differences with experimental results are in the range of 3-8%, due to theoretical empiricism, and for not taking into account parameters that affect the effective moment of inertia I_e , such as: the reinforcement ratio ρ_f , the low FRP modulus of elasticity E_f , the initial deflections of the uncracked, the bond behavior of FRP bars with concrete, the loading type and tension-stiffening effect [14].

7. Is noted the trend to have bigger errors of the theoretical predictions, with the increase of reinforcement ratio, so their curvature is quite proportional.

Although the expectation based on theoretical predictions was appropriate (except for beam T4), these specimen tests were not enough to carry out important remarks for improving the design equations for calculating deflections and crack width of GFRP reinforced concrete beams and are needed for other research.

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Technological distinctive features at obtaining castings for bicycle frames of recycled aluminum alloy

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Abstract: It was obtained alloy of remelted aluminum beverage cans. A technology for casting of blanks for bicycle frames has been developed. The resulting elements are intended to be mounted on bicycles.

KEYWORDS: SINGLE-CASTING MOLDS, ALUMINUM CANS RECYCLING

1. Introduction

The aim of the present development is to be created a technology for obtaining details forming the bicycle frame from alloy obtained by recycling of beverage aluminum cans.

Requirements to the detail: achievement an accuracy of geometric dimensions and sufficient strength. The additional processing includes cutting out the sprue channel and the dead heads. These requirements are determined by the necessity for achieving the mounting dimensions

2. Methodology and technological features

The task was solved as initially models has been made, meeting the requirements to the casting slopes, helping to their easier removing from the mold.

The details have a relatively complex configuration, due to the large difference between the thickness and overall dimensions of the castings.

Details are of two types, tentatively named Frame 1 and Frame 2.

In their volume there are voids and thermal nodes, which sets a condition for the correct orientation of the gate systems and the feeding dead heads, considering that the castings will be made in single-casting sand clay molds.

The cans are arranged in a resistance furnace and sprinkled with protective flux, consisting of sodium chloride (NaCl), potassium chloride (KCl) and cryolite (Na_3AlF_6), Fig. 1.



Fig.1. Disposition of the cans into the resistance furnace

After starting the melting, periodically the remaining cans are added, until the entire intended amount is melted. The resulting melt is poured into metal molds, and a sample for spectral analysis is taken to determine the elements presenting in the alloy.

In order to obtain the casting forms, special casting boxes were made in advance, Fig.2.

The models are placed, filled with a previously prepared sand-clay mixture and compacted. Figures 3 and 4 show the resulting forms for Frame 1 and Frame 2, respectively.

After obtaining the forms (Fig. 3 and 4), the sprue channel, feeders and overflows are oriented. Due to the identity of the details, the orientation of the sprue, feeders and overflows for one form, only, is presented (Fig. 5).

The alloy obtained after remelting the cans is melted, and a certain amount of aluminum-silicon ligature is added to it for improving the casting qualities of the melt [1].



Fig.2. Made in advance special casting boxes



Fig.3 Detail of type Frame 1



Fig. 4. Detail of type Frame 2



Fig. 5. Orientation of the sprue, feeders and overflows

The closed molds are filled with the molten alloy and allowed to cool. After solidification, the single-casting molds are destroyed and the resulting casting is removed, Fig. 6.



Fig. 6. The casting, after destruction of the sand-clay mold

This is followed by trimming of the sprues, feeders and overflows. The castings thus obtained are mounted to each other, and then are mounted on a bicycle, Fig. 7.



Fig. 7. The bicycle with the mounted details Frame 1 and Frame2

3. Conclusion

A technology for castings intended for bicycle frames has been developed. They are made of recycled aluminum alloy obtained from melted down aluminum beverage cans.

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Methods for contact and non-contact real-time measurement of temperature in the welding process

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Abstract: Methods for contact and non-contact real-time measurement of temperature during the welding process are reviewed. A real-time measurement and comparison of the obtained results is made.

Keywords: TEMPERATURE MEASUREMENT, REAL-TIME MEASUREMENTS, WELDING PROCESSES

1. Introduction

In fig. 1 is shown the contact methods for measuring temperature [1,2,3] in the welding process. The contact methods are divided into methods with placing the thermoelements in inspection holes, welding on the surface of the joint and contacting by means of strong pressure. When drilling inspection holes, the temperature is measured in the volume of the joint. In this case, holes with the diameter of the thermocouple are drilled in the welded joint, which violates the integrity of the welded parts. These measurements are carried out on prototypes of the welded joint, when it is necessary to record the temperature field during the welding process. When welding thermocouples on the surface, there is a possibility that when the thermocouples are too close to the weld pool, they will be included in the volume of the welded joint. When contacting with pressure on the surface, the thermocouples are pressed against the welded joint. In this case, it is possible that there is a bad thermal contact and the measured temperature does not correspond to the real one.

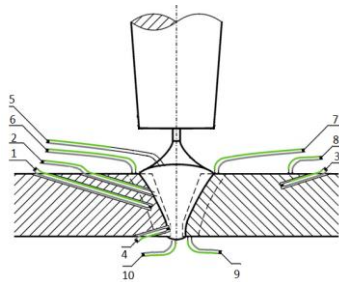


Fig. 1 Contact methods for measuring temperature in the welding process.

In inspection holes

1. Thermocouple placed in inspection hole, measuring temperature in HAZ;
2. Thermocouple placed in inspection hole, measuring temperature at the fusion line;
3. A thermocouple placed in an inspection hole, measuring the heating temperature
4. Thermocouple placed in the inspection hole at the root of the seam.

Welded to the surface

5. Thermocouple welded to the surface in a cooling weld bath;
6. Thermocouple welded to the surface in HAZ;
7. Thermocouple welded to the surface of the seam, measuring temperature at the fusion line;
8. Thermocouple welded at the end of the welded joint, measuring the heating temperature;
9. Thermocouple welded at the root of the seam.

Pressed down

10. Thermocouple tightly pressed to the root of the seam.

In fig. 2 is shown the non-contact methods of temperature [1,3,4] measurement during the welding process. Non-contact temperature measurement is carried out by pyrometers and thermal cameras. Pyrometers can only measure the temperature at a single point, while thermal cameras measure the temperature field of the weld joint. When measuring with both types of devices, it is important to adjust the value of the emissivity of the workpieces to be welded. In non-contact temperature measurement, it is possible to cast a shadow from the operator, burner, apparatus and others if they enter the field of view of the pyrometer or thermal imager. This is avoided by carefully planning the welding setup. An advantage of non-contact methods is the ability to transmit the data in real time to a computer system. Thermal cameras have an advantage over pyrometers in the number of points they can measure simultaneously. An advantage of pyrometers is the lower cost and easier data processing.

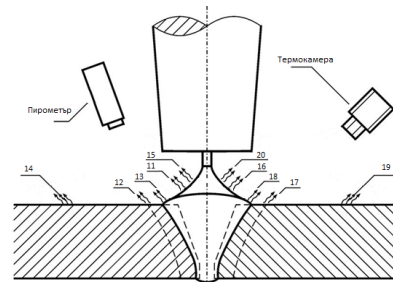


Fig. 2 Non-contact methods for measuring temperature in the welding process.

With a pyrometer

1. Pyrometer measuring the temperature in a welding bath;
2. Pyrometer measuring the temperature in the HAZ;
3. Pyrometer measuring the temperature at the fusion line;
4. Pyrometer measuring the temperature, measuring the heating temperature
5. Pyrometer measuring the temperature of the arc.

With thermal camera

6. Thermal camera measuring the temperature in a welding bath;
7. Thermal camera measuring the temperature in the HAZ;
8. Thermal camera measuring the temperature at the fusion line;
9. Thermal camera measuring the temperature, measuring the heating temperature
10. Thermal camera measuring the temperature of the arc.

2. Contact and non-contact temperature measurement of welding process

The laboratory setup is shown in Fig. 3 and consists of: 1. Welding machine Cebora 2030m; 2. Apparatus for monitoring the welding process Arc Tracker; 3. Wires for measuring welding current; 4. Wires for measuring welding voltage; 5. Laptop to Arc Tracker with Power Wave Manager software installed; 6. WiFi router TP Link; 7. Welding table; 8. Welding tractor; 9. Welding torch; 10. Bottle with shielding gas; 11. Welded details; 12. Trotec TP10 pyrometer; 13. Laptop to pyrometer with developed Matlab software product for temperature monitoring; 14. Tripod; 15. Eight-channel temperature recorder Pico TC 08; 16. Laptop to Pico TC 08; 17. Thermocouples; 18. Remote computer

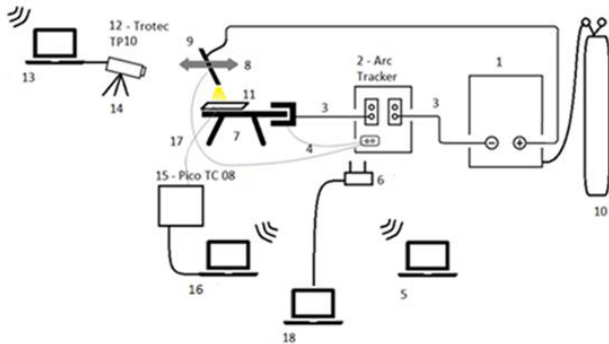


Fig. 3 Laboratory setup for contact and non-contact measuring temperature in the welding process.

The Trotec TP10 pyrometer (12) is focused on the workpieces to be welded. It is connected to a laptop via a USB connection. The distance between the pyrometer and the welded parts is 120cm. The pyrometer continuously transmits data to the laptop (13) in packets of 17 bytes for each report. The emissivity of the pyrometer is adjusted before the measurement.

Pico TC 08 (15) is an eight-channel temperature recorder that measures the temperature of the surface or in the volume of the welded parts by fixed K type thermocouples (17) in real time. A laptop (16) is connected to the Pico TC 08 recorder via a USB connection. PicoLog 6 software product is installed on the laptop for reading, visualizing the temperature in real time and storing its values.

The welding process is held on to steel plate with dimensions 350x120x6mm. the welding parameters are set to 100A welding current, 10 V – welding voltage. Speed of the welding torch is 50cm/min. welding is performed with grey electrode WCe20 Ø 2,4mm. Shielding gas is Ar with flow 15l/min,

Results of contact and non-contact temperature measurements are shown on fig. 4 and fig. 5.

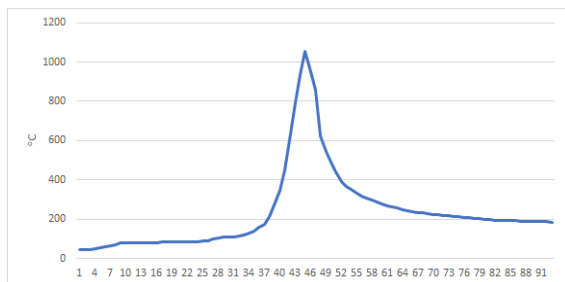


Fig. 4 Non-contact measured temperature curve from the pyrometer

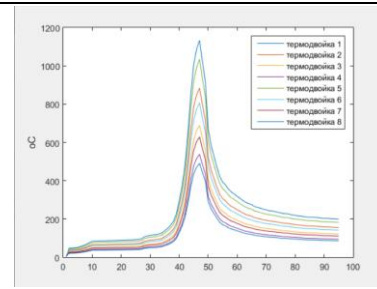


Fig. 5 Contact measured temperature curve from the thermocouples.

3. Conclusions

Optimum results in contact temperature measurement can be achieved by measuring with suitable thermocouples using three main methods – welding the thermocouple to the measured surface, pressing it strongly into the surface, placing it in inspection holes. Each of these methods has advantages and disadvantages.

Non-contact temperature measurement methods are affected by the condition and properties of the measured surfaces, and the emissivity must be adjusted before measurement. With these methods care must be taken to ensure that there are no obstructions in the field of view between the meter and the object and that the meter is not focused too close to the welding arc.

A laboratory setup has been developed, through which welding contact and non-contact temperature can be measured in real time. The measured parameters can be transmitted to a remote computer via the Internet, where the data can be visualized and archived.

Contact and non-contact measured temperatures are within 9% deviation which is good result.

Acknowledgments

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Environmentally Friendly Material Used in Building Construction: Wood-Cement Briquette for Earthquake Zones

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Abstract This study presented a sustainable construction material, wood-cement briquette, for construction indust. Wood-cement briquette has significant advantages as compared to the traditional cement briquettes such as lower carbon footprint, lower cost, easy production, environmental friendliness, sustainability. Wood-cement briquettes have a good thermal insulation and sound insulation than traditional briquettes. In addition to wood, other lignocellulosic materials such as hemp and flax can be also used in the producrion. Especially, it is a better material for buildings located in earthaqure -prone areas because the relatively elastic structure of wood makes it a good material in regions prone to seismic activity. Wood-cement briquettes are suitable material for single or dublex buildings. It is estimated that its use will considerably increase in construction industry in near future. This study, characteristics of raw materials used in wood-cement briquette, the physical and mechanical properties and potential uses of wood-cement briquettes are given in this review study

KEYWORDS: WOOD CEMENT BRIQUETTE, CEMENT, CONSTRUCTION INDUSTRY, WOOD

1. Introduction

Wood-cement briquettes are manufactured from a mixture of organic and inorganic materials, and water. As for organic material, lignocellulosic materials, especially industrial wood waste such as sawdust, and waste of annual plants after harvesting such as flax and hemp particles are used. As inorganic material, cement (usually portlant cement) is used. Some special additives are also used in the production. In the production of wood-cement briquette, industrial wood waste, MDF/particleboard/plywood wastes; It has been stated in the literature that annual plant stems such as wheat straw, coconut fiber, flax, hemp and paper mills' fibrous pulp can be used successfully. Apart from this, agricultural product wastes such as various hazelnut shells and rice paddy can be used in the production of cemented particleboard.

Wood-cement briquettes have some significant advantages when compared with other building materials such as concrete. The first advantage is the possibility of constructing buildings of one or two floors. This list also includes [1-3]:

1. Environmental friendliness. Only natural raw materials are used in production.
2. The light-weight of wood concrete greatly facilitates the construction process itself.
3. High level of fire resistance, despite the presence of wood.
4. Easy processing of wood concrete using any cutting tools, ease of operation even for non-professionals.
5. Good vapor permeability, allowing buildings to breathe deeply and provide residents with an ideal microclimate.
6. A good biological durability agains to mold fungi and fire resistance.
7. High level of sound insulation and thermal insulation characteristics.
8. Good resistance to shrinkage, ability to withstand seismic activity.
9. The price of the blocks is relatively low, if you do not compare them with their rather cheap competitors - gas or foam concrete.

The biggest advantage of all types of lightweight wood-cement briquettes is the ability to build an inexpensive (not monolithic) foundation for a building. The advantages of wood concrete include bending strength and the ability to restore its original shape after deformation. It allows for trouble-free transportation, installation of building materials and operation of the house. Many people are captivated by the ease of screwing in self-tapping screws and driving nails.

Not all tree species are equally suitable for obtaining the woody material used in cemented particleboards. Because in some wood species, the hardening of the cement is either delayed or prevented. Studies conducted in Germany revealed that 36 of the 99 tree species examined were suitable for this purpose. The results showed that coniferous woods were more suitable than leafy ones. The main mineralizer was technical sulphate aluminum, which was used to

remove sugars from wood chips. The sugars in wood interfere with the binding of the cement. The amount of water-soluble sugars and phenolic substances contained in the chips are effective on the availability of wood species. The tannic substances present in the wood have a retarding effect on the solidification of the cement. If the amount of glucose, sucrose and xylose in the woody material constitutes a concentration of 0.25% by weight in the mixture, the produced boards become unusable. This is because a layer is formed on the surface of the cement particles that prevents them from bonding with water [4].

It has been understood that this barrier layer consists of a water-insoluble calcium salt of saccharic acid consisting of carbohydrates. In addition, if the amount of hemicellulose in wood increases, the possibility of using this raw material in the production of cemented particleboard decreases. It has also been understood as a result of research that xylan obtained from leafy beech retards the solidification of cement more than poly-galacto-cart obtained from conifers. Thus, the sugar and starch present in the wood prevent solidification. Heartwood contains more substances than sapwood that can inhibit cement solidification. It has been reported in the literature that cementitious particleboards produced from wood stored in outdoor conditions have higher resistance values than wood used directly or stored indoors [5,6]. For this reason, only the bark-peeled coniferous wood raw material is used in the factories producing this type of board today.

The bark of the wood raw material to be used should be kept in the warehouses for at least 3 months in summer and 6 months in winter in a well-peeled state. Thus, wood reaches an equilibrium humidity during storage and substances that delay solidification are neutralized. However, at this time, care should be taken against the formation of rot and mold fungi that may occur in the wood. The raw materials used in the production of cemented particleboard are cement, wood chips, water and chemical additives (Bozkurt and Goker, 1990). Chemical additives called "mineral substances" (sodium silicate-aluminum sulfate) are added to the mixture to ensure good bonding of wood and cement. The chemical components of portlant cement and their ratio are given in Table 1.

Table 1. Chemical components of portlant cement and their ratio [7].

Chemical substances in portlant cement	Formula	Ratio (weight %)
Quicklime	CaO	60-67
Silicon oxide	SiO ₂	17-25
Alumina	Al ₂ O ₃	3-8
Iron oxide	Fe ₂ O ₃	5-6
Sulfate	SO ₃	1.3-3
Magnesium oxide	MgO	0.1-4
Alkali chemicals	(K ₂ O, Na ₂ O)	0.4-1.3

The thickness of the chips to be used in the production of cemented particleboard is 0.2-0.4 mm, the length is in the range of 10-30 mm,

and it is prepared as in normal particleboard production (Bozkurt and Goker, 1990). In the dosing section, chips, cement and other chemicals are mixed with water in a mixer. The amount of substances added to the mixture is adjusted according to the dry chip weight. These ratios are determined and their mixing with weighing is done automatically.

There are some peculiarities in the wood concrete production process. These include [3]:

1. Accuracy of dosage of all components. Possible deviations may be only 2-3%, but no more.
2. The amount of the water is very important. If it is not enough, then the concrete solution will not work. Because the cement will not react with water. Excess moisture reduces strength and prolongs the period required for its development.
3. Set of chemical additives. It depends on many factors. For example, for larch chips, unlike other coniferous species, they require double the amount. The volume of additives is also affected by the size of the filler and humidity.
4. A certain temperature of water for dissolving mineralizers in it. Minimum - $+15^{\circ}$. To ensure this condition, the liquid is preheated. Another possible solution is to use "hot medicine"-calcium chloride- CaCl_2 as a mineralizer.

The material is divided into 2 main types: structural and thermal insulation. The first is intended for the construction of load-bearing surfaces; it has sufficient density - from 500 to 850 kg/m^3 (according to some sources - up to 1200 kg/m^3). The second type is used only as a thermal insulation material. Its density is 400-500 kg/m^3 . There is a third, intermediate option - structural and thermal insulating wood concrete (450-600 kg/m^3). It can be used in any capacity: for the construction of main walls, as well as for the construction of partitions.

Significant Criteria in Choosing of the Fire Retardant Chemicals are as follows:

- Low-toxicity (minimal risk to human health)
- Minimal risk to atmosphere, climate and environment
- Flame spread of 25 or less or «Class B»
- Self extinguishing
- Won't spread fire
- Reduced heat release
- Disrupts volatile gases
- Releases carbon
- Suitable with process conditions (such resin blending, hot pressing) during production of wood based-panels
- Minimum effect on mechanical properties of wood and wood based materials
- Easy-supply
- Low-cost
- Easy preparation and application to wood and wood-based panels

Choice of fire retardants in relation to product and process demands depend on several factors. Potential service life problems have to be eliminated.

Important factors to consider are:

- Type of wood based substrate,
- Regulatory requirement to be satisfied,
- New build or maintenance/upgrade,
- Service life conditions/environment,
- Installation conditions,
- Maintenance requirements,
- Effects, if any, on appearance or other natural or inherent properties of the substrate.

2. Arbolit briquette

Arbolit is one of the varieties lightweight wood-cement composites. The name of the material shows French roots: arbre is translated from French as "tree". It is mainly used in rural construction. Arbolit has a number of advantages compared to traditional building materials: reduced mass of buildings, reduced the complexity of the construction of buildings decreased by 2.5

times consumption per 1 m^2 of cement, sand, high thermal resistance of structures. Arbolit, having a macroporous structure provides good ventilation in the premises, and high thermal performance, thereby reducing energy consumption for heating and ventilation of buildings. No need for additional external heat – soundproofing. The walls of the arbolit are good to be finishing as the traditional finishing materials. The characteristic surface structure of arbolite products is able to provide first-class adhesion to the traditional plaster layer and concrete surface, excluding additional reinforcement. The composition of the arbolit briquette is presented in Figure 1.

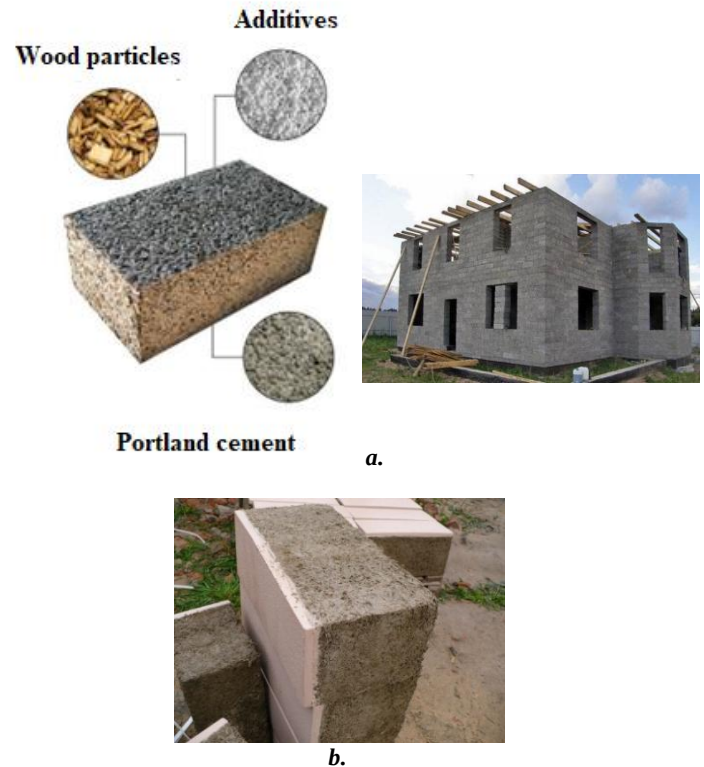


Figure 1. a: The composition of the arbolit briquette [2]. b: Decorative layer application to the surface of arbolit [3].

Arbolit contains:

- Wood chips (up to 80-90% of the volume)
- Cement
- Water
- Chemical additives to improve strength and increase chip adhesion to cement.

In a recent Russian patent, arbolit mixture contains (wt %): Portland cement 47-52; crushed wood 22-31.5; quartz sand 20-25; 3% hydrogen peroxide solution 1-1.5, with water-cement ratio constituting 1.1-1.3. [8].

Numerous reviews by private builders suggest that Arbolite is better to buy ready-made than to produce on your own (Fig. 3). For the production of a cubic meter of material, 1200 liters of wood chips, 240 liters of cement and water will be needed until the mixture begins to shine. Chips are poured first with a small amount of water, cement is added, well mixed, better in concrete mixer if necessary add water.



Figure 3. The preparation of arbolit briquettes [3].

The wood filler contains sugars that prevent the adhesion of cement paste to the surface of wood particles. To solve this problem, 2 main strategies are used:

1. Drying of wood raw materials before use in production for several months.
2. Mineralization of the surface of the chips in a solution of chemical components.

Typical values for structural blocks are density values from 550 to 700 kg/m³. However, you can buy products with a density of up to 850 kg/m³. Too high values indicate good load-bearing capacity of the elements, but inferior to the lighter in thermal insulation qualities.

Sufficient material strength for use in construction is achieved only when cement with a grade of at least 400 is used. As additive, In a 1 m³ wood-cement briquette is used 12 kg CaCl₂, 12 kg (Al₂SO₄)₃, and 12 kg (8+4) Al₂(SO₄)₃+Ca(OH)₂.

The following types of arbolita are distinguished by density:

- Thermal insulation with a density of 450 kg/m³
- Structural and thermal insulation - from 450 to 600 kg/m³
- Structural - from 600 to 850 kg/m³

The main component for the manufacture of arbolite, as already mentioned above, are joinery and furniture. The technological properties of arbolit depend on chemical additives. In addition to calcium chloride, it can be soluble glass, aluminum sulphate, harated lime, they help improve arbolite blocks and give them new properties. The technical characteristics of arbolite briquette are given in Table 2.

Table 2. Some physical and mechanical properties of arbolit [2].

Property	Unit	Result
Average density	kg/m ³	400-850
Compressive strength	MPa	0.5-1.0.
Bending strength	MPa	0.7-1.0.
Thermal conductivity of arbolit	W/(MxC)	0.008-0.17
Water absorption	%	40-85
Shrinkage	%	% 0.4-0.5
Fire resistance	h	0.75-1.50
Sound absorption	126-2000 Hz	0.17-0.60

Arbolit today is widely used in private construction for the construction of houses (up to 3 floors), cottages, garages and household buildings, the material is also in demand in the construction of low-rise industrial buildings (Fig. 4).

3. Conclusion

The result of this study showed that wood-cement briquettes could be succesffly used in one or two layers buildings. Although wood-cement briquette are widely used in rural construction, its use in urban construction is still limited. In particular, the use of wood in cement briquettes should be encouraged due to its more flexible structure than concrete and its resistance to possible vibrations in earthquake zones. Since issues such as global climate change and the carbon footprint of materials are becoming increasingly important today, it is necessary to attach importance to the use of wood sawdust in portlant cement for construction industry.

Advantages of arbolit for structural applications as given below [2]:

1. Excellent thermal insulation. Thermal conductivity coefficient of wood concrete with a density of 400 kg / m³ - 0.07 W / m * K, with a density of 500 kg/m³ - 0.09 W/m*K, 600 kg / m³ - 0.11 W/m*K, 800 kg / m³ - 0.15 W/m*K.
2. Good sound insulation
3. Excellent vapor permeability, therefore, the optimum microclimate is preserved in the house from wood concrete.
4. high resistance to fire. The material refers to refractory (combustibility group - G1), flame retardant (B1) and low-smoke-forming (D1) materials. Good biological durabil
5. Light weight saves on arrangement of the foundation and simplify the construction process. One arbolit block in volume is the same as 15 ordinary bricks, but its weight is 10 times less.
6. Easy processing,
7. Environmental friendliness.
8. Resistance to mold and rodents.
9. High strength. Cracks do not form on the surface of the blocks. Buildings can be erected without additional inter-row reinforcement
10. Ease of installation of fasteners, including nails and self-tapping screws, which distinguishes an arbolite block from polystyrene concrete or expanded clay concrete

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The assessment of Trip steel innovation potential when used for the deformation zone's parts

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Abstract: Nowadays, a lot of emphasis is placed on the car safety. It's very difficult to ensure the highest possible body strength using conventional tests. The correct testing method is the basis for the safety of the car bodies. It is less expensive and time-consuming to apply deformation characteristics testing to selected types of steel than to produce a complete body and then test its deformation properties. The three-point bending test makes it possible to determine the absorption potential of the selected sheet metal. The purpose of this article is to evaluate innovation potential of the multiphase Trip steel, which is used in the automotive industry for the body-in-white structural components, and deformation elements mainly.

Keywords: 3-POINT BENDING TEST WITH FIXED ENDS, ENERGY ABSORPTION, DEFORMATION WORK, STIFFNESS CONSTANT

1. Introduction

In car safety, many passive elements have supplemented and even replaced by active safety elements. The brake systems were supplemented with electronic control units that ensure better brake operation and vehicle controllability in skidding [1]. However, even active members in combination with passive ones will not ensure the complete safety of the vehicle crew. Therefore, scientists and car developers had to focus on the materials used for the construction of the car [2-5].

It was necessary to focus on the deformation zones, their construction, and the material from which they are made. The deformation zone is not responsible only for the safety of passengers but also pedestrians. An intersection between the strength of the material and the ability to absorb energy on the deformation path had to be found. In modern cars a "controlled" course of deformation needs to be ensured (Fig. 1). The deformation of the front part of the vehicle should have a graded course consisting of 5 stages: [6]

1. protection at low speeds - parking maneuvers,
2. compatibility - protection of a co-participant in a traffic accident,
3. self-protection - the necessity to comply with biomechanical criteria,
4. space for crew survival,
5. pedestrian protection.

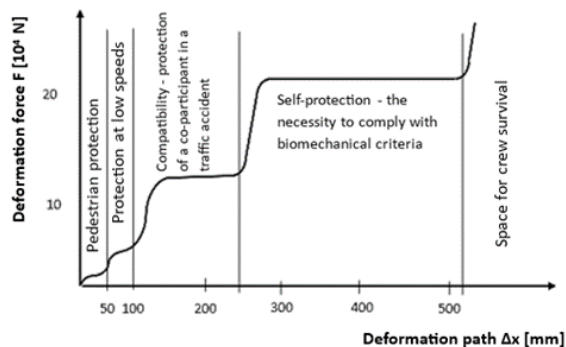


Fig. 1 Progressive course of deformation [6].

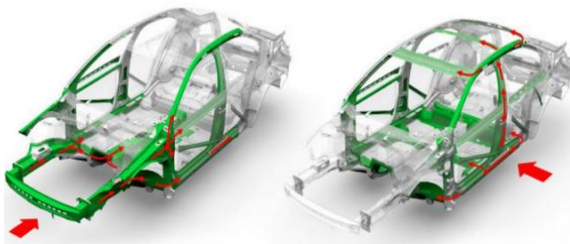


Fig. 2 Distribution of deformation forces in frontal and side impact [8].

In modern cars, deformation zones are distributed around the entire cabin of the vehicle. That means the space for the crew is sufficiently protected. While at a frontal impact of a vehicle there is enough space for deformation, the side of the car must be sufficiently rigid to withstand the side impact (Fig. 2). [6,9]

Compared to the front or rear of the vehicle, where there is sufficient length to create deformation zones, the side parts of the vehicle have minimal space to absorb deformation energy. A collision with a vehicle from the side is the most dangerous for the crew, as most vehicles are very vulnerable from the side. Therefore, the greatest number of high-strength materials are used for these areas, which are able to absorb a significant amount of energy in a side impact. [7-9]

A novelty on the market in the area of safety elements of deformation zones is the Pre-Safe structure - Fig. 3. They are actually special metal profiles, stored in the reinforcements of the body. In the event that the sensors of the vehicle's control unit detect an impact, the charge is activated and the struts are inflated. The duration of inflation is a few milliseconds. The pressure in these reinforcements reaches 1-2 MPa. The braces can hold a load of 100 kg, i.e. 1 kN. Their function is similar to the function of an airbag, but with the difference that they are made of metal material and the reinforcements do not inflate, which can also appear as a disadvantage. [7-9]

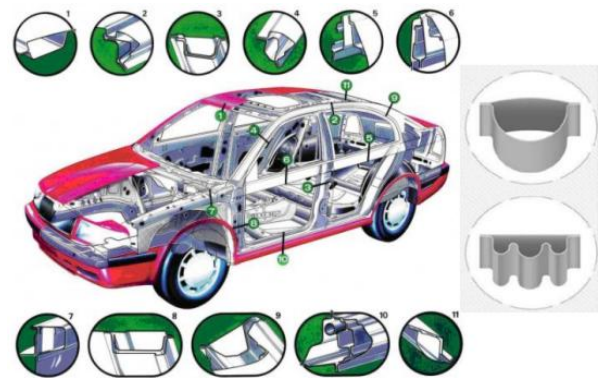


Fig. 3 Pre-Safe structure and side reinforcements of the car. [9]

The stress of the beams, bumper, roof reinforcement and doors can be tested with a three-point bending test, where can be measured the bending strength (material resistance) and deformation work. [10] Three-point bending testing is a process in which a sample is plastically deformed (usually to the point of failure) in order to obtain the desired outputs. From these tests, we can determine values such as:

- the magnitude of the resistance force required to deform the sample on a predetermined path,
- springback of the sample on a predetermined path,
- absorption potential of the material,
- the size of the path required to break the sample.

according to STN EN ISO 10 113. The strain hardening exponent and the material constant were determined according to STN EN ISO 10 275.

2. Materials and methodology of experiment

2.1 Three-point bending test

The experimental test was performed at predetermined strain rate, using a combination of three-point bending and stretching. The absorption potential of the material was determined from the force required to deform a sample with a width of 26 mm and a length before deformation $L_0 = 300$ mm (length of the loaded part of the sample $L_0 = 2 \cdot X_0 = 2 \times 110$ mm) and the thickness of the sample $a_0 = 0.75$ mm (Fig. 4).

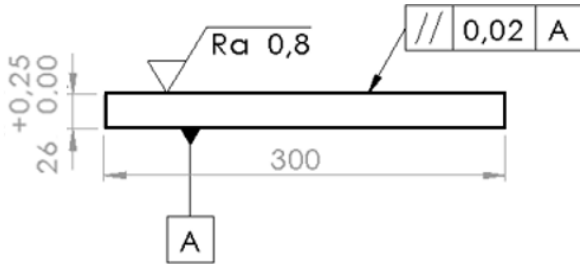


Fig. 4 Dimensions of the tested sample.

The three-point bending test was performed on a TiraTEST 2300 testing machine, equipped with the necessary preparations for holding the sample and also with a sensor measuring the magnitude of the load force. The tested samples were fixed with jaws into the machine in such a way that there was no movement of the sample during the test. The sample was loaded by force through the roller mounted on the end of the strain gauge sensor. With such a combination of clamping the sample and its bending, a combined bending and tension stress occurs. TiraTEST 2300 allows you to record the measured force and traversed path of the crossbar to the computer. The support rollers on which the sample was positioned were at a distance of 110 mm from each other and their diameter was $d = 30$ mm. The samples were stressed until failure (Fig. 5).



Fig. 5 Three-point bending test [10].

2.2 Materials and their properties

Sheets of high-strength low-alloyed steel H220 PD+Z1 (HSLA) and multiphase steel RAK 40/70 (TRIP) were used for the experiment, the chemical composition of which is shown in Tab. 1.

Table 2 shows the material properties of the investigated materials. Cold-rolled steel sheets are characterized by their anisotropy, therefore the properties were evaluated in the 0°; 45°; 90° directions. The mechanical properties were determined by a tensile test according to STN EN ISO 6892-1. The normal anisotropy coefficients (Lankford coefficients) were determined

Table 1: Chemical composition of the experimental materials.

Material	Chemical composition%								
	C	Si	Mn	P	S	Cu	Al	Cr	Mo
H220PD+Z1	C	Si	Mn	P	S	Cu	Al	Cr	Mo
	<0.077	0.019	0.358	0.011	<0.002	0.017	0.026	0.009	<0.007
	Ni	V	Ti	Nb	Co	W	Fe		
RAK 40/70	<0.002	0.003	<0.002	0.031	0.017	<0.036	99.38		
	C	Si	Mn	P	S	Cu	Al	Cr	Mo
	<0.089	0.182	1.591	0.028	<0.002	0.023	2.267	0.042	0.022
	Ni	V	Ti	Nb	Co	W	Fe		
	<0.002	0.011	<0.007	0.022	0.022	<0.002	9569		

Table 2: Mechanical properties of the experimental materials.

Material	Direction [°]	Rp0.2 [MPa]	Rm [MPa]	Ag [%]	A80 [%]	K [MPa]	n	R	Eps	Wpl [Nm]
H220PD+Z1	0	214	375	24	40	677	0.24	1.21	0.0063	
	45	217	359	26	42	651	0.23	1.76	0.0063	
	90	223	368	23	38	658	0.23	1.75	0.0072	
Average values		223	368	23	38	658	0.230	1.750	0.007	96.17
RAK 40/70+Z1	0	428	751	25	29	1484	0.298	0.64	0.0134	
	45	441	765	26	29	1515	0.3	0.81	0.0144	
	90	434	751	26	31	1408	0.285	0.76	0.0141	
Average values		434	756	26	30	1469	0.294	0.737	0.014	217.00

2.3 Experiment evaluation methodology

The evaluation of elongation, deflection and suspension of the samples was carried out according to the diagram in fig. 6, when the path of the bender is 25 mm, where the individual quantities are:

- bend path -h
- path of the bender after unloading force - h'
- angle after unloading force - α'
- angle under load - α''
- length of half of the examined part of the sample in the unloaded state - X_0'
- length of half of the examined part of the sample under load - X_0''

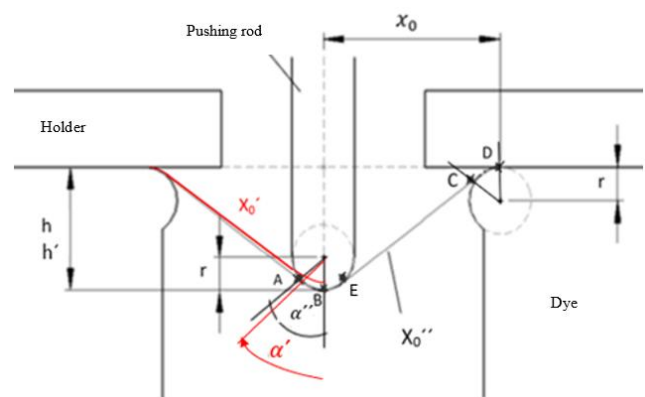


Fig. 6 Scheme of the three-point bending test with fixed ends.

The deformation of the examined part of the sample was calculated based on relations (1) and (2). The assumption was that the free part of the sample is deformed uniformly depending on the

path of the bender h until the moment when a narrowing (neck) occurs. In the initial position of the bender $h=0$, the length of the sample was 110 mm. The size of the angle α can be expressed as:

$$\alpha(h) = -2 \cdot \tan^{-1} \left(\frac{x_0 - \sqrt{h^2 - 4 \cdot r \cdot h + x_0^2}}{h - 4 \cdot r} \right) \quad (1)$$

After the sum of the lengths of the arcs AB and CD and the addition of the section EC, we express the half length of the sample x after deformations as:

$$\alpha(h) = -2 \cdot \tan^{-1} \left(\frac{x_0 - \sqrt{h^2 - 4 \cdot r \cdot h + x_0^2}}{h - 4 \cdot r} \right) \quad (2)$$

The total length of the sample is twice the x obtained from equation (2).

The magnitude of the deformation work was evaluated from the maximum force and path of the bender when the sample broke according to the relationship:

$$W_{def} = \frac{F_{max} \cdot x_{max}}{2} \quad (3)$$

The stiffness constant c can be determined from the record of the bending force F_{max} depending on the path of the bender x_{max} . With the assumed linear course of the dependence, the stiffness constant c will represent the direction of the straight line indicated in the dependence (Fig. 7,8).

3. Reached results and their evaluation

Based on the bending test scheme shown in Fig. 6 and relations (1) and (2) the angles during loading and unloading and the total length of the sample were calculated, the values of which are given in Tab. 3.

Table 3: Extensions of the tested samples – path of the bender 25 mm.

Material	H220PD	RAK 40/70
Force [kN]	9.10	12.88
Path of the bender in the loaded state h [mm]	25	25
The path of the bender in the unloaded state h' [mm]	22.32	21.49
Angle α'' in the loaded state [°]	27.71	27.71
Angle α' in the unloaded state [°]	24.75	23.82
The length of the free part of the sample in the loaded state $2 \cdot x_0''$ [mm]	121.75	121.75
The length of the free part of the sample in the unloaded state $2 \cdot x_0'$ [mm]	119.38	118.7
The difference in the length of the samples after unloading – after springback $x_0'' - x_0'$ [mm]	2.37	3.05

The length of the free part of the sample in the loaded state, with the traveled path of the bender of 25 mm in H220PD steel, was 121.75 mm, after the sample was unloaded, the material contracted by 2.37 mm, which was 0.68 mm less than in RAK 40/70 steel. On the contrary, the force required to deform the sample by 25 mm was 12.88 kN for RAK 40/70 steel, which was 3.78 kN more than for H220PD steel. The differences in values were calculated based on the data presented in Tab. 3.

Table 4: Stiffness constant and measured deformation work.

Material	H220PD (ref)	RAK 40/70
Deformation work W_{def} [J]	230.8	322.2
Stiffness constant c [N.m ⁻¹]	0.348	0.567
$W_{def} / W_{def \text{ ref}}$	-	1.39
$c / c_{ref} = a / a_{ref}$	-	1.63

The deformation work W_{def} required to deform the sample until the moment of its failure reached the value of 322.2 J for RAK40/70 steel, which is 91.4 J more than for the reference steel H220PD. The stiffness constant c increased in comparison to the reference material by 1.63x.

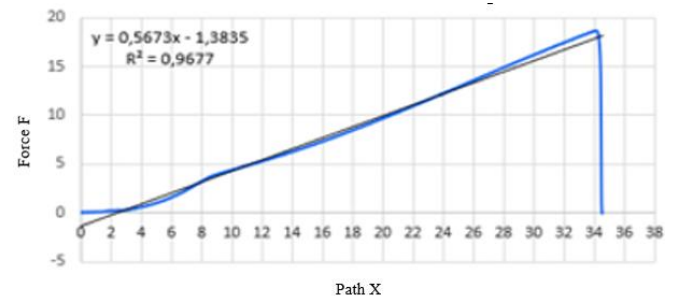


Fig. 7 Record of the dependence of the bending force on the path traveled by the bender for RAK 40/70 steel.

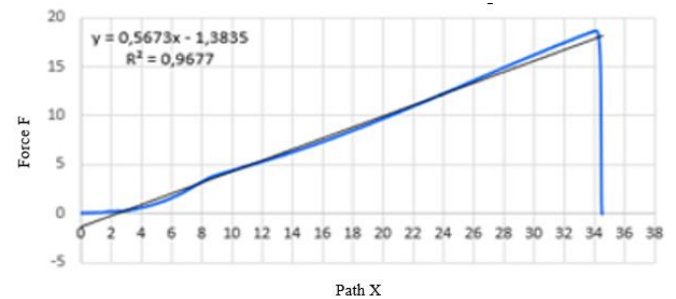


Fig.8 Record of the dependence of the bending force on the path traveled by the bender for H220PD steel.

From the point of view of the protection of the vehicle crew, it is very important to take into account the deceleration of the safety cage. In Euro NCAP, the prescribed frontal impact speed is 64 km/h-1 and in EHK it is 56 km/h-1. At such speeds, the maximum acceleration (deceleration of the vehicle) is a limit coming out from the biomechanical limits of the human body. Overload at such speeds reaches a value of around 20g. However, not only the acceleration but also the track on which such an overload occurs determines whether the passenger is able to survive an impact. The deformation path is closely related to the structure of the deformation zones, the material from which they are made and the geometry of the deformation zones themselves. At the moment the vehicle hits an obstacle, it is possible to write the energy balance condition in the form:

$$W_k = W_{def} \Rightarrow \frac{m \cdot v_0^2}{2} = \int_{x=0}^{x_{max}} F \cdot dx \quad (4)$$

where W_k is the kinetic energy, W_{def} is the deformation work that is consumed to absorb (absorb) the kinetic energy during the impact,

V_0 is the initial speed at the moment of the impact, m is the mass of the vehicle, X is the deformation path on which W_K is absorbed.

Even if the deformation elements of the car are deformed first elastically and then plastically, we consider only the plastic deformation of the deformation elements in the event of an impact. Assuming that the force required for deformation grows linearly, we can write the relation:

$$\frac{m \cdot v_0^2}{2} = \int_{x=0}^{x_{max}} F \cdot dx \quad (5)$$

It is possible to express the strength of resistance by the ratio of the stiffness constant and deformation zones and deformation path:

$$F_{max} = c \cdot x_{max} \quad (6)$$

F_{max} represents the maximum force value on the maximum deformation path x_{max} from the moment when the course of elastic deformation ends and the course of plastic deformation begins. From the law of action and reaction, it follows that at every moment of the collision, the resistance force of the structure is equal to the multiple of the vehicle's weight and its acceleration:

$$F_{SV} = F_{max, Vehicle} \quad (7)$$

or

$$c_i \cdot x = m \cdot a_{i,max} \quad (8)$$

If we consider that there will be a collision of vehicles with the same weight and the same geometry of deformation zones but made of different material, then it is possible to write the equation for a vehicle made of a reference material:

$$c_{ref} \cdot x = m \cdot a_{1,max} \quad (9)$$

and for a vehicle structure made of a different material than the reference material:

$$c_i \cdot x = m \cdot a_{i,max} \quad (10)$$

After comparing the deformation forces on the same path, we get the equation for the improvement ratio when changing the reference material to another:

$$\frac{a_{i,max}}{a_{max,ref}} = \frac{c_i}{c_{1,ref}} \quad (11)$$

It follows from equation (11) that the ratio of the stiffness constants of the considered and reference material is proportional to the ratio of their decelerations or body overload. This means that if we change the material used for the construction of the deformation zones while maintaining the same geometry and deformation path, we can predict the amount of overload on a person in a vehicle collision based on the stiffness constant of the material. With such a material change, it is necessary to ensure that there is no increase in overload, therefore, when using a material with a higher stiffness constant, it is possible to reduce its thickness while maintaining the same deformation characteristics and at the same time reducing the weight of the component.

Conclusion

The aim of the experiment was to compare the absorption characteristics of micro-alloyed steel H220PD and TRIP steel RAK40/70 with a nominal thickness of 0.75 mm for their use in the deformation zones of the car body. The deformation characteristics were evaluated by a three-point bending test with fixed ends. Based on the experiments and their evaluation, it is possible to state:

- when replacing micro-alloyed steel with stronger trip steel, an increase in absorption capacity by 1.39x was found;

- when comparing stiffness constants, there was an increase of 1.63x;

It was found that with the application of a stronger material of the same thickness, there will be an increase in passenger overload at the same time. Therefore, at the same level of overload, by applying a stronger material, it is possible to reduce its thickness and thereby achieve a lower weight of the component while preserving its deformation characteristics.

Acknowledgment

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Adoption of a digital approach to shipshape simulation trials with CFD

Усвояване на дигитален подход за симулационни изпитания на корабна форма с CFD

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Abstract|: *The prediction of maneuverability is a classic problem in ship hydrodynamics. Likewise, ship motions in restricted waters have been studied for a long time.*

It is an indisputable fact that full-scale or model tests of the respective ship meet IMO requirements and provide the necessary information for the maneuverability of the ship in deep unconfined waters. However, they are unable to provide practical insight into understanding of ship maneuverability in shallow water, as the maneuvering behavior of a ship in such areas differs significantly.

Ship maneuvering in coastal areas and harbor approaches, where space is limited, movement speeds are low, and traffic heavier requires deeper researching.

The aim of the present work is to predict the hydrodynamic derivatives in the mathematical model of the maneuvering of ship in shallow waters based on CFD programs with free access like FreeCAD, OpenFOAM and ParaView.

The sequence of solving the task is described with details in this work:

- | | |
|---|---|
| 1. Generating the shape of the studied body | 6. Selection of the calculation algorithm |
| 2. Creating the domains around the experimental body, sizes and boundaries | 7. Substances modeling |
| 3. Defining the continuum, areas and subareas of study, and boundary conditions | 8. Motion modeling |
| 4. Generation of the computational grid | 9. Modeling of currents and energy |
| 5. Defining the continuum – physical models | 10. Flow turbulence modeling |

Results have been obtained for the linear hydrodynamic derivatives in the mathematical model for the maneuvering motion of a ship. They are compared with available experimental and theoretical data in the literature.

KEYWORDS: DIGITAL, SIMULATION, FREE SOFTWARE, CFD, FREECAD, OPENFOAM, PARAVIEW

Preparation and adsorption properties of mixed zinc-calcium phosphates

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Abstract: Here we present data on the preparation and adsorption properties of mixed zinc-calcium phosphates in aqueous dispersions. The phosphates were prepared by co-precipitation from aqueous solutions followed by autoclaving. The effects of various Ca/Zn initial molar ratios and the type of Ca- and Zn-precursor salts (chlorides and acetates) on the structure, morphology and adsorption properties of the obtained phosphates were investigated. Preliminary data on the adsorption of methylene blue indicated that the as obtained mixed zinc-calcium phosphates are promising candidates for application as adsorbents.

Keywords: ZINC, CALCIUM, PHOSPHATES, ADSORPTION, MICROSTRUCTURE

1. Introduction

Nanostructured calcium phosphate has been an object of scientific interest for development of vaccine adjuvants, adsorbents and materials for tissue engineering [1-5]. Calcium phosphate is a non-toxic compound naturally present in the organism and this further makes it attractive for biomedical research and applications. On the other hand, zinc compounds are also relatively non-toxic and some zinc compounds, like zinc oxide (ZnO), have already found applications in cosmetics, dermatology and in many new products under development [6-9].

Here we present some preliminary data on the use of Zn(II) as a potential substitute for Ca(II) in calcium phosphates. In our experiments we prepared various dispersions of mixed Ca-Zn phosphates by co-precipitation from mixed solutions of Ca/Zn chlorides or acetates with a solution of disodium hydrogen phosphate followed by thermal treatment for 1 hour at 115°C. The effect of the Ca/Zn molar ratio in the initial solutions on the structure, morphology and adsorption capacity of the obtained phosphates was investigated.

2. Experimental section

Preparation of Ca-Zn phosphates. To obtain samples from 1A to 1E solutions (0.15 M) of calcium chloride and zinc chloride were mixed in various Ca/Zn molar ratios and were precipitated by drop wise addition of 0.15 M solution of disodium hydrogenphosphate at room temperature and vigorous magnetic stirring. The obtained milky-white dispersions were stirred for additional 10-15 min and then were autoclaved at 115°C for 1 hour. Samples from 1A to 2E were prepared in similar way, but calcium and zinc acetates were used instead of the chlorides.

Methods for characterization. The as obtained suspensions were imaged by using a light microscope Amplival (Carl Zeiss, Jena) equipped for observation in phase-contrast and Canon 800D camera. A drop of each suspension was placed on a glass slide and covered with a cover glass. X-ray powder diffraction (XRD) data were recorded by using a X-ray diffractometer Empyrean (PANalytical) with CuK α radiation.

Adsorption studies. The as obtained phosphates were tested as adsorbents in the form of suspensions. For that purpose, 1.00 ml of each phosphate suspension was mixed with 5.0 ml of aqueous solution of methylene blue and was left for 30 min at room temperature. The suspension was then centrifuged to separate the phosphate particles from the solution and the optical absorption of the obtained supernatant was measured spectrophotometrically at a wavelength of 668 nm. The optical absorbance of the initial solution of methylene blue was 0.65. The results of adsorption studies of methylene blue were given as the percent of adsorbed dye (with respect to the total amount of dye) at this initial dye concentration.

3. Results and discussion

The precipitated phosphates in all cases of the various Ca/Zn molar ratios were milky-white fine suspensions that slowly sedimented upon standing. Phase-contrast microscopy observation

of suspensions revealed the presence of needle-like microscopic crystals, arranged in clusters and predominantly found in the Zn-rich phosphate suspensions (Figs. 1 and 2). The Zn-free calcium phosphate appeared like "amorphous" mass. Our previous studies [10] have demonstrated that calcium forms nanocrystalline apatite under similar conditions. Samples obtained at Ca/Zn molar ratio of 75/25 is a mixture of microscopic crystals and amorphous material.

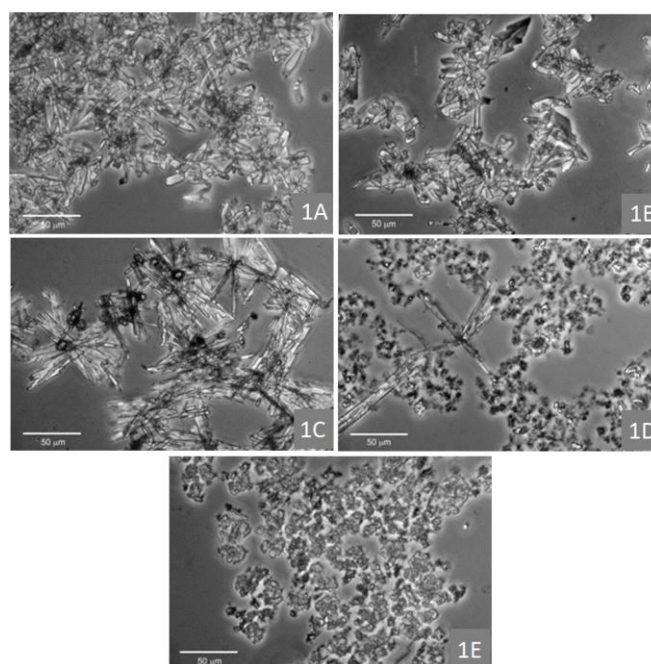


Fig. 1 Phase-contrast microscopy images of the Ca-Zn phosphate suspensions obtained from chloride solutions (samples 1A-1E; for sample descriptions see Table 1). The size bar represents 50 micrometers.

X-ray powder diffraction analysis of dried samples was performed in order to reveal any crystal phases present. The obtained results are summarized in Table 1 and the respective XRD patterns are shown in Figures 3 and 4.

Table 1: Compositions of the different samples of Ca-Zn phosphates as obtained by co-precipitation followed by autoclaving. Samples 1A-1E were prepared from chlorides and samples 2A-2E were prepared from acetates.

Sample	n(Ca)/n(Zn)	Crystal phase	Amorphous material
1A	0/100	Hopeite	-
1B	25/75	Hopeite + Parascholzite	-
1C	50/50	Parascholzite	traces
1D	75/25	Parascholzite	+
1E	100/0	Apatite	+
2A	0/100	Hopeite	-
2B	25/75	Parascholzite	-
2C	50/50	Parascholzite	++
2D	75/25	Parascholzite	++
2E	100/0	Apatite	+

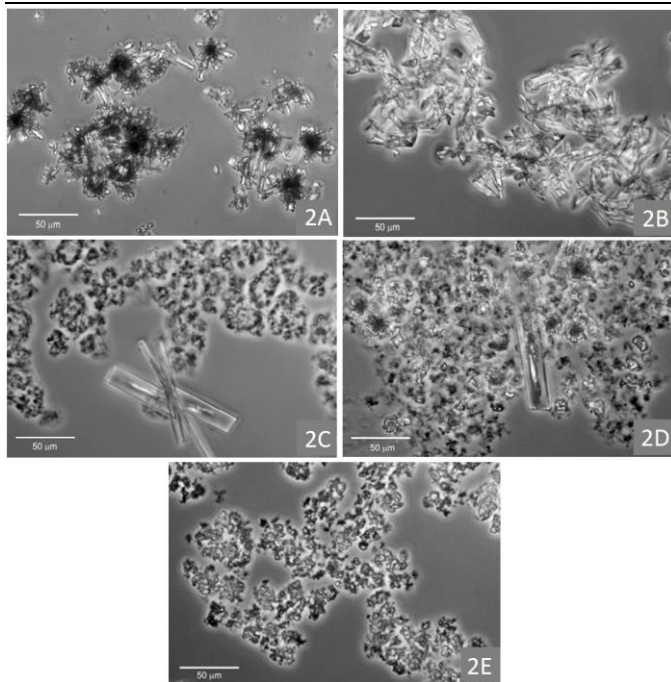


Fig. 2 Phase-contrast microscopy images of the Ca-Zn phosphate suspensions obtained from acetate solutions (samples 2A-2E; for sample descriptions see Table 1). The size bar represents 50 micrometers.

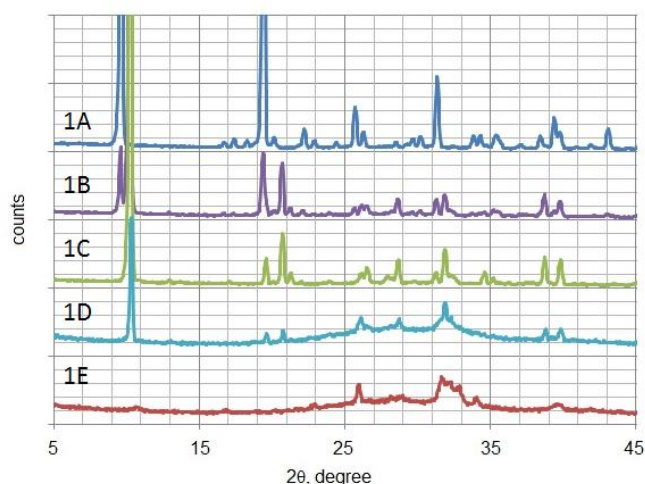


Fig. 3 XRD profiles of the different samples of Ca-Zn phosphates obtained from Ca and Zn chlorides and described in Table 1.

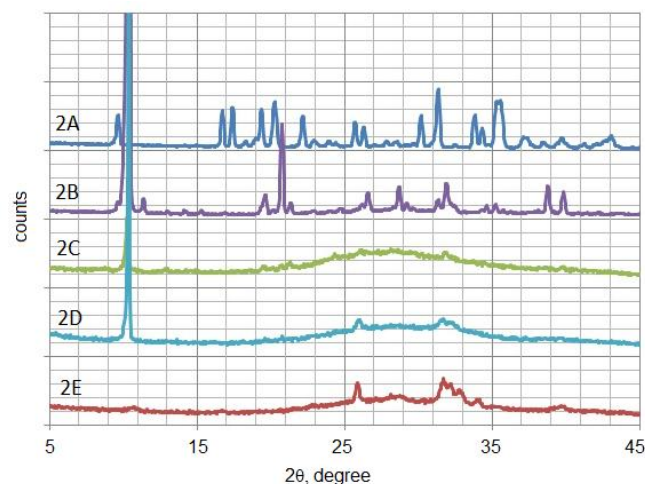


Fig. 4 XRD profiles of the different samples of Ca-Zn phosphates obtained from Ca and Zn acetates and described in Table 1.

XRD analysis indicated that the Ca-free zinc phosphate (1A and 2A) contained pure crystalline hopeite ($\text{Zn}_3(\text{PO}_4)_2 \cdot 4\text{H}_2\text{O}$). Sample 1B (Ca/Zn ratio of 25/75) contained a mixture of hopeite and parascholzite ($\text{CaZn}_2(\text{PO}_4)_2 \cdot 2\text{H}_2\text{O}$), while sample 2B contained parascholzite. Sample 1C (Ca/Zn ratio of 50/50) contained mostly parascholzite phase and some traces of amorphous-like material, while the corresponding sample 2C was mostly amorphous with some parascholzite crystals. Samples 1D and 2D (Ca/Zn ratio of 75/25) contained some parascholzite microcrystals dispersed within amorphous-like calcium phosphate. The defined crystals could be observed by light microscopy in the samples with pure calcium phosphate (1E and 2E), but the XRD analysis indicated the presence of nanocrystalline apatite.

Studies of adsorption of methylene blue as a model dye showed that the composition of suspensions did not have a big effect on the adsorbed amount of dye – in all cases about 20 to 30% of the initial dye was adsorbed. The adsorption of methylene blue on surfaces with negative zeta-potential is expected to be favored by its cationic nature. Therefore, we assume that the predominant forces of interaction between the Ca/Zn phosphates and methylene blue are electrostatic in nature. Previous studies on the adsorption of methylene blue on hydroxyapatite nanoparticles supposed that the mechanisms for the adsorption in this case may include electrostatic attraction, hydrogen bonding, and Lewis acid-base interactions [11]. Further studies on the adsorption capacity of Ca/Zn phosphate suspensions are currently in progress and will be reported in future articles.

4. Conclusions

In this article we presented the preparation and characterization of various Ca/Zn phosphates in the form of aqueous suspensions as potential adsorbent materials. The phosphates were prepared by coprecipitation from aqueous solutions of Ca/Zn chlorides or acetates followed by autoclaving for 1 hour at 115°C. The pure zinc phosphate crystallized as hopeite and the pure calcium phosphate formed nanocrystalline apatite. The mixed Ca/Zn phosphates consisted predominantly of microcrystalline parascholzite and different amounts of amorphous material. The as obtained phosphates were found to be promising candidates for adsorbents, especially for cationic substances.

5. Acknowledgements

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Development of Modular Flue Gas Waste Heat Exchanger for ORC (Organic Rankine Cycle) Systems

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Abstract: The escalating global demand for sustainable and efficient energy solutions has spurred increased exploration into waste heat recovery technologies. Among these, the integration of Organic Rankine Cycle (ORC) systems with diverse industrial processes stands out as a promising avenue for effectively harnessing low-grade waste heat. This integration not only holds the potential to significantly improve overall energy efficiency but also plays a crucial role in mitigating the environmental impact associated with industrial operations. Recognizing this potential, the primary focus of this research lies in the meticulous design, optimization, and performance evaluation of a modular Flue Gas Waste Heat Exchanger (FGWHE). This modular FGWHE is strategically crafted to seamlessly integrate with ORC systems across a spectrum of applications, offering versatility and adaptability to varying industrial settings. This paper further extends the exploration of this research through a comprehensive presentation of Computational Fluid Dynamics (CFD) simulations. These simulations delve into the intricacies of a specifically designed modular FGWHE tailored for Organic Rankine Cycle systems. Through detailed CFD analyses, the performance characteristics, heat transfer efficiencies, and fluid dynamics within the modular FGWHE are rigorously examined. The simulation outcomes provide valuable insights into the thermal behavior and overall effectiveness of the modular FGWHE under various operating conditions.

KEYWORDS: ORGANIC RANKINE CYCLE, WASTE HEAT RECOVERY, FLUE GAS WASTE HEAT EXCHANGER, MODULAR DESIGN, EFFICIENCY.

1. Introduction:

The utilization of waste heat from industrial processes has gained considerable attention as a viable means to enhance overall energy efficiency. ORC systems have proven effective in converting low-temperature waste heat into electricity, making them an attractive option for a wide range of industries. The integration of a modular FGWHE with ORC systems presents a novel approach to optimize energy recovery from flue gases, which are a common source of waste heat in industrial settings.

The primary objectives of this research are to develop a modular FGWHE design tailored for seamless integration with ORC systems and to optimize the thermal performance of the FGWHE to maximize heat recovery from flue gases as well as to evaluate the overall efficiency of the integrated ORC system with the modular FGWHE.

Studies by Smith et al. (2018) and Chen et al. (2020) have delved into the fundamental principles of ORC systems, emphasizing the importance of selecting suitable working fluids and optimizing operating conditions for maximum efficiency. These works provide insights into the thermodynamic processes governing ORC technology.

Research by Wang et al. (2019) and Zhang et al. (2021) explores diverse applications of ORC systems, particularly in industrial processes. The integration of ORC with various heat sources is examined, highlighting the need for adaptable heat exchangers to accommodate different waste heat streams.

Recent studies by Li et al. (2022) and Sharma et al. (2021) underscore the significance of industrial waste heat as a valuable resource. These works emphasize the importance of recovering low-grade waste heat and converting it into useful energy, aligning with the objectives of this research.

The challenges and opportunities in waste heat recovery are explored by Liu et al. (2019) and Gupta et al. (2020). Understanding the barriers to effective heat recovery and proposing innovative solutions is crucial for the successful integration of waste heat recovery systems.

Traditional FGWHE designs have been extensively studied by Jones et al. (2017) and Kim et al. (2018). These studies provide insights into conventional heat exchanger configurations, emphasizing the need for advancements to enhance their efficiency and adaptability.

Innovative heat transfer enhancement techniques are explored by Wu et al. (2020) and Park et al. (2022). These studies investigate methods such as surface modifications and fluid dynamics to improve heat transfer within FGWHEs, contributing to the development of more efficient designs.

While existing literature provides a solid foundation, there is a noticeable gap in research concerning modular FGWHE designs tailored for integration with ORC systems. Few studies address the specific requirements of modularity and compatibility with various industrial processes. This research aims to fill this gap by proposing and developing a modular FGWHE design optimized for ORC systems.

Identified research gaps highlight the need for a focused investigation into modular FGWHEs, setting the stage for the development and optimization of a novel modular FGWHE for ORC systems. This paper aims to contribute to the existing body of knowledge by addressing these gaps and advancing the field of waste heat recovery in industrial applications.

2. Methodology:

This section outlines implementation of a domestic, modernized product integrating engineering designs and advanced boiler technology, specifically Air Quench Cooler (AQC) and Pre-Heater (PH) heat exchangers, within the context of Waste Heat Recovery (WHR) facilities utilizing the Organic Rankine Cycle (ORC) system. The objective of these facilities is to mitigate carbon emissions and decrease reliance on renewable resources by converting high-temperature flue gas into electrical energy. In contrast to conventional systems, the discussed facilities utilize the ORC system, which employs oil rather than steam, offering distinct advantages in water conservation.

A key drawback of SRC systems is the substantial water consumption (200 m³/day) during renewable energy production. In alignment with a Green Energy approach, our company adopts the ORC system technology to address this environmental concern. The differences between SRC and ORC systems extend to the design of heat exchangers employed within these systems.

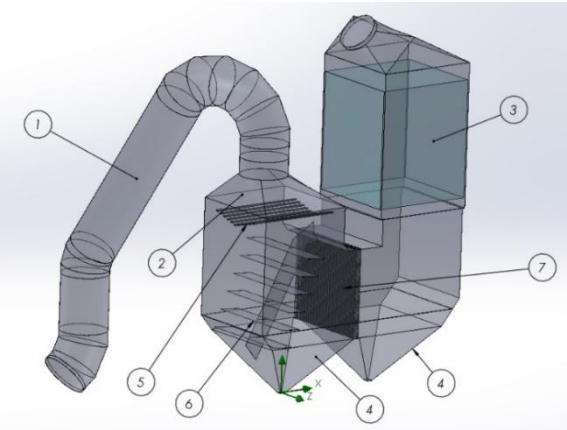
This article highlights advancements achieved through the synergy of our company's experience and engineering prowess, setting our project apart from global precedents. The AQC and PH boilers, integral components of the discussed project, have been meticulously designed to align seamlessly with the ORC system.

A notable innovation is the production of monoblock-form heat exchangers, a departure from conventional designs. This approach minimizes errors stemming from excess resources, reduces assembly and maintenance costs, shifts the majority of manufacturing processes to controlled workshop environments, and facilitates thorough and efficient inspections. These enhancements collectively contribute to the heightened reliability of our product.

3. *CFD Analysis:*

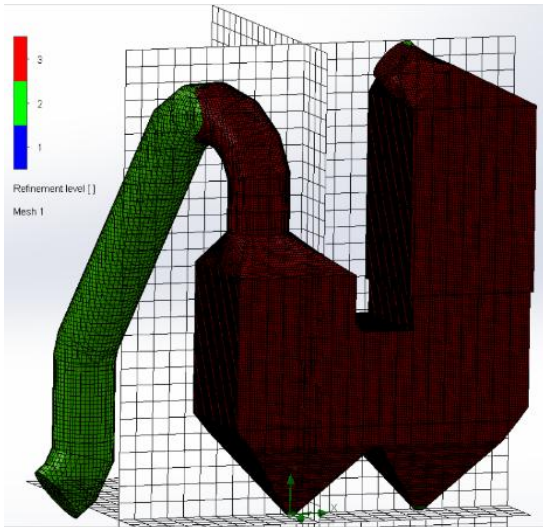
Here the flue gas behaviour and distribution inside AQC boiler, with particular focus on the boiler inlet section, where a good gas distribution at the first heat exchanger tubes is required. The CFD analysis includes the AQCboiler inlet duct, to check if its routing is affecting the gas distribution, and the boiler itself up to outlet flange. The flue gas distribution downstream the heat exchanger tubes does not affect the boiler performances.

The geometry studied includes the following components as seen in Fig. 1:



- 1. AQC boiler inlet duct
- 2. AQC boiler inlet hood
- 3. AQC boiler tubes
- 4. AQC boiler hoppers
- 5. AQC boiler inlet hood deflectors
- 6. AQC boiler inlet section deflectors,
- 7. AQC Boiler screens,

Fig. 1 The geometry



X min	-7.874 m	Number of cells	(X) 24
X max	10.064 m	Number of cells	(Y)30
Y min	-1.468 m	Number of cells	(Z)20
Y max	20.622 m	Total Cell count	1263560
Z min	-11.816 m	Fluid Cells	1263560
Z max	2.814 m	Solid Cells	201792
X size	17.938 m	Partial Cells	141162
Y size	22.090 m		
Z size	14.629 m		

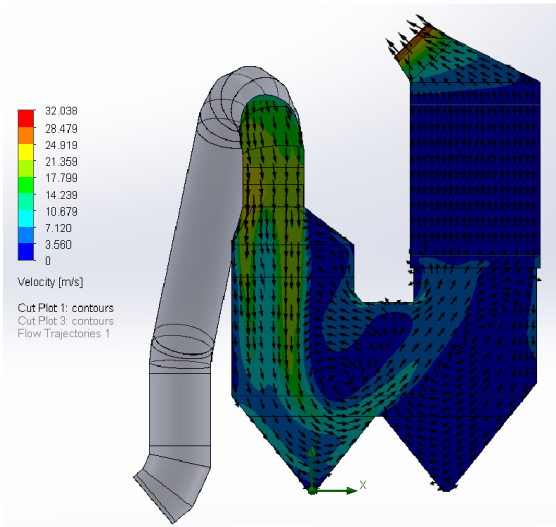
Fig. 2 Computational Domain

The CFD simulation is an internal analysis which is considering only the volume included inside the geometry as a valid volume for calculation. The CFD analysis calculated also the pressure drop of the complete geometry, starting from the inlet duct up to boiler outlet flange. For this calculation, the software requires to set the pressure calculation at each point as a goal and the pressure drop calculation as an equation set as the difference between pressure at inlet and pressure at outlet.

The flue gas distribution has been studied first on the original geometry, without any deflector inside, to understand if the distribution is already acceptable and which kind of deflectors are eventually required.

The geometry change between inlet circular duct and inlet hood is not helping in trying to open the gas “jet” and the flue gas is oriented at quite high velocity to the first boiler hopper. The geometry is partially able to reduce the flue gas velocity, but not as efficiently as expected and finally the flue gas bounces back on the hopper and reaches the first boiler tubes with a not optimal distribution.

Based on above results on the original geometry, it has been decided to add some deflectors, trying to avoid the flue gas “jet” at boiler inlet and to reach a better distribution at first tube bundle. In addition, CTN experience with previous similar installation has helped in finding the correct solution for deflectors. Deflectors inside inlet hood and inside inlet chamber have been added to break the flue gas “jet” and to distribute better the gases inside inlet chamber, reducing flue gas velocity and trying to give a horizontal direction to flue gas to avoid the rebound effect on the first hopper. A screen between inlet chamber and heat exchanger boiler side has been added to facilitate the flue gas distribution from the inlet chamber to the second chamber. Flue gas new distribution is shown in Fig.4.



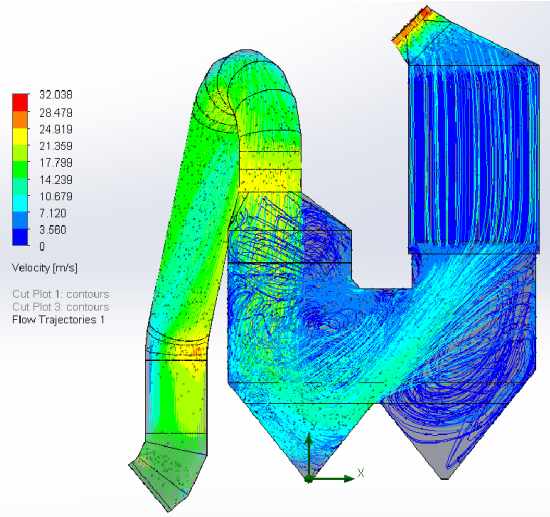


Fig. 3 The flue gas distribution

4. Results and Discussion:

The AQC boiler inlet geometry is not well optimized for a good flue gas velocity reduction and distribution inside the first chamber and then inside the heat exchanger chamber. The deflectors added are the result of the study and real operation experience on previous similar boiler geometry and the result of a dedicated study for this boiler geometry, with the final aim of reaching the first tube bundle with a mean velocity of maximum 5 m/s and the most uniform distribution possible. Even considering that several deflectors have been added to the original geometry, the resulting boiler pressure drop remains aligned with the expected values for AQC boiler. In addition, the flow behavior in the first hopper is such that possible dust accumulation on the deflectors is reduced; anyway the deflectors design and size will be optimized during detailed engineering in view of possible dust accumulation reduction.

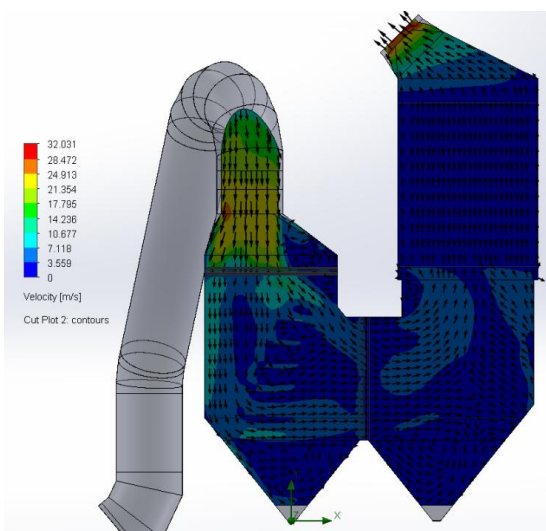


Fig. 4 The flue gas distribution

5. Conclusions:

In summary, this paper has detailed the development and commercialization of modernized heat exchangers, specifically the Air Quench Cooler (AQC) and Pre-Heater (PH) boilers, tailored for integration with the Organic Rankine Cycle (ORC) system within Waste Heat Recovery (WHR) facilities. The key findings of this research include the successful implementation of the ORC system in Turkey, highlighting its advantages over Steam Rankine Cycle

(SRC) systems, particularly in water conservation during renewable energy production.

The innovation presented in this study lies in the meticulous design of monoblock-form heat exchangers, a departure from conventional models. This design choice not only enhances efficiency but also reduces costs associated with assembly and maintenance, shifting manufacturing processes to controlled environments for improved reliability. The integration of Industry 4.0 principles further positions these heat exchangers at the forefront of sustainable energy solutions.

Implications for future research include the exploration of additional advancements in modular Flue Gas Waste Heat Exchanger (FGWHE) designs, considering variations in industrial processes and waste heat characteristics. Further investigation into the scalability and adaptability of these heat exchangers to diverse ORC systems and industrial applications is warranted.

The potential impact of the modular FGWHE on enhancing the efficiency of ORC systems in various industrial applications is substantial. By optimizing heat recovery from flue gases, these modular heat exchangers contribute to increased energy efficiency and reduced environmental impact. The adaptability of the design to different industrial contexts opens avenues for widespread implementation, offering a versatile solution to harness low-grade waste heat. The ripple effect of these advancements is anticipated to result in tangible improvements in the overall sustainability and energy efficiency of industrial processes, aligning with global initiatives for a cleaner and more sustainable energy future.

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Field Service Management (FSM) Simulation Model

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Abstract: This work is dedicated to the development of a simulation model of a Field Service Management (FSM) system. Its tasks include modelling the management of the activities of employees of a field service company: maintaining requests, dispatching orders and field workers, monitoring the quality of work performed. The goals of developing a model of a FSM are to increase the speed of customer service, ensure the process of quality control of work performed, reduce transport and time costs, and provide field workers with the necessary information to understand the scope and location of work. All this leads to improved quality of technical support and service and, as a result, customer satisfaction.

Keywords: FIELD SERVICE MANAGEMENT, FSM, AGENT, AGENT-BASED MODELING, MODEL, DISPATCHER

1. Introduction

In a Field Service Management system, it is necessary to simultaneously coordinate many processes: processing flows of incoming and outgoing information, tracking and distributing service resources (Technicians) and technical equipment, managing employees who are on the road, monitoring the quality of the work they perform, etc. The proposed modeling technique allows us to take into account various qualitative characteristics of field agents and their collective behavior, while obtaining adequate assessments of the implementation of the assigned collective task. The basis of the modeling methodology is a multi-agent simulation system for field service, which takes into account the targeted group behavior of a team of agents.

Currently, the market for modern FSM systems is growing at a significant pace [1][2], but the following tasks have still not been fully implemented - programming the rational behavior of an individual service resource agent, decision-making by the agent based on a collective task, assessment by the agent of the results of completing the common and his own task.

The object of study is models of agents capable of functioning as part of a team. The key point is the interaction between group members, which creates a system of constant feedback, and the target function is the direction of behavior not of an individual, but of the entire group of agents within the framework of a common task.

The relevance of the problem under study is due to the following factors:

- Research shows that more than half of organizations use manual field service management;
- A significant number of enterprises plan to transfer part of their operations to vendors in the coming years;
- About half the time, field workers lack key resources and information;
- Most companies are not confident that they have the necessary skills to use the vast amount of available information to significant benefit.

There are more and more places in the world around us that require periodic maintenance or repair. These are ATMs, vending machines, coffee machines, climate systems, intercoms, gas, water and electricity meters, elevators, rental cars or scooters, or the already commonplace routers of the Internet provider in our housing. Organizations responsible for the operation of a wide variety of equipment are interested in its efficient maintenance in terms of speed of work completion, optimization of material and non-material costs. The final result of their work directly affects the loyalty of customers who provide direct or indirect revenue to the organization. Inconsistency between the quality of work and the current state of the market leads to customers refusing their services and deprives companies of a competitive advantage in terms of meeting customer needs and service level agreements (SLA). [3][4]

To solve operational problems and optimize internal processes, a FSM system is being developed based on a simulation model and its analysis, which allows organizing the interaction of the company's key roles with data describing the customer's problem and the step-by-step stages of its solution.

2. Product requirements

2.1. Current state analysis

Using the Business Process modeling technique, we will create a model of an existing Internet provider in terms of providing services to end users (customers) and the company's existing infrastructure, geographically distributed in different parts of the city.

The key roles are: Operator, Dispatcher, Technician and QA.

The first accepts requests for service from customers, assigns priority to the request and places it on the list of requests awaiting execution.

The dispatcher compares the data on available technicians and attaches a request to them in accordance with the technician's qualifications and the materials he has, after which he transfers the request to the technician for execution.

He also receives reports from the technician on completed service appointments (SA), closes work orders and prepares reports and invoices for payment by the customer for the service.

The technician receives the SA request, goes to the place where it will be performed and carries it out. After which he draws up a report on the work done and materials used, signs it with the customer of the service (if the order came from the customer, and not from the company itself) and sends it to the dispatcher.

The QA specialist analyzes information in service appointments, work orders and pictures after the job has been completed. Based on the enterprise approval rules, he makes a decision on accepting the work as high-quality, or creating a new service appointment for additional work.

There is also an auxiliary role of the administrator, who is responsible for filling databases with organizational data, for example, a list of customers, a list of service contracts, a list of employees, a list of territories with working hours, a list of mobile workers and their qualifications.

With the existing business process model, there are the following shortcomings that negatively affect the satisfaction of customers, employees and enterprise management:

- Inability to predict the cost of future work;
- It is difficult to divide the city geographically into parts to delimit the work of technicians;
- Large overhead and time costs for moving technicians to work sites. Often their movements around the city are not optimized, since the technician is not always sent to the nearest location;
- Inability to control the movement and current location of technicians;
- Inability to timely inform customers about a technician's visit to ensure access to customer equipment;
- The difficulty of accounting for materials available to technicians that may be needed when performing work;
- Inability to control the quality of work performed;
- There is no way to track the execution time of the service appointment;
- There is no option for reminders about excessive waiting times for technician visit.

2.2. Future state analysis

To eliminate existing shortcomings and ensure flexibility, a following list of functional requirements has been compiled:

- The ability of creating a preliminary calculation according to the terms of the work order;
- The ability of entering requests from third-party services;
- The ability of dividing the service territory into non-overlapping zones;
- The ability to visually display the schedule of the planned work of each technician up to the minute;
- The ability to assign technicians to zones to minimize movement around the city;
- The ability of displaying a map indicating the SA address;
- The ability of observing the current position of the technician on the map;
- The ability to inform the customer of the work order about the Technician arrival time;
- The ability to take into account the materials available to the Technician vehicle;
- The ability of tracking the materials consumed by the Technician during the work;
- The ability of taking pictures of the result of work and perform quality control procedure;
- The ability to track service appointments closed as a “temporary solution” with subsequent execution of the service appointment as a “permanent solution”;
- Track the time of an open work order;
- Track Service Level Agreement of an open work orders in accordance with the existing customer contract;

3. Creating a simulation model

For this work, agent-based modeling is used [5], which is often used for the needs of human resource management [6].

In the environment under consideration, independent agents have predetermined characteristics and rules. Based on this, each agent individually assesses the current situation and makes decisions. The decisions made influence and change the system as a whole.

Agents, which are real components of the system, make decisions in the context of certain conditions. In the simulation model, the behavior of agents is assessed over a certain period of time associated with the completion of a task or the transition of the system from one state to another. The purpose of the assessment is to predict the possible development of the system as a whole. The task of each agent is to perform the assigned work in a certain environment, taking into account the available abilities. It is the presence or absence of certain abilities that influences the choice and type of problem to be solved.

There are the key abilities necessary for agent of the model [7]:

- The ability to process information coming from other agents and transmit it;
- The ability to prioritize assigned tasks is used to analyze and prioritize incoming service requests. Applications can be either external, from consumers of services and affect only this consumer (local and limited impact), or internal, related to the repair, modernization and development of the existing infrastructure of the enterprise and affect many existing and potential consumers (global and long-term impact);
- Ability to work with others and evaluate their abilities;
- The ability to set goals that can be goals for other agents;
- The ability to achieve the expected result of the goal;
- The ability to make decisions based on available information. If it is impossible to make a decision, request additional clarification;

In Agent-Based Modeling we implement the idea that our system can be modeled using agents, an environment and a description of agent-agent and agent-environment interactions.

For the current purpose we used NetLogo software [8].

4. Analysis and system design

As part of the analysis and system design work, an analysis of the product requirements was carried out, on the basis of which the technical design of the developed system was made. For graphical presentation of diagrams, the Unified Modeling Language (UML) is used [9].

To visualize use cases, a use case diagram has been compiled. It reflects the relationships between actors and use cases, the main purpose of which is to describe functionality and behavior, allowing the customer, end user and developer to jointly discuss the designed or existing system.



Fig. 1 Use Case diagram.

An activity diagram was created to visualize the activity. An activity is a specification of executable behavior in the form of coordinated sequential and parallel execution of individual actions, interconnected by threads that go from one node to the inputs of another.

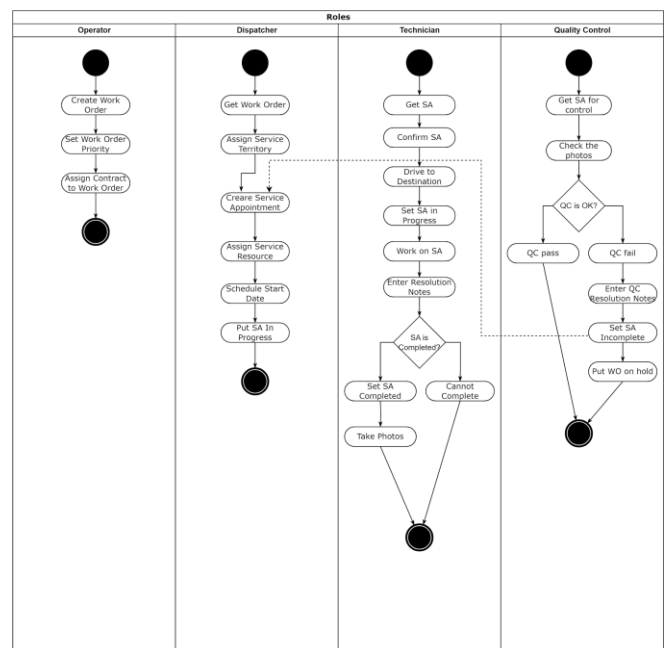


Fig.2 Activity diagram.

To visualize the life cycle of agents and the interaction of actors (roles), a sequence diagram was created. It allows us to show the multi-stage interaction of agents and their environment.

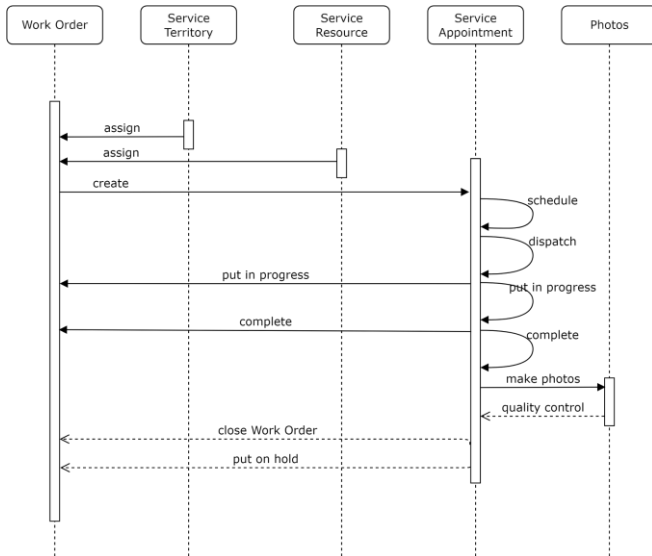


Fig.3 Sequence diagram.

In the process of creating the model, the following simulation model information blocks were identified:

Account is used to represent the entity of the customer to whom the company provides services and maintenance.
Main property:

- Name - to store the name of the customer.

Contract is used to represent an entity with information about contracts with customers.

Main properties:

- Name - for storing the name (number) of the contract;
- Account - identifier of the customer.
- Due Date—The expiration date of the service agreement.
- SLA Period - the service period (days) during which the work must be completed (after submitting a work order).

Work Order is used to represent an entity about work that needs to be done from the customer opinion or from internal company office.

Main properties:

- Number - to store the application number;
- Priority - to store the priority of the application. Possible values range from 1 (highest) to 4 (lowest);
- Contract - for storing the customer contract;
- Address - for address where service should be performed;
- Description - for information about what needs to be done in accordance with contract and the customer's complaint;
- Service Territory - to store a service area with Address;
- Status - to store the current status of the work order. The value is assigned automatically by the system depending on the actions of the Dispatcher or QA. Possible values:
 - New - the application has been created, no activity has been performed (default value);
 - In Progress - the work order has been accepted;
 - On Hold - the work order is suspended;
 - Completed - the work order has been completed;
 - Closed - all associated SAs have been completed;
 - Cannot Complete - the request can't be completed;
 - Cancelled - the application has been cancelled (Usually before any work on it begins).
- Created Date - to store the creation date. Set automatically by the system when creating an application; Used to inform the Dispatcher that the SLA has been exceeded according to the contract for non-finished work orders;

- Completed Date - to store the closing date. Set automatically by the system when the work order is closed. Used to assess the excess of the SLA for completed work orders.

Main actions:

- Change Status - a command to change the status in connection with an event that occurred (actions of the Dispatcher or Technician);
- Change Service Territory - a command to select/change the service area whose employees can perform work;
- Create Service Appointment - command to create a service appointment within the current service request.

Service Territory is used to represent the entity of the service areas, which may or may not be overlapping areas of the city.

Main properties:

- Name - to store the name of the service area;

Service Resource is used to represent the entity of field workers (Technicians) who can perform a specific type of jobs.

Main properties:

- Name - to store the ID of the Technician. May include abbreviations with his skills for easy identification.;
- Skills - to store skills for those jobs for which the Technician is qualified to perform.

Service Appointment (SA) is used to represent the entity of the work performed as part of work order. For one work order, there may be several service appointments for different Technicians, if the work cannot be done completely in one visit of specialists.

Main properties:

- Work Order – to relate the owner (work order);
- Scheduled Date/Time - to store a date when the SA is due;
- Duration - planned time to complete SA, min;
- Actual Start Date/Time - actual work start time (in fact);
- Actual End Date/Time - actual work end time (in fact);
- Status - to store the current status of the SA. The value is assigned automatically by the system depending on the actions of the Dispatcher and Technician. Possible values:
 - New - SA is not scheduled;
 - Scheduled - SA is scheduled. Assigned when the Scheduled Date/Time and Service Resource for a given request are assigned;
 - Accepted - Technician has read the service appointment details and is ready to start;
 - Dispatched - Technician is on the way for the work;
 - In Progress - Technician arrived and started work;
 - Cannot Complete - Technician does not have the opportunity to complete the work;
 - Completed - Technician has completed the work;
 - Incomplete - Technician did not complete the work; To complete, Dispatcher needs to create a new SA;
 - Cancelled - The work order has been cancelled. To resume work, Dispatcher needs to create a new SA.
- Resolution Notes - for completed work details;
- QC passed - a flag about quality control successfully passed;
- QC Resolution Notes - for quality control notes by QA;

Main actions:

- Change Status - a command to change the status in connection with an event that occurred (actions of the Dispatcher or Technician);
- QC passed - a command to close a SA (and work order if there are no other open SA);
- QC failed - a command to close a SA and create a new one to repeat the work.

Photo is used to represent the entity of pictures after the Technician has completed the job and is reviewed by the QA team.

Main properties:

- Location - To store information about the location of a picture taken by a Technician.

Main action:

- Upload Photo - for automatically uploading images from Technician's mobile device camera and specifying the necessary information about the image in the object.

5. Development of the dispatcher module algorithm

During the analysis of the dispatcher requirements, a number of criteria were collected that need to be implemented by creating a "Dispatcher Module":

- The module should display on the time scale the current disposition of service appointments with specified Scheduled Date/Time and Service Resource;
- The module should allow changing the Scheduled Date/Time by horizontally moving the graphic image of the service appointment;
- The module should allow you to change the assigned Service Resource by vertically moving the graphic image of the SA to the line with the another Service Resource;
- The module should do "auto-distribution" of service appointments: automatically set the Scheduled Date/Time and Service Resource for the new appointment, changing their status to "Scheduled". A special algorithm is used for this.

The following criteria are used to operate the algorithm:

- Priority - higher priority work orders are processed first;
- Geolocation - the location of the place of SA execution in relation to the place of execution of the previous SA is taken into account (to minimize travel time and distance);
- Service Territory - the territory to which the Technician belongs is taken into account. It is allowed to fulfil requests from another Service Territory if there is a significant difference in the workload of the Technicians. But working on "foreign" territory is not encouraged due to the delimitation of service areas and is considered high-cost for the purposes of the algorithm;
- Skills (Qualifications) - if SA contains information about the required skills of the technician, then the skills of the available Service Resource are taken into account when automatically distributing service appointments;
- Duration - the planned duration of the work is taken into account. Longer jobs are considered more expensive.

To develop a methodology for assessing the effectiveness of planning the Technician's working day, we will introduce the weight of each criterion:

Table 1. Criteria and coefficients

Criteria	Details	Criterion weight coefficient	Criterion conversion factor
Priority	Work Order priority (0..4)	$p_1=80\%$	$p_2=100$
Geolocation (distance)	The distance from the previous SA location (or from the office for the first SA)	$l_1=50\%$	$l_2=3$
Geolocation (travel time)	Travel time from the previous SA location (or from the office for the first SA)	$t_1=70\%$	$t_2=1$
Service Territory	The flag to show if Technician is not assigned to the current Service Territory	$s_1=80\%$	$s_2=100$
Duration	The estimated length of the service appointment	$d_1=30\%$	$d_2=1$

Let us introduce the concept of the cost functional for moving to one object:

$$b = f(P, L, T, S, D),$$

where P - Priority of the service request;

L - distance to move from the previous object to the next, km. The

system receives this data from the service [Google Matrix API];

T - time to move from the previous object to the next, min. The

system receives this data from the service [Google Matrix API];

S - flag that shows that Technician is not assigned to the Service Territory of current Service Appointment, 0 or 1;

D - planned duration of work, min.

When estimating costs, we use criterion weight coefficients (p_1, l_1, t_1, s_1, d_1) to determine the weight of each criterion for reduction. We use criteria conversion factors to reduce criteria values to a common unit of measurement (p_2, l_2, t_2, s_2, d_2) according to table 1.

As a result, the costs of moving to an object in a chain of movements can be calculated using the formula

$$b = p_1 * p_2 * P + l_1 * l_2 * L + t_1 * t_2 * T + s_1 * s_2 * S + d_1 * d_2 * D.$$

For example, if there are different service appointments that differ only in priority and one more criterion (different ones), we have the value set:

Table 2 Test data

Priority and differences in Service Appointments	P	L	T	S	D	Sum, units	Delta, units	Delta, %
P1	1	5	30	0	30	120.5	0.0	0.0
P1, double distance	1	10	30	0	30	128.0	7.5	5.9
P1, double travel time	1	5	60	0	30	141.5	21.0	14.8
P1, alien Serv.Terr.	1	5	30	1	30	200.5	80.0	39.9
P1, more work time	1	5	30	0	50	128.5	8.0	6.2
P2	2	5	30	0	30	200.5	80.0	39.9
P2, double distance	2	10	30	0	30	208.0	87.5	42.1
P2, double travel time	2	5	60	0	30	221.5	101.0	45.6
P2, alien Serv.Terr.	2	5	30	1	30	280.5	160.0	57.0
P2, more work time	2	5	30	0	50	208.5	88.0	42.2

The compiled diagram shows that the "cost" of executing the next work order is largely influenced by the priority of the application and the flag if Technician is not assigned to the Service Territory of the current Service Appointment.

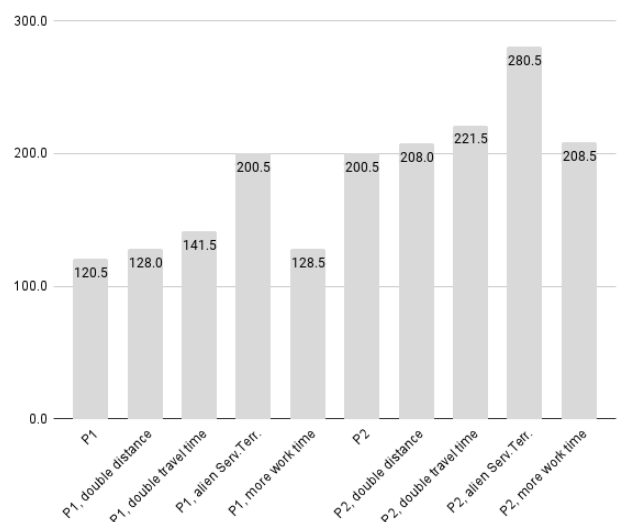


Fig. 4 Diagram of the dependence of "costs" when selecting an order for execution.

Thus, the algorithm calculates costs for all service appointments with "New" status and assigns them to the Technicians with the

lowest cost value as the most valuable in terms of material and time costs, as well as value according to the priority.

Next, the algorithm is repeated for the remaining undistributed service appointments.

6. Model testing results

When testing the model in practice, it proved that the proposed algorithm makes the order of service appointments in such rule: the lowest cost service appointments are placed first for execution.

Costs include not only real material and time costs, but the number of appointments can be done during the day (e.g. two short service appointments have less costs than one during the same time).

It is displayed on the Dispatcher panel in graphical form:

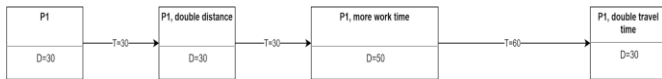


Fig. 5 The graphical representation on Dispatcher Dashboard for one Technician.

The figure clearly shows the timescale of working hours, during which time periods are planned for performing work and for moving the Technician to the place of work.

Similarly, when using this cost estimation technique, a schedule of all active Technician is drawn up:

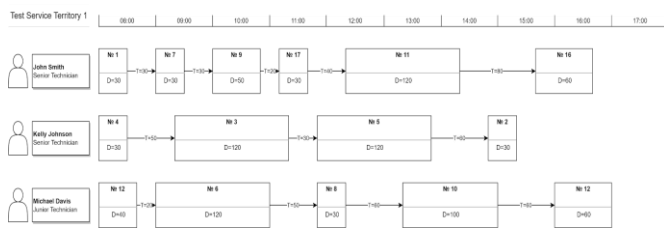


Fig. 6 The graphical representation on Dispatcher Dashboard for many Technicians.

The figure schematically shows the work schedule of employees belonging to the “Test Service Territory 1” Service Territory. The Dispatcher has the ability to make adjustments to the schedule using Drag&Drop technology and simply moving blocks of work both along the timescale (horizontally) and between Technicians (vertically).

After such changes, the dispatcher module automatically updates Scheduled Date/Time on service appointments and informs customers about changes via SMS messages.

In case if significant changes happened, the dispatcher module algorithm is executed again to re-calculate “costs” and rearrange Service Appointments on the Technician schedule.

. Testing in practice

This system was used in practice with a real organization - an Internet service provider (ISP) [10]. Its work orders included maintenance of client equipment and modernization of the core hardware owned by ISP. The capabilities of the system gave positive feedback from both company personnel and clients during the test period.

As a result of testing, it was found that for high-quality implementation of the system it is necessary to carefully analyze the division of the city into service areas and empirically select the coefficients of the dispatcher module. The latter is necessary due to various dependencies not taken into account in the current model. For example, the presence of traffic jams and their dependence on the time of the day, the density of urban development and parking restrictions in the city streets for official vehicles.

There is a need to add the breaks for Technicians for the lunch and the rest in the middle of the day in future modelling.

8. Conclusion

Based on the results of the article, it can be seen that the developed methodology for modelling a FSM system completely solves all tasks assigned to it and makes it possible to use the maximum of the advantages of the selected modelling technology.

The FSM system, developed on the basis of the proposed methodology, made it possible to bring FSM service to a qualitatively new level. The analysis of system data within the framework of the model allowed us to note the following positive achievements:

- Automated dispatch of requests has been implemented;
- The quality of task completion has increased;
- The deadlines for completing service appointments have been reduced;
- Ensures that “temporary repairs” and subsequent “permanent repairs” are tracked in one main work order;
- Places (equipment) that most often require technical intervention have been identified.

Important information on identified problem areas made it possible to plan preventive work at problem sites and optimize the work of the organization as a whole, reducing costs.

The FSM system has made it possible to increase the transparency of service at all stages of processing customer requests, increased the speed and efficiency of informing the customer about departure and rescheduling of the visit (in case of a delay at the previous facility) automatically via SMS messages.

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Energy optimization of the building through the use of thermal insulation, solar panels, and efficient boiler

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Abstract: This study presents an evaluation of the application of thermal insulation, solar panels, and an efficient boiler in a kinder garden to improve energy efficiency. The main objective of this study is to identify and analyze the benefits of using these technologies in reducing energy losses, increasing clean energy production, and achieving economic benefits. Thermal insulation is used to limit the transfer of heat between the building and the external environment, reducing energy losses for heating and cooling. In our case we have a saving of 7148 kWhr/year. The installation of the solar panel plant for heating sanitary water has brought an annual economic benefit of 102,583 ALL per year, meanwhile the choice of a gas boiler for heating the premises has been more cost effective compared to the use of oil.

Keywords: ENERGY OPTIMIZATION, THERMAL INSULATION, SOLAR PANELS, EFFICIENT BOILER

1. Introduction

Tirana is the most populated city in Albania and has the largest share of energy consumption in the country. One of the effective options to address energy and environmental concerns is to retrofit existing buildings. Furthermore, optimizing building system facets, such as thermal insulation, cooling, and heating, can reduce energy consumption. The building industry has a huge potential for energy reductions. Various factors such as weather, envelope, energy systems and occupancy behavior/patterns have an impact on building energy demand [1].

The conflict between Russia and Ukraine has caused an energy crisis that has directly affected the heating, cooling, and transportation energy costs of households. This crisis has increased the prices of additional goods and services across global supply chains. In addition to the current energy crisis, the predominant source of carbon dioxide emissions, the primary greenhouse gas responsible for global warming, is the widespread use of fossil fuels to produce energy [2]. Energy savings from energy efficiency offer additional co-benefits and contribute to energy supply security and climate change mitigation. According to the Intergovernmental Panel on Climate Change (IPCC) report [3], total greenhouse gas (GHG) emissions have increased between 1970 and 2019, with a larger absolute increase after year 2000. The building sector was responsible for 32% of the final energy consumption and 19% of the global equivalent CO₂ emissions. The strategy for renovation published by the European Commission states that in order to achieve the target of reducing greenhouse gas emissions by 55% by 2030, it is necessary to reduce greenhouse gas emissions from buildings by as much as 60%, their final energy consumption by 14% and energy consumption to heat and cool by 18%. Some studies have concerned the optimization of thermal insulation [4], others the improvement of the plant efficiency [5], others the energy-saving potential [6]. Raimundo et al. [7] focused their study on identifying the most advantageous thermal insulation solutions for opaque elements for buildings located in the Portuguese temperate climate. Dylewski and Adamczyk addressed the economic and environmental benefits of using thermal insulation on the external walls of buildings located in the various Polish climate regions [8]. Dall'O' and Sarto [9] investigated the technical and economic potential for increasing energy efficiency of 49 school building complexes in Lombardia. Solar heating systems offer a sustainable path for the decarbonization of the energy supply for space heating and domestic hot water production in the residential sector. Solar energy systems, such as solar thermal collectors and PV modules, and wind energy have been developed with the aim of clean and sustainable energy production worldwide. Lee and Baek [10] developed a method for calculating solar collector efficiency using the heating load. They suggested some parameters for better evaluation of the collector efficiency. Li et al. [11] proposed several control plans based on climatic data, domestic hot water (DHW), and power costs for a building in Singapore. Through these parameters, they evaluated various economic objective factors.

Vincelas et al. [12] investigated the impacts of various energy resources and envelope materials on building energy consumption. Solar heating offers several benefits, including lower fuel consumption, reduced pollution, and minimal maintenance requirements [13]. Hansen and Vad Mathiesen [14] investigated the impact of solar thermal energy on carbon dioxide emissions from technology and fuel substitution. Solar heating has been found to have a higher impact on carbon savings during summer due to the higher solar ratio. Solar thermal integration can reduce the overall use of fuel and thus decrease dependence on this highly demanded energy source in future. Lather and Das [15] determined that, compared to gasoline, compressed natural gas emits 10–13% less carbon dioxide and 15–30% less carbon monoxide while having approximately 25% lower combustion level than gasoline, which enhances fuel combustion performance.

2. The case study

The case study evaluates the impacts of thermal insulation, solar panels, and an efficient boiler in a small kinder garden in Tirana. It is located in the center of the country, enclosed by mountains and hills. The average altitude is about 110 meters above sea level. Temperatures vary throughout the year from an average of 6.7 °C in January to 24 °C in July.

Kinder garden is composed of two floors, ground and first floor. Ground floor has an area about 199 square meters having three rooms, a technical room, hall, balcony and toilet. First floor has an area of 126 square meters having two rooms, hall, balcony and toilet. It has a small garden, with flowers and trees. Kinder garden was modeled with AutoCAD as shown in Figure 1 and Figure 2.

The study involves two different external wall namely when the exterior insulation is installed and, respectively, in its absence. The result of the analysis was used to assess the reduction of thermal loads, fuel consumption of heating system, namely an oil boiler. The main properties of the opaque enclosure elements, are summarized in Table 1; for each element, the description starts from the internal (heated) space. Windows are double glazed with aluminum frame. The internal height of each floor is 3.m, and the unheated basement is placed under ground floor.

HAP (Hourly Analysis Program) from Carrier is used to calculate the thermal loads on two stages: 1- Building without insulations, 2- Building with insulations. HAP is used to calculate the thermal loads and the amount of energy needed through the introduction of country specific information such as climate, latitude and longitude, spaces dimensions and materials used in walls, floors and roofs. Enter the information for each space in the kinder garden, such as the name of the space, floor area, room lighting, the number of people, walls and windows areas of space exposed to sun radiation, roof area if exposed to sun radiation.

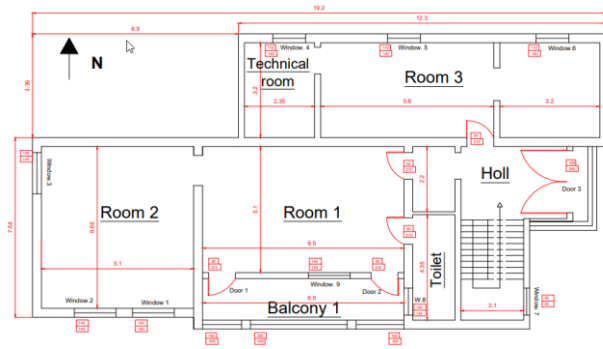


Fig.1. Ground floor

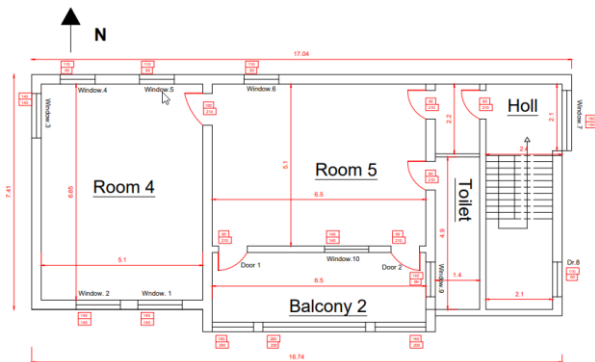


Fig.2. First floor

After completing the introduction of all information about spaces, then program analyzes and calculates the thermal loads in kilowatt. hour (kwh) as shown in Table 2. The results show that the total amount of energy for non-insulated building = 14918 kw. h/year. Thermal insulation in buildings is an important factor to achieving thermal comfort for its occupants. Insulation reduces unwanted heat loss or gain and can decrease the energy demands of heating and cooling systems. When insulated the walls, the thermal transmittance U-value become less than from non-insulated be.

Table 1. The main properties of the opaque enclosure elements

Layers: Inside to Outside (with insulation)	Thickness	Density	R-Value
Inside surface resistance	mm	Kg/m ³	m ² K/W
	0.000	0.0	0.12064
Gypsum plaster	15.000	720.8	0.06667
Common brick	260.000	1922.2	0.35768
RSI - board insulation	50.000	32	2.40746
Stucco	25.000	1858.1	0.03464
Outside surface resistance	0.000	0.0	0.05864
Totals	350.000		3.05
Overall U - Value			0.328 W/m ² /K
Layers: Inside to Outside (without insulation)	Thickness	Density	R-Value
Inside surface resistance	mm	Kg/m ³	m ² K/W
	0.000	0.0	0.12064
Gypsum plaster	15.000	720.8	0.06667
Common brick	260.000	1922.2	0.35768
Stucco	25.000	1858.1	0.03464
Outside surface resistance	0.000	0.0	0.05864
Totals	300.000		0.64
Overall U - Value			1.567 W/m ² /K

Table 2: Total thermal loads

	DESIGN HEATING WITH INSULATION		DESIGN HEATING WITHOUT INSULATION	
	Sensible	Latent	Sensible	Latent
Total Loads	14918	0	7770	0

The results show the total amount of energy for insulated building =7770 kWh/year. Yearly Savings will be 14918-7770 = 7148 kWh/year. In this case, we have a saving of 47.9% value, which is considerable. In a long-term perspective this value has a very large impact as the saved value of the energy needed for heating is exceptional. Undoubtedly, to apply thermal insulation, an initial capital will be needed, but the facility will repay the cost spent on thermal insulation after a certain period, and after paying it off, the economic benefit will significantly reduce the value of the electricity bill.

Due to climate change, the exhaustion of fossil fuel resources and the increasing costs of conventional energy, the heating sector should use renewable energy sources and the most promising being solar thermal energy [16]. The amount of thermal energy request for DHW constitutes a significant part of the total energy demand of the building. To reduce the primary energy requirement, it was provided the installation of solar flat plate panels of 25 m² on the terrace of the building. We assume that we will have about 40 people in the kindergarten. Of these 40 people, we are assuming that 15% of them will use the shower in one day, so 0.15*40=6 people. The need for sanitary water per person per day is 50 l. The remaining 40-6=34 people who will use sanitary water for various needs during the day and we are receiving this request of 15 l per person. So 34*15=510 l of water. The total amount of sanitary water per day is 6*50+510=810 l of water/day.

The following calculations are made taking into account the following conditions:

- Angle of inclination 30°
- The direction of the solar panels is from the south

The following table shows the average values of water temperature throughout the months of the year.

Table 3 Average value of water temperature for each month at °C

Jan	Feb	Mar	Apr	May	Jun
14.2	16	15.6	17.3	20.1	21.7
Jul	Aug	Sep	Oct	Nov	Dec
23.2	23.2	21.5	20.5	16.99	15.4

Table 4 Average value of air temperature for each month in °C

Jan	Feb	Mar	Apr	May	Jun
6.65	10.25	11.3	12.8	18.4	21.6
Jul	Aug	Sep	Oct	Nov	Dec
24.85	24.55	21.25	19.15	11.9	8.9

Table 5 Values of monthly solar radiation over the flat surface unit (MJ/m²day)

Jan	Feb	Mar	Apr	May	Jun
6.33	8.712	13.17	18.07	21.96	24.44
Jul	Aug	Sep	Oct	Nov	Dec
24.95	22.72	17.53	11.74	7.334	4.896

We calculate the energy needed for heating sanitary water.

$$E_n^{daily} = m * C_{pu} * \Delta t_u, \quad E_n^{monthly} = E_n^{daily} * n_d$$

Table 6 Required daily/monthly energy for heating sanitary water (MJ)

	Jan	Feb	Mar	Apr	May	Jun
Daily	104.4	98.3	99.7	93.9	84.4	79.0
Monthly	3237.4	2753.2	3090.2	2817.6	2617.3	2370.1
	Jul	Aug	Sep	Oct	Nov	Dec
Daily	73.9	73.9	79.7	83.1	95.0	100.4
Monthly	2291.4	2291.4	2390.4	2575.2	2849.2	3111.3

Annual energy required for heating sanitary water:

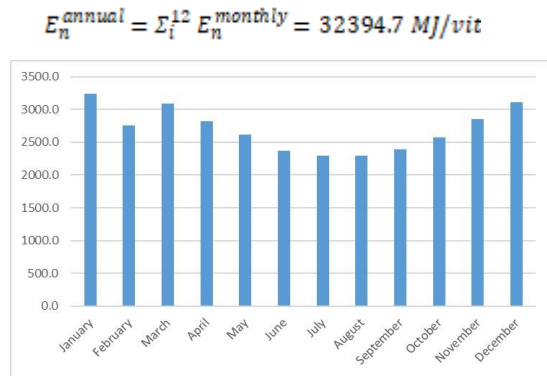


Fig 3. Monthly energy required for heating sanitary water (MJ)

We find the solar radiation per unit area:

Table 7 Solar radiation on the surface unit (KJ/m2day)

	Jan	Feb	Mar	Apr	May	Jun
H_0	14428.0	19940.2	26849.6	34256.3	40390.5	40738.8
$H_{0\beta}$	12928.4	14253.2	13770.5	13270.5	12691.8	10992.4
	Jul	Aug	Sep	Oct	Nov	Dec
H_0	40638.0	36328.2	29472.8	21832.0	15667.0	12989.4
$H_{0\beta}$	10604.0	10468.5	11093.8	11734.7	12428.6	14520.0

Where:

- H_0 is the solar radiation on a flat surface
- $H_{0\beta}$ is the radiation on an inclined surface

Table 8 Daily and monthly solar radiation (MJ)

	Jan	Feb	Mar	Apr	May	Jun
Daily	8.9	11.4	15.1	18.8	21.4	21.9
Monthly	277.1	319.1	468.7	563.0	664.9	658.4
	Jul	Aug	Sep	Oct	Nov	Dec
Daily	21.9	20.2	17.1	13.3	9.8	7.6
Monthly	680.2	626.2	514.0	410.9	293.6	236.7

Table 9 Monthly energy obtained from solar panels for heating sanitary water (MJ)

Jan	Feb	Mar	Apr	May	Jun
2489.1	2732.4	3412.7	3407.8	3422.2	3338.6
Jul	Aug	Sep	Oct	Nov	Dec
3336.9	3105.5	2927.9	2852.1	2547.8	2140.1

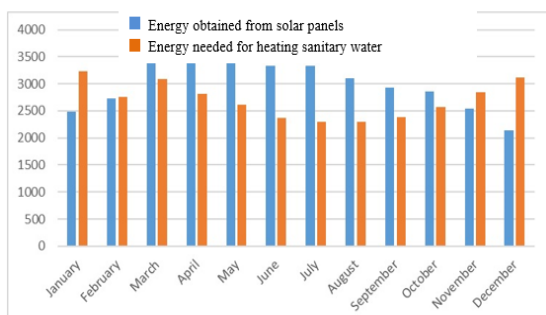


Fig 4. Energy needed and energy obtained from solar panels (MJ)

Table 11 Contribution of the sanitary water heating plant for each month (%)

Jan	Feb	Mar	Apr	May	Jun
76.9	99.2	110.4	120.9	130.8	140.9
Jul	Aug	Sep	Oct	Nov	Dec
145.6	135.5	122.5	110.8	89.4	68.8

3. Results and discussion

The installed surface of the solar panel plant is 25 m² and this plant covers almost the entire need for sanitary water in the winter season. Throughout the rest of the year, the plant provides 100% of hot sanitary water. The city of Tirana and the whole country is not connected to the international natural gas network, so the options for choosing a boiler for the heating system are LPG (Liquefied Petroleum Gas) and diesel.

In the case where there is no thermal insulation, the power of the boiler from the calculations should be 15kW. Let's make a calculation of how much the heating cost is for:

The gas boiler

In the case of the gas boiler that I have considered, there is a fuel consumption of 1.28 kg/h. The boiler will work an average of 10 hours a day and in the city of Tirana we need heating for about 150 days, so the boiler will work 1500 hours/year.

The annual consumption of the boiler would be 1500 hours/year * 1.28 kg/hour = 1920 kg/year of fuel (Gas). This annual consumption converted into liters is 3242.88 liters/year. The cost of providing this amount of fuel is:

3242.88 liters/year * 60 ALL/liter = 194,572.8 ALL/year

If heating would be done with an oil boiler, we would have the following situation:

The considered boiler has a power equal to that of the gas case (15kW) and a fuel consumption of 1.25 kg/h.

The working hours of the boiler are the same as in the previous case, i.e. 1500 hours/year and the annual fuel consumption will be 1.25*1500=1875 kg/year (diesel).

This annual consumption converted into liters is 2206 liters/year.

The cost of providing this amount of fuel is:

2206 liters/year * 180 ALL/liter = 397,080 ALL/year

As we can see, heating with a gas boiler has a cost many times lower than that with diesel, and therefore the boiler chosen is the gas one.

We calculate how much the gas boiler would consume in the case where we have applied thermal insulation:

The power of the boiler will now be 9 kw and for this boiler the fuel consumption is 0.95m³/h which corresponds to 1.121 kg/h.

The annual consumption of the boiler would be 1500 hours/year * 1.121 kg/hour = 1681.5 kg/year fuel (Gas)

This annual consumption converted into liters is 2840 liters/year.

The cost of providing this amount of fuel is:

2840 liters/year * 60 ALL/liter = 170,400 ALL/year

So we have a saving of 194,572.8-170,400=24,172.8 ALL/year

Initial investment

This boiler will cost 150,000 ALL. The solar panel plant will cost approximately ALL 1,250,000. Thermal insulation of the building will cost approximately:

The cost per m² is 450 ALL.

The building has a side area + terrace of 600 m² which will be thermally insulated

The cost is 450 ALL/m² * 600 m² = 270,000 ALL. Total = 1,670,000 ALL

Economic benefit

If the water was heated with electricity, the cost of heating it would be:

Total energy needed for heating sanitary water = 32394.7 MJ/year

Cost of electricity + VAT = 11.4 ALL

$11.4 \text{ (ALL/kwh)} * 32394.7 * 1000 / 3600 \text{ (kwh)} = 102,583 \text{ ALL/year}$

The annual economic benefit from solar collectors and the application of thermal insulation together reaches the monetary value of ALL 102,583/year + ALL 24,172.8/year = ALL 126,755.8/year.

If we make the ratio of the amount spent against the annual monetary benefit, we will get the payback period (1,670,000 ALL)/(126,755.8 ALL) $\approx$ 13 years

Let's assume that the lifetime of this investment will be 20 years

We subtract the payback period 20-13=7 years

These 7 years, the entire monetary value saved is profit for us, and more specifically $7 * 126755.8 = 887290.6 \text{ ALL}$.

This value is a value that does not take into account the increase in the price of electricity or the price of fuel.

CONCLUSIONS

The investment in thermal insulation has resulted in a significant reduction of heat losses by 47.9%, bringing an economic benefit of 24,172.8 ALL per year. The installation of the solar panel plant for heating sanitary water has brought an annual economic benefit of 102,583 ALL per year, helping to reduce the cost of electricity or fuel. The choice of a gas boiler for heating the premises has been more cost effective compared to the use of oil. The payback of the investment is reached after 13 years and the monetary values from the exploitation for the remainder of the life of the plant are all profits. The reduction of heat losses, the use of renewable energy for heating sanitary water and the choice of a gas boiler for heating the premises show an increase in efficiency and a reduction in energy costs.

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НОВИТЕ ТЕХНОЛОГИИ КАТО ВЪЗМОЖНОСТ ЗА ДИГИТАЛНА ТРАНСФОРМАЦИЯ НА БИЗНЕСА

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Abstract: В статията е направен семантичен анализ на понятията „цифровизация“ и „дигитализация“ в контекста на тяхната поява и развитие, като е изяснена същността им. Анализирани са и основните характеристики на съвременните информационни и комуникационни технологии (ИКТ), водещи до висока ефективност и създаващи предпоставки за осъществяване на нови политики и смяна на бизнес модела. Дигиталната трансформация на бизнеса е разглеждана като организационна промяна, която е функция на възможностите, които предоставят съвременните дигитални технологии, на тяхното приложение в икономическата и социокултурната сфера, и на новите изисквания на пазара. Представено е разбирането на автора, че осъществяването на дигитализацията има непрекъснат и системен характер, и води до структурни и функционални промени, свързани с процеса на дигитална трансформация. Направен е анализ на някои показатели за България в индекса за навлизането на цифровите технологии в икономиката и обществото (DESI).

Keywords: ДИГИТАЛИЗАЦИЯ, ИНФОРМАЦИОННИ И КОМУНИКАЦИОННИ ТЕХНОЛОГИИ, ДИГИТАЛНИ ИНОВАЦИИ, ДИГИТАЛНА ТРАНСФОРМАЦИЯ НА БИЗНЕСА.

NEW TECHNOLOGIES AS AN OPPORTUNITY FOR DIGITAL TRANSFORMATION OF BUSINESS

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Abstract: The article makes a semantic analysis of the concepts of "digitalization" in the context of their emergence and development, and their essence is clarified. The main characteristics of modern information and communications technologies (ICT), leading to high efficiency and creating prerequisites for the implementation of new policies and change of the business model, are also analyzed. The digital transformation of business is considered as an organizational change that is a function of the opportunities provided by modern digital technologies, their application in the economic and sociocultural sphere, and the new requirements of the market. The author's understanding that the implementation of digitalization is of a continuous and systemic nature, and leads to structural and functional changes related to the process of digital transformation. An analysis of some indicators for Bulgaria in the Digital Economy and Society Index (DESI) was made.

Keywords: DIGITALIZATION, INFORMATION AND COMMUNICATIONS TECHNOLOGIES, DIGITAL INNOVATIONS, DIGITAL TRANSFORMATION OF BUSINESS.

1. Въведение

Цифровата икономика в глобален мащаб се развива динамично и представлява важен двигател на иновациите, конкурентоспособността и растежа, с голям потенциал за развитие на предприемачеството и на малките и средни предприятия. Развитието на електронния бизнес и електронната търговия, автоматизираното промишлено производство и интелигентните производствени предприятия, интелигентните транспортни системи и транспортни средства, интелигентните енергийни системи и други са част от новата цифрова икономика. Облачните технологии, интернет технологиите, включително интернет на нещата, технологиите за оползотворяване и използване на потенциала на големите масиви от данни, индустриалната и сервизната роботика и изкуствения интелект са основните технологични предпоставки за развитие на цифровата икономика и осъществяване на дигитална трансформация на бизнес моделите.

В Националната програма цифрова България 2025 [1] и стратегията на ЕС за единен цифров пазар [2] са формулирани някои основни направления, свързани с дигитализацията и дигиталната трансформация на бизнеса и социалната среда – гарантиран достъп до онлайн продукти и услуги, подобряване качеството и работата на цифровите мрежи, и в крайна сметка постигане растеж на европейската цифрова икономика. Цифровата трансформация настъпва бързо с потенциал и претенцията да промени изцяло бизнеса и обществото. Интеграцията на новите цифрови технологии във всички сфери на бизнеса и публичния сектор води до фундаментална промяна в естеството на пазарите и продуктите, начините на производство, доставки и плащания, мащабите на капитала,

който функционира глобално и изискванията към човешкия капитал. Увеличава се производителността, реализират се нови идеи, технологии, нови управленски и бизнес модели и се създават нови канали за достъп до пазара, при това с относително ниски разходи. Интернет на нещата (IoT, Internet of things), блокчейн технологиите, високоскоростните цифрови мрежи от пето поколение 5G и изкуствения интелект (AI, Artificial Intelligence) се считат за ключови технологии при осъществяването на така наречената Индустрия 4.0 и дигиталната трансформация (DT) на бизнес моделите и обществото като цяло.

В статията ще бъдат разглеждани някои съществени характеристики и различия в семантиката на съвременните понятия като цифровизация, информатизация, дигитализация, дигитална трансформация, облачни технологии, интернет на нещата, изкуствен интелект и др. в контекста на новите изисквания, които те поставят пред фирмите, както и възможностите и отговорностите, които те налагат като нов стандарт на фирмените политики.

2. Резултати и дискусия

Според много икономисти и мениджъри трите термина – цифровизация, дигитализация и дигитална трансформация са модерни термини, които са идентични и се използват най-вече в сферата на проучването на пазарите, т.е. за нуждите и осъществяването на маркетинга.

Цифровизацията в началния етап се е свързвала със замяната на хартиените носители, с архивирането на статични данни (имена, документи, кореспонденция) върху електронни устройства. Тя по своята същност е преобразуване и

компресиране на аналогови сигнали в битове и байтове като по този начин се създава дигитално копие на аналоговите продукти. Оригиналът остава непроменен, но копията могат да се възпроизведат, допълнително да се копират и тиражират. Това е лесно, защото за разлика от аналоговата, дигиталната информация има само две различни възможни състояния. Това прави много по-надеждно самото копиране, архивиране и тиражиране и дава оптимални възможности за нейното кодиране, декодиране и защита. Спецификата на цифровата информация я прави „дистрибутивна“, „репликативна“ и „интерактивна“. Както посочват J. S. Brennen и D. Kreiss „цифровизацията е процес на превръщане на аналоговата информация в „нематериална“ информация от битове с дискретни стойности [3]. Предимствата на цифровата информация са много: прецизност; бърз обмен; сигурност на преноса на информация; минимален риск от грешки и възможности за компресиране на данните; лесна обработка; пренос без загуби; лесен достъп за ползвателя на данни; добри възможности за защита при съхраняването на информацията; възможности за анализ и изясняване на въпроси от вероятностно-статистически характер и въпроси свързани с вземане на управленски решения и теория на риска; възможности за бързо, лесно и прецизно тиражиране.

Що се отнася до термина дигитализация J. S. Brennen и D. Kreiss посочват в свое изследване, че дигиталните платформи променят начина, по който се осъществява международния бизнес, като съкращават разходите за задгранични сделки и операции. Те създават глобални пазари и потребителски общности, като същевременно осигуряват на фирмите многобройни клиенти и ефективни начини за постигане на отлични резултати [4].

Началото на дигиталната трансформация се свързва с ориентираните към клиента решения, които се решават с помощта на технологиите. Дигиталният бизнес всъщност е системно използване на технологичните новости и адаптирането на процеси към тях, възможностите за работа в мрежа и свободен трансфер на информация между различни субекти.

Нашата теза, е че всички съвременни термини като цифровизация, дигитализация, информатизация, компютризация и дигитална трансформация са част от родовото понятие автоматизация на процесите на човешките дейности, свързани с използването на машини за търсене, архивиране, анализ и обработка на съществуваща и достъпна информация. В този смисъл може да се приеме, че по своята дълбока същност тези понятия в някаква степен са идентични. Те, разбира се, са и достатъчно различни. Тези разлики идват от степента на автоматизация, от степента и целите на тяхното използване по хоризонталата и вертикалата, от тяхната сложност, от мащабите и сферите на приложимост, от ефективността и резултативността на тяхното приложение, от степента на тяхното влияние върху развитието на човешките дейности, от възможностите да заместят човека и големи групи от хора, имитирайки и осъществявайки реално тяхната дейност. С други думи автоматизацията на човешката дейност еволюира от цифровизацията до дигитализацията, а от там до изкуствения интелект и дигиталната трансформация. Изложеното от нас разбиране не противоречи на утвърдената и използваната в литературата терминология по въпроса и съвременното дефиниране и семантичен анализ на тези понятия.

Дигиталната трансформация на фирмата е сериозен фундамент и предпоставка, гарантираща добри възможности в иновационното и устойчиво развитие на фирмата. Освен това дигиталната трансформация по същество е иновационен организационен процес и като такъв изисква системен подход и представлява един непрекъснат във времето цикъл.

Фигура 1. Цикъл на дигитална трансформация



Във фигура 1 са описани етапите на фирмено поведение при осъществяване процеса на дигитална трансформация. В този цикъл всяко решение се разглежда като проблемна ситуация, която може да е индуцирана от външен за организацията източник - нови научни и технологични открития, промени във възприятието, нагласите и ценностите на потребителите. Трансформацията може да бъде провокирана и от чисто вътрешни тласкащи за компаниите фактори, без значение дали те са в производствената сфера, търговията или услугите.

Глобалната информатизация, интернет, облачните технологии като инструмент и причина за дигиталната трансформация, променят коренно и съдържанието на понятието конкуренция. Според В. Калайджиева борбата за лидерство води до създаване на алианси и сдружения, за да се гарантират достатъчно кадрови, финансови и материално-технически ресурси, които да обезпечат решаването на актуални проблеми от взаимен интерес. Дигитализацията е изключително важно условие и обезпечение на тези процеси. Създаването на клъстери на регионален, географски и отраслов принцип като неформални или формални мрежи от предприятия, са проява на именно такива интегративни процеси. Това естествено се обуславя и от предимствата, които това единение дава по отношение разпределяне и управление на риска [5]. Ескалацията на трансфера на съвременни технологии, чрез лицензионна търговия и търговия с високо технологични продукти, както и свободното движение на кадри и специалисти при мащабните миграционни процеси са основните фактори, обуславящи тази тенденция. В световен мащаб всички специалисти са обединени в становището си, че науката, иновациите и дигитализацията осигуряват и гарантират високия икономически растеж, високата производителност, опазването на околната среда и други бизнес позитиви. Подобна теза е издигната като водеща за следващите години и на срещата на Г-8 през 2007 г. [6].

Глобалната информатизация в съвременното общество се свързва с програми и концепции като интернет на нещата, облачните технологии (Cloud Technology), високоскоростните 5G мрежи, Индустрия 4.0, експертните системи, блокчейн технологиите, изкуствения интелект, изкуствените невронни мрежи (ANN, Artificial Neural Networks), машинното обучение (Machine Learning) и дълбокото машинно обучение (Deep Learning).

Тези дигитални технологии дават сериозен тласък и възможности за бързо осъществяване на европейската идея за свободно движение на хора, стоки, услуги и капитали. Идеята за създаване на единен пазар вече не се свързва основно с понятия като „Еврозона“ и „Шенгенско пространство“. Фокусът се измества все повече към създаването на единно цифрово пространство. Трите фундамента, на които ще стъпи изграждането на единен цифров пазар в Европа са облачните изчислителни технологии, изкуствения интелект и анализа и обработката на големи бази от данни (Big data computing).

Икономиката, основана на знанието, все повече се отъждествява с понятието икономика, основана на данни и

свързаност. Високоскоростната цифрова мрежа 5G има съществен принос в създаването на инфраструктурата на устойчивото развитие, което освен с изграждане на проспериращи икономики е свързано с изграждане на екосистеми, осигуряване на добри условия за живот на планетата, сближаване на държавите от ЕС, достойно човешко съществуване, премахване на бедността и глада, осигуряване на качествено образование и достъп до здравеопазване, социална справедливост и др. Интернет на нещата, онлайн търговията, рекламата и услугите, 3D принтирането, експертните системи, блокчейн технологиите и други проявления на изкуствения интелект отдавна са факт в икономиката и социалната сфера. Без тези технологии трудно можем да си представим съвременната търговия, автомобилната и космическата индустрии, медицината, образованието, осъществяването на финансови и други транзакции на данни, роботизирани и кибер-физичните устройства, с които се свързва бизнеса и социално-културната среда. Използването на новите технологии от типа изкуствен интелект е свързано, разбира се, и с рискове и негативни тенденции. По тази причина в ЕС вече е факт създаването на принципи и регламенти, които са регулатор и нормативна рамка.

Според нас, от дигитализацията най-пряко и сериозно са повлияни сектори като индустриалното производство, логистиката, доставките и транспорта, туризма и хотелиерския бизнес и online търговията. В интернет търговията е наложително фирмите все повече да използват „потопящи“ технологии като създават 3D и VR/AR (Виртуалната реалност/Добавена реалност) среда, за да може на клиента да се осигури виртуално изображение или прототип на предлагания продукт. Все повече са потребителите на стоки и услуги, които подкрепят фирмите, чиято дейност е съобразена със съвременните изисквания на наложените нормативно еко стандарти – лед осветление, екоавтомобили, умни прибори и домове.

Компютърният софтуер дава изключително добри възможности за решаване на задачи от линейното, нелинейното, динамичното, стохастичното, дискретното и евристичното оптимизиране. Освен това дигитализацията дава възможности за тестване на изготвени от компанията изоморфни и хомоморфни модели на реални проблемни ситуации, стига да са изучени добре причинно-следствените връзки, да са дадени достатъчен брой аналогии с подобна проблемна структура и да са добре избрани съществените показатели за работа на системата и реалния проблем.

Все по-съществена роля ще имат съвременните методи за измерване на иновативността и конкурентоспособността, даващи възможност при фирмения анализ на резултатите да се вземат адекватни мерки и решения за промени в политиката и поведението на фирмата. Иновативността винаги е разглеждана като един от индексите за определяне на конкурентоспособността. Конкурентоспособността обаче, също като иновативността, е синтетичен показател, който обединява в себе си редица постижения на фирмата. На практика в много случаи е трудно да се определи чрез измерване на статистически данни каква точно част от повишението на конкурентоспособността се дължи на внедрени дигитални иновации. Каквато и методика обаче да бъде подбрана за използване, тя очевидно трябва да включва нови, по-актуални, адекватни на новата електронна среда, аналитично-оценъчни показатели [5]. Съществуват различни подходи за изследване степента на информатизация като някои от най-често използваните показатели са свързани с: използването на ИКТ в производствените процеси и в комуникацията с партньори и клиенти; оценяване използването на онлайн услуги; участие в трансфер на дигитална информация и данни; развитие и функциониране на електронно правителство; мрежова свързаност; интернет на нещата;

състояние на високоскоростните цифрови мрежи като 5G; използването на дигитални портфейли (блокчейн технологии и криптовалюти); използване на изкуствен интелект във виртуалния свят и внедрени във физически устройства (роботи, автомати) и др.

От 2014 г. насам Европейската комисия наблюдава напредъка на държавите членки в областта на цифровите технологии и публикува годишни доклади за индекса за навлизането на цифровите технологии в икономиката и обществото (Digital Economy and Society Index, DESI). Всяка година в докладите относно DESI се включват профили на отделните държави, които помагат на държавите членки да идентифицират области, в които са необходими приоритетни действия, както и тематични глави, в които се предоставя анализ на равнище ЕС в ключови области на цифровата политика. В индекса DESI се прави класация на държавите членки според тяхното равнище на цифровизация и се анализира техният относителен напредък през последните пет години, като се отчита отправната им точка. От 2023 г. DESI вече е интегриран в доклада за състоянието на цифровото десетилетие и се използва за наблюдение на напредъка по отношение на цифровите цели. ЕС предложи значителни ресурси в подкрепа на цифровата трансформация. 127 милиарда евро са предназначени за реформи, свързани с цифровите технологии и инвестиции в националните планове за възстановяване и устойчивост. Това е добра възможност за ускоряване на цифровизацията, повишаване на устойчивостта на съюза и намаляване на външните зависимости [7].

В класацията на индекса за навлизането на цифровите технологии в икономиката и обществото за 2022 г. България заема 26-о място от 27-те държави-членки на ЕС. Резултатът на България в DESI нараства средно с 9% годишно през последните пет години. Предвид позиционирането на България, този темп на растеж не е достатъчен, за да може страната да догони останалите страни-членки на съюза. По отношение на четирите основни аналитико-оценъчни показатели – човешки капитал, свързаност, внедряване на цифрови технологии и цифрови обществени услуги, които това ранкиране използва, резултатите показват изоставането на страната ни по отношение на процесите свързани с дигитализацията.

Таблица 1. Човешки капитал – DESI 2022 г.

Човешки капитал	България DESI 2022 г.	ЕС DESI 2022 г.
1a1 Поне основни умения в областта на цифровите технологии % лица	31 % 2021 г.	54 % 2021 г.
1a2 Цифрови умения над основните % лица	8 % 2021 г.	26 % 2021 г.
1a3 Поне основни умения за създаване на съдържание в областта на цифровите технологии ¹ % лица	44 % 2021 г.	66 % 2021 г.
1b1 Специалисти по ИКТ % от заетите лица на възраст 15 – 74 години	3,5 % 2021 г.	4,5 % 2021 г.
1b2 Жени — специалисти по ИКТ % специалисти по ИКТ	28 % 2021 г.	19 % 2021 г.
1b3 Предприятия, осигуряващи обучение по ИКТ % предприятия	7 % 2020 г.	20 % 2020 г.

¹ Прекъсване в динамичните редове за показатели 1a1, 1a2 и 1a3. Стойностите не са съпоставими с тези в предишните доклади за DESI.

164 Абсолвенти по дисциплини в областта на ИКТ % абсолвенти	4,6 % 2020 г.	3,9 % 2020 г.
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Източник: Адаптирана по Индекс за навлизането на цифровите технологии в икономиката и обществото (DESI), 2022 г. България; https://egov.government.bg/wps/wcm/connect/egov.government.bg-2818/fb96226c-2dca-49d6-a951-0f1b4b729588/DESI_2022_Bulgaria_bg.pdf?MOD=AJPERES&CVID=ofRit7D

По отношение на човешкия капитал, България отново се нарежда на 26-то място сред 27-те държави от ЕС, като най-лоши са резултатите свързани с продължаващото обучение по ИКТ (показател **1a2** и **163**), където изоставането от средноевропейското ниво в процентна дименсия е близо 3 пъти. Това в някакъв смисъл предизвиква дискусии въпроси като се вземе предвид фактът, че в същото време броят на завършващите студенти в специалности свързани с ИКТ е по-висок от средноевропейското ниво – за България е 4,6%, а за ЕС-3,9%.

Таблица 2. Свързаност – DESI 2022 г.

Свързаност	България DESI 2022 г.	ЕС DESI 2022 г.
2a1 Цялостно разпространение на фиксирания широколенов достъп до интернет % домакинства	63 % 2021 г.	78 % 2021 г.
2a2 Разпространение на фиксирания широколенов достъп до интернет със скорост поне 100 Mbps % домакинства	22 % 2021 г.	41 % 2021 г.
2a3 Разпространение на интернет със скорост поне 1 Gbps % домакинства	0,42 % 2021 г.	7,58 % 2021 г.
261 Покритие с високоскоростен широколенов достъп от следващо поколение % домакинства	93 % 2021 г.	90 % 2021 г.
262 Покритие на фиксираните мрежи с много голям капацитет (ММГК) % домакинства	85 % 2021 г.	70 % 2021 г.
263 Покритие с оптични линии до сгради % домакинства	85 % 2021 г.	50 % 2021 г.
2в1 Радиочестотен спектър за 5G Разпределителен спектър като % от общия хармонизиран радиочестотен спектър за 5G	25 % 4.2022 г.	56 % 4.2022 г.
2в2 Покритие с 5G мрежи ² % населени места	40% 2021 г.	66 % 2021 г.
2в3 Разпространение на мобилния широколенов достъп до интернет % лица	73 % 2021 г.	87 % 2021 г.
2г1 Индекс за цената на широколеновия достъп до интернет Резултат (0 – 100)	86 2021 г.	73 2021 г.

Източник: Адаптирана по Индекс за навлизането на цифровите технологии в икономиката и обществото (DESI), 2022 г. България; https://egov.government.bg/wps/wcm/connect/egov.government.bg-2818/fb96226c-2dca-49d6-a951-0f1b4b729588/DESI_2022_Bulgaria_bg.pdf?MOD=AJPERES&CVID=ofRit7D

По отношение на свързаността България по данни от 2021 г. се нарежда на 19-то място. Този показател е най-добър за страната в сравнение с останалите, макар да не води до престижно класиране в ранкинга на ЕС. Резултатите в случая се колебаят около средните за Европа стойности. Сериозните

² Покритието с 5G мрежи се отнася до процента на населените места, покрити от поне един оператор, за който съобщават операторите и националните регулаторни органи.

негативи са свързани с използвания от домакинствата интернет със скорост поне 1 Gbps (показател **2a3**) и показателите **2в1** и **2в2**, свързани с високоскоростните мрежи от типа 5G.

Таблица 3. Интегриране на цифрови технологии – DESI 2022 г.

Интегриране на цифрови технологии	България DESI 2022 г.	ЕС DESI 2022 г.
3a1 МСП с поне основно равнище на цифров интензитет % МСП	25 % 2021 г.	55 % 2021 г.
361 Електронно споделяне на информация % предприятия	22 % 2021 г.	38 % 2021 г.
362 Социални медии % предприятия	13 % 2021 г.	29 % 2021 г.
363 Големи данни % предприятия	6 % 2020 г.	14 % 2020 г.
364 Компютърни услуги в облак % предприятия	10 % 2021 г.	34 % 2021 г.
365 Изкуствен интелект % предприятия	3 % 2021 г.	8 % 2021 г.
366 ИКТ за екологична устойчивост % предприятия със среден/висок интензитет на екологични мерки посредством ИКТ	68 % 2021 г.	66 % 2021 г.
367 Електронни фактури % предприятия	10% 2020 г.	32 % 2020 г.
3в1 МСП, които осъществяват продажби онлайн % МСП	10 % 2021 г.	18 % 2021 г.
3в2 Оборот от електронна търговия % оборот МСП	4 % 2021 г.	12 % 2021 г.
3в3 Трансгранични продажби онлайн % МСП	4 % 2021 г.	9 % 2021 г.

Източник: Адаптирана по Индекс за навлизането на цифровите технологии в икономиката и обществото (DESI), 2022 г. България; https://egov.government.bg/wps/wcm/connect/egov.government.bg-2818/fb96226c-2dca-49d6-a951-0f1b4b729588/DESI_2022_Bulgaria_bg.pdf?MOD=AJPERES&CVID=ofRit7D

Интегрирането на цифровите технологии в стопанските дейности продължава да представлява слабо място за България (26-то място). Най-силно е изоставането свързано с използването на облачните технологии, електронните фактури и електронната търговия (показатели **364**, **367**, **3в2**) – приблизително 3 пъти по-лоши от средноевропейските процентни стойности за тези показатели. Останалите показатели също са с ниски стойности, далеч от лидерите и средното ниво за ЕС (данните са за 2021 г.).

Таблица 4. Цифрови обществени услуги – DESI 2022 г.

Цифрови обществени услуги	България DESI 2022 г.	ЕС DESI 2022 г.
4a1 Потребители на услуги на електронното управление % потребители на интернет	34 % 2021 г.	65 % 2021 г.
4a2 Предварително попълване на формуляри Резултат (0 – 100)	58 2021 г.	64 2021 г.
4a3 Цифрови обществени услуги за граждани Резултат (0 – 100)	59 2021 г.	75 2021 г.
4a4 Цифрови обществени услуги за предприятия Резултат (0 – 100)	76 2021 г.	82 2021 г.
4a5 Отворени данни % от максималния резултат	78 % 2021 г.	81 % 2021 г.

Източник: Адаптирана по Индекс за навлизането на цифровите технологии в икономиката и обществото (DESI), 2022 г. България; https://egov.government.bg/wps/wcm/connect/egov.government.bg-2818/fb96226c-2dca-49d6-a951-0f1b4b729588/DESI_2022_Bulgaria_bg.pdf?MOD=AJPERES&CVID=ofRit7D

[0f1b4b729588/DESI_2022_Bulgaria_bg.pdf?MOD=AJPERES&CVID=ofRit7D](https://www.industry40.eu/0f1b4b729588/DESI_2022_Bulgaria_bg.pdf?MOD=AJPERES&CVID=ofRit7D)

България отчита ниски резултати по отношение на цифровите обществени услуги, като се нарежда на 25-то място в ЕС като най-малък е процентът на потребители на услуги на електронното управление (показател **4a1**). Останалите показатели са по-ниски от средностатистическите стойности.

Индексът за навлизането на цифровите технологии в икономиката и обществото показва най-съществена разлика между държавите членки по отношение на "Човешкия капитал". С показателите в DESI не се отчита влиянието на дигитализацията върху пазара на труда, но въпреки това те могат да се използват за анализ на това до каква степен дигитализацията е актуална тема в социалната интеграция. При сравняването на данните за различните държави в DESI и Social Scoreboard (набор от социални показатели) са налице значителни съответствия и корелации в техните резултати и позиции.

Съвременните иновации са свързани най-вече с дигитализацията и дигиталната трансформация на бизнес моделите. Новите технологии и идеи могат да допринесат за разрешаването на предизвикателствата, свързани с околната среда и да улеснят постигането на устойчивост. Според D. MacLean, M. Andjelkovich и T. Vetter широкомащабното устойчиво развитие не може да се постигне без глобални комуникации и обмен на знания [8]. М. Филипова, М. и Р. Юлева посочват, че иновациите са в основата на високата конкурентоспособност на българските предприятия, прехода към цифрова икономика, както и ключов фактор за реализирането на зелена икономика [9]. В контекста на казаното, можем да твърдим, че е необходимо преосмисляне на стратегическите подходи и насочване на бизнеса към екологично ориентирано мислене и социално отговорно поведение [10].

Целите на ЕС и ООН, свързани с устойчивото развитие 2016-2030 г. предвиждат не само конкурентоспособна икономика, основана на използване на съвременни дигитални технологии, а и баланс между икономиката и функционирането на социалната сфера (здравеопазване, образование, бедност) и съхраняването на екосистемите чрез осъществяване на кръгова (зелена) икономика. Новите дигитални технологии и дигиталната трансформация на бизнеса са ключов фактор за реализацията на тези европейски проекти, свързани със стратегията за единен цифров пазар в Европа и устойчивото развитие.

3. Заключение

Съвременната дигитализация основателно се свързва и отъждествява с понятия като интернет на нещата, облачни технологии, 3D печат, 5G мрежи, машинно обучение, дълбоко машинно обучение, изкуствени невронни мрежи, изкуствен интелект, експертни системи, блокчейн и още много други информационни и комуникационни технологии.

Приложението им в промишлеността, търговията, услугите и бита на хората има толкова масов характер, че по-лесно е да се споменат областите, където те не се прилагат, отколкото да се опише тяхната актуалност, приложимост и влияние. При това, става въпрос за съществени, положителни, количествени и качествени параметри на това влияние и промяна, която не изключва, разбира се, риск и компликации от психологически характер и грешки, които могат да бъдат допуснати поради скоростта, с която се „случват“ дигиталните промени.

Дигитализацията и дигиталната трансформация на бизнеса са неизбежен и обективен процес, обусловен от бързото и агресивно проникване на ИКТ във всички стопански, социални, политически и културни сфери на обществото. При това става въпрос за промени свързани с мащабни, значителни и

стресиращи трансформации. Дигитализация на бизнеса е осъществявана в рамките и на предишни индустриални революции. В момента обаче става въпрос за трансформация на човешкото мислене, общуване и поведение, за нови, несъществуващи никога до сега комуникационни канали, за достъп и използване на информационни методи от всякакво естество с универсално приложение. В сферата на бизнеса тотално се променя комуникацията между компанията, клиента и партньорските фирми. При това тази промяна има съществени не само количествени, но и качествени характеристики. Става въпрос за цялостна промяна на бизнес модела.

Данните за България по много показатели в индекса за навлизане на цифровите технологии в икономика и обществото показват, че в много аспекти свързани с дигитализацията изоставаме. При това не само от водещите в ЕС държави, но и от средноевропейските стойности на тези показатели. Изводът, който се налага е, че предстоят и трябва да се осъществят много промени на национално, регионално и фирмено равнище, за да се осъществява ефективно процеса на дигитална трансформация на бизнеса и обществото.

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Impact of e-commerce on the logistics sector

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Abstract: The introduction of digital technologies into modern life has turned e-commerce into a global industry, having a significant impact on the logistics sector and supply chain management. The Covid-19 pandemic has contributed to the rapid growth of online commerce, creating additional challenges for companies in the logistics sector. **The purpose of this report** is to examine the trend in the development of e-commerce and its relationship with the logistics sector. The results of a study related to the differences in costs in electronic and traditional commerce are presented.

Keywords: e-commerce, logistics sector, logistics services

1. Introduction

The rapid development of information technology (IT) and its implementation in companies is changing their business models for trade and business. [1] Today, most companies have invested, implemented and integrated IT infrastructure to achieve higher economic growth. Using electronic commerce (EC) as a transaction model is a priority for most companies. [2]

In recent years, e-commerce has become one of the fastest growing and most profitable industries. In the past 2022, the size of the e-commerce market has reached \$12.6 trillion. Forecasts for the development of the market until 2032 are for significant growth and reaching 57.22 trillion US dollars at a CAGR of 15% (Fig. 1). [3]

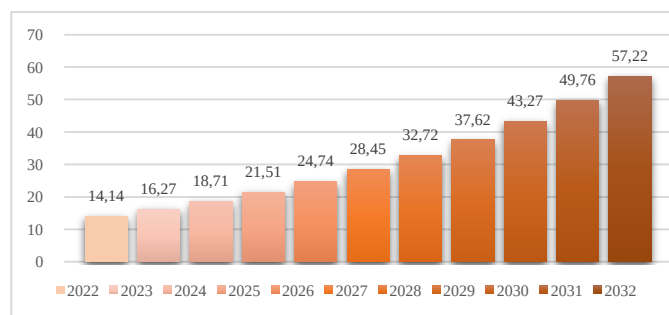


Fig. 1. E-Commerce Market Volume Forecast, 2022-2032, Trillion \$

Source: <https://www.verifiedmarketresearch.com/product/e-commerce-market/>

E-commerce was one of the fast-growing sectors before the pandemic and was growing at double-digit rates, but Covid 19 and consumer demand have further accelerated the shift from brick-and-mortar to online commerce. Among the main reasons for the growing market demand are accepted - the continued spread of the Internet throughout the world, which will lead to an increase in the number of users and the new 5G technology. [4]

Expectations for the period 2022-2032 are that the business-to-business (B2B) segment will hold the larger market share compared to the business-to-consumer (B2C) segment as in 2022, when B2B realizes 65% of the sector's revenue, and B2C forms 35% (Fig. 2).[5]

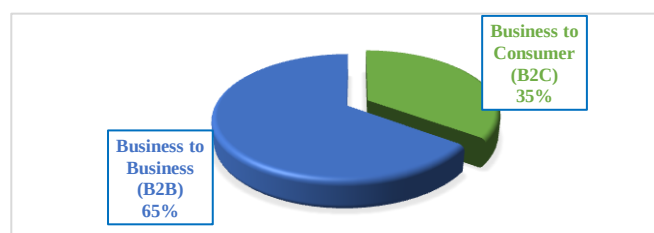


Fig. 2. E-commerce market share by types, 2022 (%) [5]

The breakdown of estimated e-commerce revenue by geographic region for the four-year period from 2022 to 2026 is presented in Fig. 3. The data shows that the largest volume of revenue in the sector will be achieved in the Asia region, followed by the North America and Europe region, with the largest growth of 19% will be the Central and South America and Africa regions.[6]

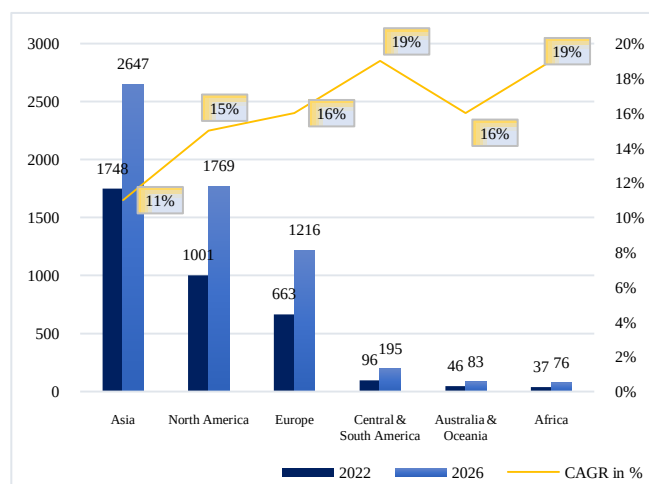


Fig. 3. Forecast e-commerce revenue by region, 2022-2026 in USD billion

Source: <https://ecommercedb.com/insights/the-north-american-ecommerce-market>

2. Literature review

The concept of "electronic commerce" is synonymous with the concept of "internet commerce". The two concepts are used to express a process in which two or more participants enter into transactions using a computer, a local network and the Internet. [7]

The term e-commerce is associated with real-time business transactions over telecommunications networks. This term has a broad application, including the virtual browsing of goods, the selection of goods for purchase and payment methods. In e-commerce, there is no prior agreement between the parties - customer and seller. It is carried out over the Internet by the use of all technologies, or a combination of them, created for the exchange of data, access to data and recording of information. In the National Strategy for Electronic Commerce of the Republic of Bulgaria [8] the term electronic commerce is formulated as "a continuous cycle of data processing and exchange through which a unified and integrated information provision of the participants in the overall commercial transaction regardless of the field of activity, industry, country, etc."

Electronic commerce comes in various forms and varieties, summarized in fig.4 [9]

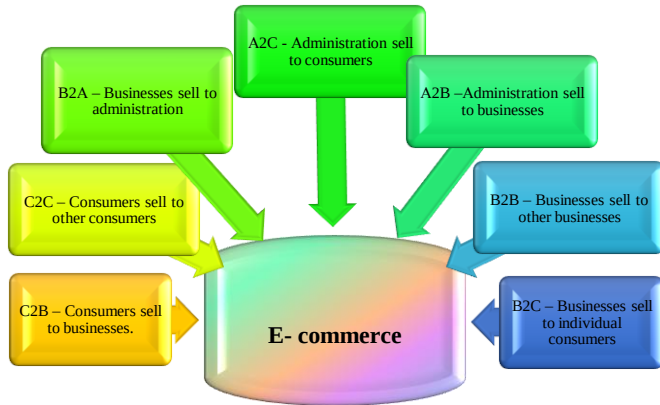


Fig.4. Types of e-commerce

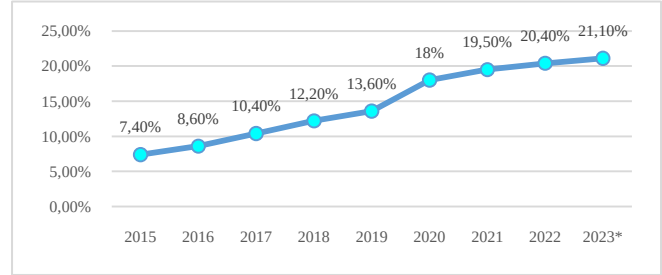
- **Business-to-business (B2B).** This type of E-commerce refers to organizations that provide goods and services to other legal entities. The implementation of transactions requires a very high level of security in the exchange of information. The business-to-business market refers to:
 - Firms selling goods and services to each other, with one organization playing the role of seller and the other playing the role of buyer.
 - Transactions and information related to reverse processes between suppliers, partners or channels, such as ordering, payment, general and advanced procurement services, distribution assistance and logistics management.
- **Business to Consumers (B2C).** This type of E-commerce refers to all companies and organizations that provide goods and services to consumers using the capabilities of the Internet. The company's focus is on the consumer as the end customer or buyer.
- **Consumers to Businesses (C2B).** In this type of E-commerce, consumers demand specific goods or services from the business.
- **Consumer to consumer (C2C).** This type of E-commerce is done through an auction site. One user announces what he offers and another user expresses a desire to purchase the offered product/service. The site owner provides the connection between the buyer and the seller in order for the transaction to take place. Usually, the intermediary keeps a part of the value of the transaction in the form of a fee for the service rendered.
- **Business to administration (B2A).** This type of E-commerce concerns the interaction between businesses, (commercial organizations) and government organizations at local, regional and international levels.
- **Consumer to administration (C2A).** In this type of E-commerce we are talking about interaction between consumers and government authorities, usually in the social and tax spheres, via the Internet.

Depending on the type of goods and services delivered via the Internet, two types of E-commerce can be distinguished - direct and indirect:

1. the direct means requesting, buying and delivering intangible goods and services online, such as software, music, movies, etc.

2. indirect - is the ordering of goods and services over the Internet, but the delivery is carried out physically through traditional delivery methods.

3. Analysis and discussions



An increase in customer preferences for e-commerce was seen in the years before the pandemic, but Covid 19 has further accelerated the shift from brick-and-mortar to online commerce. (fig.5) [13]

Fig. 5. Growth of e-commerce, 2015-2023, in %

Source: <https://www.trade.gov/impact-covid-pandemic-ecommerce>

The growth of e-commerce in recent years has contributed to an increase in demand for logistics services. This also affected investor interest in the logistics sector. (fig.6) [14]

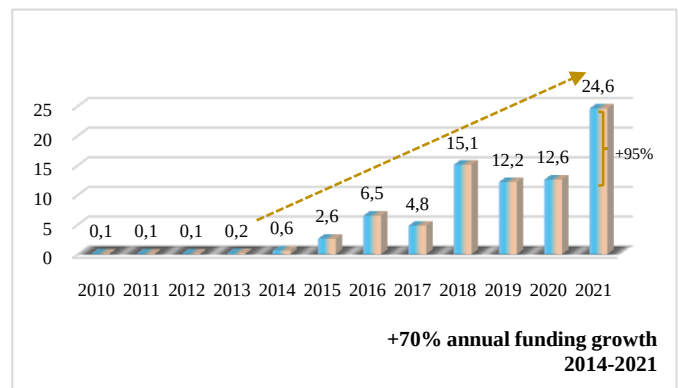
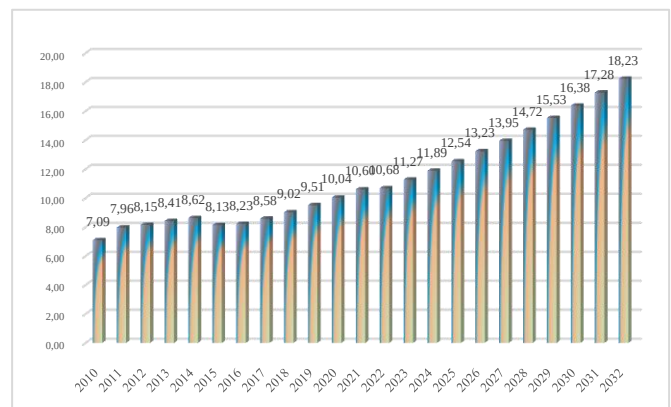


Fig. 6. Globally funding for logistics startups, млрд. \$

Source: <https://www.mckinsey.com/startup-funding-in-logistics>

The data from fig. 6 confirm the financial attractiveness of the logistics sector on a global scale with increased investor interest reported in 2021. After 2014, there has been a significant increase in start-ups in the sector. For the period 2014-2021, the growth was a total of 70%, but for only 2021, the data reported an increase of 95% compared to the previous year.

Logistics is of great importance for achieving economic growth and developing e-commerce. The size of the global logistics market

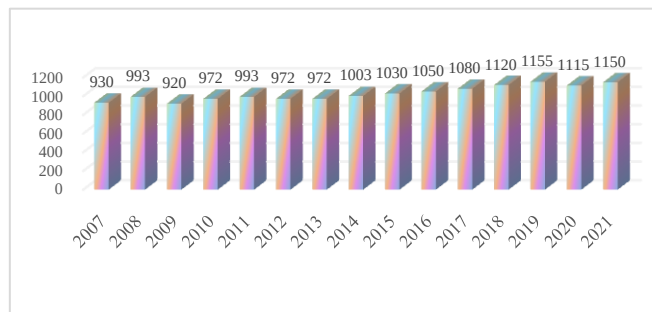


for 2022 is estimated at \$10.68 billion (Fig. 7). Data for the period 2010 – 2022 show stable growth. Expectations for the sector are that by 2032, the market size will grow to about \$18.23 billion with a compound annual growth rate (CAGR) of 5.48%. [15,16]

Fig. 7. Logistics market size, млрд. \$

Source: <https://www.precedenceresearch.com/logistics-market>

Against the background of the global trend, data on the revenue of the logistics sector in Europe for the period 2007-

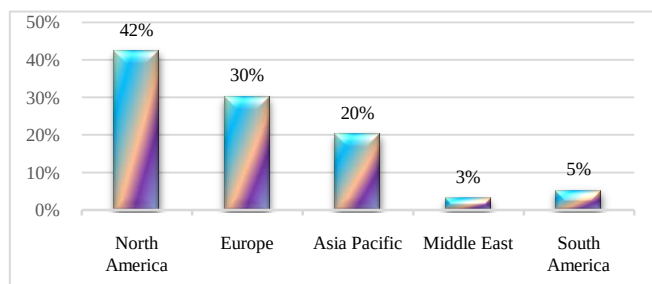


2021 shows relative stability. (Fig. 8) Reported revenue growth over a fifteen-year period is 23.66%, which equates to an average of 1.6% growth per year. [16,18]

Fig. 8. Logistics market size in Europe, billions EUR

Source: <https://www.statista.com/logistics-market-segment-volume-europe/>

The distribution of the global logistics market by geographical regions is presented in fig. 9. According to the data, the largest share of 42% is occupied by North America. In second place is Europe with a share of 30%. In third place are South America with 5%, and in fourth place is the Middle East with 3% of the market



share. [17,18]

Fig. 9. Logistic market by geographical regions

Source: <https://www.maximizemarketresearch.com>

Studies show that there is a shift in customer preferences from brick-and-mortar to online shopping. This growth is due to the advantages that customers are finding in the various levels of online commerce – from product personalization, optimized search through mobile devices, fast and secure payment processes and hassle-free delivery.

As e-commerce grows, so does the need for efficient logistics services. Logistics provides a number of benefits, among which – increased competitiveness of the organization in terms of flexibility, delivery, quality and cost, higher level of customer satisfaction, improved delivery performance, lower operating costs, etc.

Research shows a direct link between growth in e-commerce and the logistics sector. Online sales are becoming a major factor having a direct impact on the logistics market. (fig.10) [22, 23]

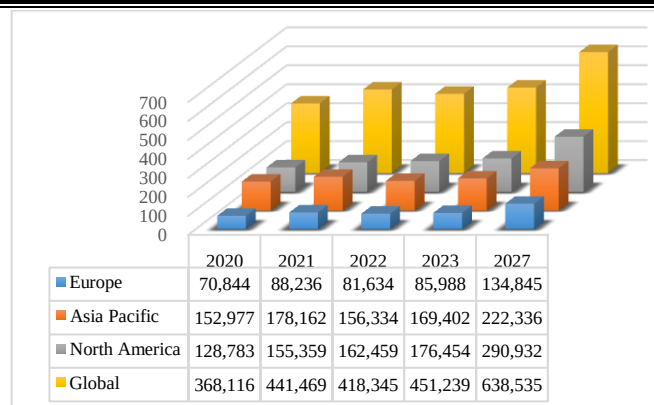


Fig. 10. Global e-commerce logistics market by region 2020-2027, \$ billion

Source: <https://www.giiresearch.com/global-e-commerce-logistics.html>

The data from fig. 9 show that the global e-commerce logistics market is growing annually. In 2022, it is estimated to be \$451.239 billion. Growth for 2023 compared to the previous year is expected to increase by 7.9%. It is forecast to reach \$638.535 billion by 2027 with a CAGR of 10.3%.

The trend for retail sales through e-commerce shows steady growth. (fig. 11) [19]

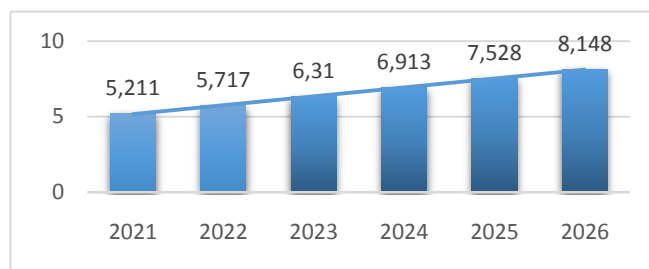


Fig. 11. Global E-Commerce Retail Sales Status and Trend, 2021-2026 in \$ Billion

Source: <https://www.forbes.com/advisor/business/e-commerce-statistics/>

Studies show that there is a shift in customer preferences from traditional to online shopping. This growth is due to the advantages that customers find in the various levels of online commerce - from product customization, optimized search through mobile devices, fast and secure payment processes and hassle-free delivery. In fig. 12 presents the change in the volume of sales through traditional and e-commerce in the period 2015-2022 and forecast until 2026. [20,21]



Fig. 12. Comparison between sales volume in electronic and conventional trade

Source: <https://www.insiderintelligence.com/content/global-retail-e-commerce-forecast-2023>

As the volume of e-commerce grows, so does the need for efficient logistics services. [10,11] Logistics provides a number of

benefits, among which – increased competitiveness of the organization in terms of flexibility, delivery, quality and cost, higher level of customer satisfaction, improved delivery performance, lower operating costs, etc.[12,13]

The development of the logistics sector in a country depends not only on the economic conditions and the intensive production and trade of the economic organizations in it, but also on the effectiveness of the conditions that the environment provides. [14,15] In this regard, a study was made of the Logistic Performance Index (LPI) of the World Bank, reflecting the main factors determining the overall efficiency of logistics in a country. The six components of the LPI include:

- ❖ The effectiveness of releasing the goods from border control (speed, simplified procedures, predictability of formalities).
- ❖ The quality of commercial and transport infrastructure (sea, rail, road transport, information technology).
- ❖ Hassle-free organization of cargo at a competitive price.
- ❖ Competence and skills of people providing logistics services (transport operators, customs brokers).
- ❖ The ability to locate and track shipments.
- ❖ Frequency with which the cargo reaches the customer within the scheduled or fixed delivery time.

The data for 2022 put our country in the 51st position (with a score of 3.2) on a par with Romania. (fig. 13). In the survey conducted among more than 1,000 logisticians from 155 countries, the leading place for 2022 is occupied by Singapore with a score of 4.3. The lag behind the leader in the ranking is in the six components. However, the data show that the conditions in Bulgaria in the logistics sector, in all directions, are above the average for the Europe and Central Asia region. [24, 25]

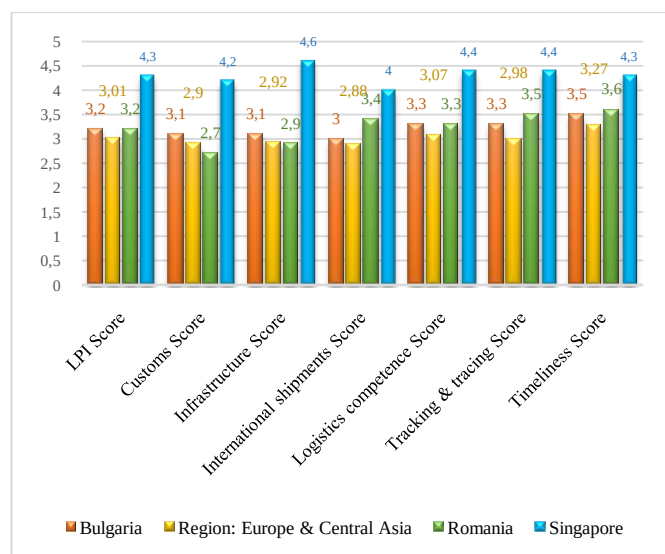


Fig. 13. Comparison of LPI for Bulgaria, Europe and Central Asia, Romania and Singapore, 2023.

Source:
<https://lpi.worldbank.org/international/scorecard/column/C/BGR/2023/R+ECS+2023+C+ROU+2023+C+SGP+2023>

With a score of 3.2, Bulgaria falls on the border between the group of partial performers and consistent performers.

4. Research results

A survey conducted among 173 companies from various industrial sectors in Bulgaria, carrying out online and traditional (conventional) trade shows a percentage distribution of the share of the types of logistics costs that they have to carry out for the same product. The results are presented in Fig. 14 and show the structure of costs in both types of trade - traditional and electronic for the same product. The cost structure in both trades is similar in that production costs (30%) and marketing costs (10%) are the same. In other directions, the cost structure differs significantly:

- **In traditional trade**, labor costs (18%) and rents (15%) occupy the largest share. They depend on the qualifications of the staff employed and the location of the commercial establishment. Other expenses mainly include utility and supply costs. Transport costs represent about 3% of the total logistics costs depending on the origin of the goods.
- In the case of e-commerce, in the structure of costs, operating costs occupy the largest share (20%). These include software and platform costs for financial transactions that require maintenance and periodic updates. Next comes shipping costs (nearly 7%), which are often offered free to customers or at a deep discount, as well as costs that include returns. Warehouse costs are low, around 3%, as most e-commerce distribution centers are located in suburbs or outside cities,

The results show that by offering the same selling price, an online retailer can make about a 30% profit margin, compared to roughly 16% for a retailer choosing a traditional form of trading. In order to increase their market share, online retailers can afford lower price offers.

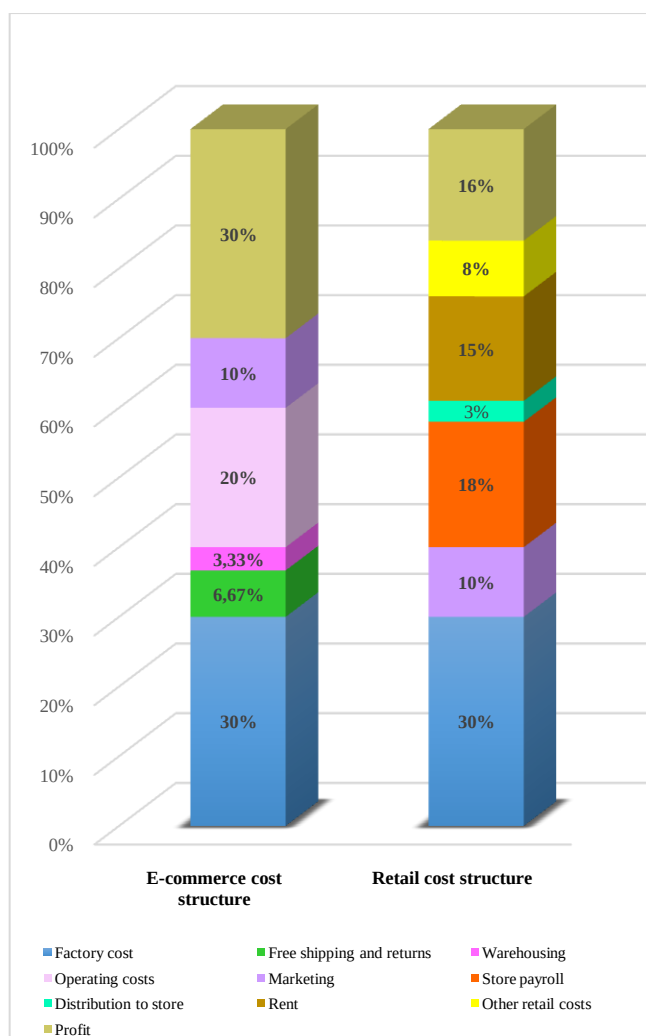


Fig. 14. Distribution of logistics costs in electronic and conventional trade, %

Studies show that e-commerce is becoming an increasingly preferred place for consumers to shop. The reasons for this are:

- ❖ **Convenience, both for the business and the customer.** The consumer can purchase necessary goods and services from any point, and the business must maintain constant availability in its physical locations.
- ❖ **Low costs** - offering a good logistics policy and affordable prices, combined with high quality of goods and services, the merchant that you will be the preferred choice of customers.
- ❖ **Availability** - the advantage of online stores is that they have no working hours or holidays.

- ❖ **Opportunity for greater profits** - by accessing a much larger number of potential customers, at lower costs.
- ❖ **Faster adaptation and changes** – the pace of development of e-commerce makes it easier and faster to adapt to the continuous changes of the market.
- ❖ **Security** - e-commerce provides access to secure statistical information for easy control of stock availability or number of orders. It also relies on security mechanisms for both parties regarding payments and transactions.

4. Conclusion

With the growth of the e-commerce market on a global scale, the growth of the logistics services market is being reported. This dependence attracts significant investor interest in the logistics sector. Bulgaria lags behind in terms of the six indicators included in the Logistic Performance Index (LPI) of the World Bank compared to the leader in the ranking for 2022. However, the conditions in Bulgaria in the logistics sector, in all directions, are above the average for the European region and Central Asia. This shows that the logistics services market in the country is in the process of development and follows the trends in the development of the logistics services market in the world. Studies show that e-commerce is becoming an increasingly preferred place for consumers to shop.

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Design, production, and evaluation of product quality for electric vehicle parts

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Abstract: The final products that emerge from innovative production processes for different electric vehicle parts are Aluminum profiles of all designs for applications such as doors, structural and semi-structural parts, etc. The production line of these products is automated, where every work process, is controlled by CNC panels in which they are implemented and programmed with different software. The automation of the production processes tends to improve the quality of the product and tends to optimize the production process to minimize and decrease production waste. This paper presents the production process of different electric vehicle parts and how their quality is evaluated by using PFMEA analysis according to the quality standards. The implementation of quality standards resulted in product quality and enterprise quality management system improvement.

Keywords: ALUMINUM PROFILES, AUTOMATED PRODUCTION PROCESS, PRODUCT QUALITY, PFMEA ANALYSIS

1. Introduction

The process of materials selection in the product development process is always referred to as a complex step by industrial manufacturers. Different industrial manufacturers attempt to develop a systematic method to select the best material that suits their products. A few factors determine the best material and the complexity level rises. There are two main reasons why the material selection is required [1]:

1. To design an existing product with better performance, lower cost, increased reliability, and reduced weight.
2. The selection of materials is the primary consideration of product design because overall product performance is directly influenced and determined by the materials selection process.

The automotive industry uses light alloy materials, reinforced plastics, and polymers to produce different vehicle parts. These materials offer improved properties such as strength impact, easy moldability, improved aesthetics, and reduced weight compared to conventional automotive components [2]. Their potential for maximum mass reduction and the potential to reduce carbon emissions from lightweight vehicles are the main advantages that offer opportunities in the automotive industry [2]. Until now the factors restraining the market are high material costs and large investments in materials research activities by companies [3].

According to [4] the typical weight distribution in cars is Steel 71% (of vehicle body panels), Cast Iron 15% (of body parts engine, gearbox, axle), tires (tires, tubes), and others including Zinc, Copper, Aluminum, Polymers, etc. The use of aluminum in automotive applications has increased by more than 80% in recent years [5]. Aluminum castings have been applied to various automotive parts for a long time. As a major trend, the material for the engine blocks, which is one of the heaviest parts, switches from cast iron to aluminum, resulting in significant weight reduction.

2. Materials to produce automobile parts.

Everest Shpk Company was established in 1997 and is one of the leading companies in Albania that produces aluminum profiles for different applications such as doors, windows, and accessories. According to the company [6] the production process of aluminum ingots consists of a propane gas furnace with a capacity of 25 – 27 tons as shown in Figure 1 (but the furnace is filled depending on the number of ingots to be produced). The melting temperature of aluminum is 713 °C inside the furnace. Aluminum casting is done in the interval of temperatures 740 – 750 °C. To remove impurities in the oven, flusses are thrown so that the latter remains on the surface of the molten material and is manually removed from the furnace. In the furnace, aluminum scraps, different aluminum waste materials to be recycled from different production sectors, are thrown for the aluminum ingots production cycle.



Fig. 1 The furnace of aluminum ingots production [6]

In the furnace, ingots of the 6060 series are produced because they are more suitable for production, they are corrosion resistant, weldable, etc. Aluminum 6060 is part of the aluminum-silicon magnesium family. The chemical composition of the aluminum 6060 produced for automotive parts is shown in Table 1 and the mechanical properties are shown in Table 2.

Table 1: AL 6060 chemical composition [6]

Element	Al	Si	Cu	Mn	Mg	Cr	Zn	Ti	Fe
Percentage %	97.9-99.3	0.3-0.6	0.1	0.1	0.35-0.5	0.05	0.15	0.1	0.1-0.3

Table 2: AL 6060 properties [6]

Properties Type	Properties	Symbol	Units	Value
Physical	Density	P	g/cm ³	2.71
Mechanical	Young's modulus	E	GPa	70
	Poisson coeff.	V	na	0.34
	Linear expansion	ΔL	μm/m-K	23.4
Thermal	Melting temperature	Tm	°C	660

After the production process of aluminum ingots, the material is subject to thermal treatment. The thermal treatment processes are

After preparing the Process Flow Diagram, should be prepared the PFMEA-Potential Failure Mode and Effect Analysis. Failure mode and effects analysis, or PFMEA, is a methodology that aims to allow organizations to anticipate in discover failure opportunities during the design phase by identifying them during the design or manufacturing process [7]. PFMEA was developed in the 1950s and was one of the earliest methods used for the analyses. Today it remains a very effective method to reduce the possibility of failure. For Everest Shpk Company these are some of the characteristics that can affect the production process:

1. Material properties.
2. Product Geometry.
3. Product Tolerances.
4. Interactions with other components and/or systems.
5. Environments, use, degradation, interactions of systems.
6. Human factors.
7. Methods followed during material processing.
8. Materials used.
9. Machines used.
10. Impact of measurement systems on acceptance.
11. Environmental factors during the process of work.

Based on these factors Figure 7 shows the PFMEA diagram and analysis for the production process of electric vehicles.

GA PFMEA - SEVERITY RANKING				GA PFMEA - OCCURRENCE RANKING				GA PFMEA - DETECTION RANKING			
Effect on Product/Component	Rank	Effect on Process/Manufacturing	Rank	Failure Mode	Rank	Failure Mode	Rank	Effect on Product/Component	Rank	Effect on Process/Manufacturing	Rank
SAFETY critical - NEGLIGENT RISK - NO HAZARD	10	SAFETY critical - NEGLIGENT RISK - NO HAZARD	10	100 per 100,000	100%	100 per 100,000	100%	NO DETECTION	10	NO DETECTION	10
SAFETY critical - NEGLIGENT RISK - NO HAZARD	9	SAFETY critical - NEGLIGENT RISK - NO HAZARD	9	20 per 100,000	20%	20 per 100,000	20%	NOT LIKELY TO DETECT AT 100%	9	NOT LIKELY TO DETECT AT 100%	9
LOSS OF PRIMARY FUNCTION	8	LOSS OF PRIMARY FUNCTION	8	10 per 100,000	10%	10 per 100,000	10%	PROBLEM DETECTION POST-PRODUCTION	8	PROBLEM DETECTION POST-PRODUCTION	8
DEGRADATION OF PRIMARY FUNCTION	7	DEGRADATION OF PRIMARY FUNCTION	7	10 per 100,000	10%	10 per 100,000	10%	PROBLEM DETECTION AT SOURCE	7	PROBLEM DETECTION AT SOURCE	7
LOSS OF SECONDARY FUNCTION	6	LOSS OF SECONDARY FUNCTION	6	10 per 100,000	10%	10 per 100,000	10%	PROBLEM DETECTION POST-PRODUCTION	6	PROBLEM DETECTION POST-PRODUCTION	6
DEGRADATION OF SECONDARY FUNCTION	5	DEGRADATION OF SECONDARY FUNCTION	5	10 per 100,000	10%	10 per 100,000	10%	PROBLEM DETECTION AT SOURCE	5	PROBLEM DETECTION AT SOURCE	5
ABSENCE controls in all vehicles	4	ABSENCE controls in all vehicles	4	10 per 100,000	10%	10 per 100,000	10%	PROBLEM DETECTION POST-PRODUCTION	4	PROBLEM DETECTION POST-PRODUCTION	4
ABSENCE controls in all vehicles	3	ABSENCE controls in all vehicles	3	10 per 100,000	10%	10 per 100,000	10%	PROBLEM DETECTION AT SOURCE	3	PROBLEM DETECTION AT SOURCE	3
ABSENCE controls in all vehicles	2	ABSENCE controls in all vehicles	2	10 per 100,000	10%	10 per 100,000	10%	PROBLEM DETECTION POST-PRODUCTION	2	PROBLEM DETECTION POST-PRODUCTION	2
NO EFFECT	1	NO EFFECT	1	10 per 100,000	10%	10 per 100,000	10%	PROBLEM DETECTION AT SOURCE	1	PROBLEM DETECTION AT SOURCE	1

Fig. 7 PFMEA diagram of production process [6]

The three main factors represented in the PFMEA diagram are: 1. Severity; 2. Occurrence; and 3. Detection. To evaluate and calculate the risk of occurring failures, it is used the formula:

$$RPN = Severity \times Occurrence \times Detection$$

By analyzing the results from PFMEA analysis we can discover that the main factor resulting in failure is the chemical compound of aluminum alloy because it will directly affect the product quality. For the other processes, the possibility of the occurrence is 1, so the failures are eliminated during the design process.

5. Conclusions

Quality Management is one of the most invested areas in today's industry and in Everest Shpk Company. Its continuous research and further development have brought and continue to bring a lot of benefits for the company that has invested in the creation of a quality department.

The above documents are a good start to implementing TQM. The main improvements brought by the implementation of the Quality Management System in Everest Shpk Company to produce the electric vehicle parts are:

1. Clear identification of work processes and elimination of losses based on Lean manufacturing.
2. Using the 5S method enables better visual control and reduces the possibility of making a mistake.
3. The involvement of workers in the implementation of this system has improved climate cooperation. Workers feel more involved and valued.
4. Investment needs in some processes of design and production are identified.

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The National Climate Change Adaptation Strategy for the Transport Sector in Bulgaria – Review of Design Norms and Maintenance Standards

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Abstract: *The National Climate Change Adaptation Strategy (NCCAS) for the "Transport" sector until 2030 was developed in the period 2017 – 2019. After 4 years in the context of several overlapping crises, the recommendations contained in the main adaptation measures document have largely not been implemented even in the initial phase. Those recommending the review and updating of legislation regarding adaptation to climate change were not subject to optimization. The article analyzes the problem of lagging behind in Bulgaria in relation to supplementing the standards and presents ideas for methodological approaches through which adaptation measures can be implemented in the design and maintenance of the road infrastructure.*

Keywords: NATIONAL CLIMATE CHANGE ADAPTATION STRATEGY, DESIGN AND MAINTENANCE STANDARDS, CLIMATE ADAPTATION, REGULATION, METHODOLOGICAL APPROACHES, OUTSTANDING MEASURES

1. Introduction

In recent decades, faced with global warming and rapid climate change, European Union countries have focused on preventing their catastrophic consequences and reversing their adverse direction. This is not a task that can be accomplished in a short period, as it requires restructuring and changes in many areas while rising levels of carbon emissions and the greenhouse effect are driving the planet towards ever higher temperatures and their adverse consequences. Therefore, adaptation of key sectors of the economy to the new challenging conditions is necessary. Bulgaria, as a member of the EU, is also working in this direction by planning and implementing the required measures. The transport sector, with its vital role in economic stability, also faces the need for urgent adaptation to changing conditions.

In this context, it is essential to clarify what constitutes adaptation in the context of climate change. It is understood as the process, actions, or measures that societies and systems adopt to deal with the realities of climate change. The aim is to reduce their vulnerability and increase the ability of systems to withstand the impact of climate change. It can be reactive (in response to manifested changes) or proactive (anticipatory, in anticipation of changes).

At the beginning of 2019, with a clear awareness of these challenges, with the help of experts from the World Bank, Bulgaria developed a "National Climate Change Adaptation Strategy and Action Plan" [1]. The strategy aims to properly direct future efforts by covering an analysis of the impact of climate change on critical sectors of the economy (agriculture, forestry, biodiversity, ecosystems, water, energy, transport, urban environment, health, tourism, and risk management disasters). It offers recommendations for overcoming barriers to adaptation, which must be implemented in the 11-year period from October 2019 (the document was adopted by decision No. 621 of the Council of Ministers of Bulgaria) until the end of 2030. However, four years after its adoption, we face the reality of delays and lack of active implementation of the proposed measures in many sectors, including transport.

The article aims to analyze and evaluate the degree of implementation of the National Climate Change Adaptation Strategy (NCCAS) for the Transport sector until 2030 in design norms and maintenance standards.

The main tasks of the article include:

- Analysis of the current situation regarding the implementation of the NCCAS for the "Transport" sector until 2030, in the context of several overlapping crises and the lack of progress concerning the update of the regulatory framework for adaptation to climate change;
- Analysis of the effects of climate change on transport infrastructure;

- Suggestions for methodological approaches that can support the integration of adaptation measures in the design and maintenance of road infrastructure.

2. NCCAS status five years after admission

The complex world situation in recent years has pushed into the distant future the need for a new approach to forming transport infrastructure objects, which would implement and apply the principles of sustainable development in Bulgaria, especially in the transport sector. The superimposition of the three large groups of crisis events in a short period led to severe shocks in the transport construction sector (especially in road construction). Practically, the series of crashes started at the beginning of 2020 with COVID-19, continued in 2021 and until now. Instability arising from political and economic reasons further significantly damaged and devalued the positive image and funding regarding the transport infrastructure. After February 2022, the financial shocks from the situation in Ukraine further reduced the opportunities for modern sector development. All this automatically led to a focus on the implementation of projects "piecemeal" and practically completely froze the possibility of working on the recommendations that the document on climate change adaptation (CCA) [2] set after October 2019. This halts the activities that should ensure the adaptability and resilience of the Transport sector.

The delay to date requires catching up on all elements of sustainable transport infrastructure modeling at an accelerated pace to expect commitments to be met (even in part) by the 2030 deadline.

A significant drawback for Bulgaria's transport sector at the moment is the fact that between 2019 and 2023, the report on adaptation to climate change [2] is the only document assessing and recommending actions to be taken to adequately respond, prevent, and react during the operation of the transport infrastructure concerning expected future extreme climatic events of national status.

Until now, the ongoing activities on the analysis of the expected extreme values of climate phenomena and those on the implementation of prevention recommendations do not provide a practical opportunity to achieve an adequate level of adaptation of the "Transport" sector for the five-year previous period.

For comparison, in the last five to seven years, countries such as the USA, England, Ireland, Brazil, and others [3, 4] have been looking for a projection of climate models when organizing the stages of the investment process in their transport infrastructure (from design, through maintenance to crisis prevention). In this way, socio-economic parameters are set for the saving of significant capital investments, which must be attributed to the maintenance of the functionality of the transport infrastructure (continuity of the transport service and a high level of road safety) in the medium and long term perspective.

3. Analysis of the effects of climate change on transport infrastructure

Climate change generates cumulative risk factors for transport infrastructure. In the long term, adapting the transport sector to climate change will affect the entire life cycle of transport modes. Following the signing of the Paris Agreement in 2016, the sector's commitments were stated through Part 7 in [1]. In accordance with it, an assessment of the Transport sector [2] was also prepared, where an initial scope and general guidelines were defined based on an analysis and a conclusion on the degree of risk.

The tracking of the processes during the operation of the transport infrastructure and their reference to the conclusions and recommendations in [1, 2, 5, 6] was summarized according to Fig. 1. It is a graphic representation of the significance of extreme climatic events concerning the main parameters of transport in Bulgaria (infrastructure and traffic) and the sensitivity of the sector to climatic risks.

Referring to the assessment of the Transport sector in [2] and scientific monitoring of the sensitivity of the transport infrastructure in our country [5, 6], the following more significant cases of climate risks caused by major climate events – high/low temperatures can be indicated, precipitation and storms, snowfalls and snowstorms, combinations between two and more factors.

4. Proposals for methodological approaches and solutions for integrating adaptation measures in the design and maintenance of road infrastructure

According to the conclusions in [2], to build adaptive capacity in the sector, it is necessary to work intensively in two large groups of tasks: 1) data collection and 2) formation of knowledge and capacity.

On the other hand, to fulfill the two groups of tasks, a package of adaptation measures should be developed [2], which refer to the following four groups of activities:

4.1 Guidelines for updating and supplementing design standards.

The norms for the design of the transport infrastructure were created with a high degree of conservatism, which makes them suitable from the point of view of set design parameters under standard operating conditions [7-9]. Documents that are not covered by national regulations, such as [10, 11], can be included under a condition. In addition, normative documents and standards are separate and independent documents that are not developed in a common system of rules. This hinders complex solutions related to the pressures of climate change.

The adaptation of the normative documents should be aimed at three essential elements of the normative base in Bulgaria:

- First, building institutional capacity, in which to create an available professional expert base of specialists to whom timely and regular updating of morally outdated documents can be assigned. Organizing this item should start immediately.
- Second, completing the newly created and available documentation with requirements arising from climate risks. These additions and extensions should cover extreme parameters of the operating conditions the potential for their modification, and be uniform as principles in the many accompanying regulations, including those related to operation and maintenance.
- Third, the unification and binding of normative and sub-normative documents covering the entire package of requirements for the design of transport infrastructure in terms of design parameters, which together are necessary for the volume of investment projects (from preliminary design studies to technical projects).

Climatic phenomenon	Vulnerability of transport infrastructure						Mitigation
	transport infrastructure			Attitude towards transport safety			Stages of prevention: ①- Level standards ②- Performance ③- Operational support
	Roads (streets)	Rail roads	Transport facilities, incl. airstrips	Car roads	Rail roads	Transport facilities	
High temperatures	🔴	🔴	🟡	🔴	🔴	🟡	① ② ③
Low temperatures	🔴	🔴	🟡	🔴	🟡	🟡	① ② ③
It's raining	🔴	🟡	🔴	🔴	🟡	🔴	① ② ③
Storms (wind, hail)	🟡	🟡	🟡	🟡	🟡	🟡	① ② ③
Snowfall	🔴	🟡	🟡	🔴	🟢	🟢	① ② ③
Droughts	🔴	🔴	🟡	🔴	🔴	🟡	① ② ③
Fogs	🔴	🟡	🟡	🔴	🟡	🟡	① ② ③
Snow storms	🔴	🟡	🟡	🔴	🟡	🟡	① ② ③
Sea level rise - excitement	🟡	🟢	🔴	🟡	🟢	🔴	① ② ③

Climatic phenomenon	Sustainability	Mitigation	Impact on the user and consequences
	Attitude towards maintenance and traffic management	Stages of prevention: ①- Level standards ②- Performance ③- Operational support	
High temperatures	☺	① ② ③	TOTALLY NEGATIVE for traffic continuity and road safety
Low temperatures	☹	① ② ③	
It's raining	☹	① ② ③	
Storms (wind, hail)	☺	① ② ③	
Snowfall	☹	① ② ③	
Droughts	☺	① ② ③	
Fogs	☺	① ② ③	
Snow storms	☹	① ② ③	
Sea level rise - excitement	☺	① ② ③	

Fig. 1 Vulnerability ranking of Bulgaria's transport infrastructure to the effects of climate change. **Legend:** highest sensitivity – red color / lowest sensitivity – green color

4.2 Guidelines for optimization of project preparation procedures.

It is necessary to work on developing regulations, instructions, or guides for the consideration of climate change by types of transport within the scope of each investment project.

To implement an adaptation option, one must start with optimization in three directions:

- First, introducing the principles of sustainable development and defining the concept of "life cycle" for transport infrastructure. This will help organize planning activities at all stages of the investment process.
- The second is adopting an approach that, in addition to being a pollutant, to a large extent in the medium and long term, climate change will increase the vulnerability of the transport infrastructure. Therefore, this object must be treated as a victim entity of our national industry, which must be provided within the framework of the preparation of the projects.
- Third, the optimization of the procedures and parts of the projects should be done for scientifically determined relevant current climate models for forecasting and, if possible, seek to simulate the interaction between climate risks and the relevant objects of the base, possibly with the help of new computational technologies and artificial intelligence [12].

4.3 Guidelines for updating and supplementing standards and procedures for operation and maintenance

The documentation and the procedures it provides are shaped by several national standards for railway and road infrastructure [14-24]. Only a part of them are open access, and about roads, no national-level updates of their variants adopted at the end of the 20th century are known [20-24]. The minimum initial steps to catch up with the serious backlog in updating this type of documentation can be given in the following activities:

- Building institutional capacity to regulate renewal processes and increase the adaptability of maintenance procedures and standards during operation. Establishing connectivity between the nationally designated administrative structures that are responsible for the processes in this part. In this way, the framework for processing the documentation and activities will be set;
- Optimization of applied materials and methods with all the results obtained from research and innovation. Introducing a wide range of technological innovations and systematic condition monitoring to enable transport infrastructure to function effectively in the face of the dynamics of changing climate conditions. Entry of scientific research into the processes of practice. This element can be developed within the framework of "Education 4" to the Fourth Industrial Revolution.

4.4 Guidelines for increasing the effectiveness of emergency activities

This task requires a strategic framework that contains a criticality assessment and programs based on which to develop crisis management plans. Within these plans, the dynamics of climatic events must be considered, for example, floods, geological risks, fires, intense snowfalls, and others.

Increasing the effectiveness of risk prevention activities in connection with CCA requires planning to cover two large groups of tasks – 1) determining the level of service and 2) related to solving the crisis event that has occurred. Recommendations for improving the management of transport infrastructure processes can be summarized according to the stages of development of the emergency situation:

- **Warning phase:** the emphasis should be on a real-time information transmission model to expect the effectiveness of the early warning principle. This means the use of a nationally available (open access and free platform for institutions and organizations) information model by analogy with the European Union's Earth observation and monitoring program "Copernicus" [25, 26].
- **Phase of the occurring crisis:** here, the problems of mastering the occurring event for the transport infrastructure are practically of a global nature for the country's territory. This is due to the separation of responsibilities of the institutions that must secure the developing effects with potential consequences on the service and human health and life.
- **Phase of suppressing the residual effects and dealing with the consequences:** here, the institutional capacity must provide a unified database on the level of resources invested and the affected sub-directions in the Transport sector. This way, databases will be accumulated, especially regarding recurring crisis events linked to extreme climate events. This will not only refine the prevention measures by types of risks on a territorial basis but also provide a framework for the optimality of the response in the acute phase of the situation, again by types of climatic events.

5. Reasons for non-implementation of the recommendations of the National Climate Change Adaptation Strategy in Bulgaria

Within the framework of the study carried out about a general review of the design norms and standards for the maintenance of the transport infrastructure in connection with the implementation of the recommendations under the CCA [1, 2], a significant delay in the implementation of all the recommendations that were made in the documents of The 2019 National Climate Change Adaptation Strategy and Action Plan. Indeed, the program's launch coincided with a series of overlapping international and national crises. This should logically delay the procedural implementation of [1, 2], especially in the "Transport" sector, but in terms of adaptation measures, which refer to the design, operation, and maintenance of the transport infrastructure, there is practically no progress.

The main reasons for this are:

- **Lack of institutional capacity**

This refers to 1) starting procedures for awarding an expert-level request for renewal, optimization, and binding of the documentation with climatic risk factors, as well as the mutual binding of all legal, by-law normative documents in a common package; 2) launching procedures to create connectivity between agencies and institutions that are responsible for activities in emergencies; 3) synchronizing the received information between them to assess the actual extent of the invested resource for the response and elimination of the consequences.

- **Lack of collected, archived, appropriately processed, and accessible databases** relating to the state of impact on the "Transport" sector.

At the national level, a coordination model for creating common archives has not been developed and, therefore, does not function. Currently, every instance and/or institution that is responsible for given sub-sector policies and is possibly required to keep an archive maintains some level of it. Additionally, they are usually unavailable, incomplete, and inconsistent with information from other agencies relevant to the transport service and its carrier. Without data, it is not possible to obtain a statistical basis with which to supplement the regulations for design, maintenance, and operation.

- **Lack of models for the interaction between climatic elements and those of the transport infrastructure** and, accordingly, for the correct forecasting of risk factors such as degree of manifestation and significance. Without implementing climate models and methods for simulating the risk factors, it will not be possible to set parameters in the normative documents, which will be taken into account within the entire investment process and life cycle of the relevant linear facility.

The stated reasons seriously complicate the adaptation of the transport infrastructure to the changing climatic conditions in Bulgaria, which may have negative consequences on the sustainability and safety of the sector in the long term. It is essential to pay attention to these problems and to take concrete steps to overcome the identified obstacles to the successful implementation of the recommendations of the NCCAS.

To overcome the identified problems, a clear institutional framework is essential. It should include launching procedures for regularly updating and optimizing climate risk documentation, as well as creating an effective communication link between the various agencies and institutions responsible for emergency management. In addition, standard procedures for collecting, archiving, and analyzing data on climate impacts on transport infrastructure need to be developed and implemented. The creation of a centralized and accessible database can support the process of making informed decisions and updating the regulatory framework. In addition, the development and implementation of models for the interaction between climate conditions and transport infrastructure, as well as the prediction of risk factors, are essential for correctly

setting parameters in regulatory documents. This may include collaboration with academic institutions and modern technologies such as artificial intelligence to analyze and simulate different scenarios. With joint efforts and commitment from all interested parties, it is possible to overcome the identified obstacles and improve the adaptation of the transport infrastructure to the changing climatic conditions in Bulgaria.

6. Conclusion

The present study analyzes the reasons for the non-implementation of the recommendations of the National Strategy on CCA in Bulgaria and proposals for methodological approaches and solutions aimed at the integration of adaptation measures in the design and maintenance of road infrastructure in response to climate change as well as additional guidelines for adaptation of the transport sector to climate change in Bulgaria, focusing on updating operation and maintenance standards and procedures, as well as improving emergency response. Key points include:

- Updating and supplementing the existing design norms, with the aim of reflecting climate risks and unifying the various regulatory documents into a common system of rules.
- Development of guidelines for optimization of project preparation procedures, including introduction of sustainable development principles and consideration of transport infrastructure as a victim of climate change.
- The potential use of new technologies and artificial intelligence to simulate the interaction between climate risks and transport infrastructure in the design process.
- Renewal of standards and procedures: It is proposed to build institutional capacity to regulate the processes of updating documentation and increase the adaptability of maintenance procedures and standards. It is also recommended to optimize the materials and methods used, introduce technological innovations, and track the condition of the infrastructure over time.
- Increasing effectiveness in emergency situations: A strategic framework and crisis management programs are proposed that take into account the dynamics of climate events. Key aspects are the phases of warning, responding to the crises that have occurred, and extinguishing the residual effects. It is also recommended to build a unified database of resources and affected areas, as well as optimization of the response to different types of climate events.

The publication highlights the need for intensive work on data collection and knowledge and capacity building to improve the sector's adaptive capacity and respond effectively to climate change challenges, as well as the need for clear communication and coordination between different institutions, as well as the inclusion of scientific research in practical processes to improve the sustainability and safety of the transport infrastructure in the country.

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The National Climate Change Adaptation Strategy for the Transport Sector in Bulgaria – Review of Data Collection Procedures, Emergency Situations, Institutional Capacity

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Abstract: *The National Climate Change Adaptation Strategy for the "Transport" sector until 2030 was developed in the period 2017 – 2019. After 4 years in the conditions of several overlapping crises, the recommendations contained in the document on main adaptation measures relating to institutional capacity building have not started. This is observed against the background of activity from a number of countries that are looking for models to assess the sensitivity of the transport infrastructure to climate events and, from there, measures to achieve sustainability and adaptability in the medium term. The article analyzes the problems of backwardness in Bulgaria and offers recommendations for increasing the participation of all interested participants in the transport sector.*

Keywords: TRANSPORT SECTOR, INSTITUTIONAL CAPACITY, EMERGENCIES, RESILIENCE AND ADAPTABILITY, ADAPTATION MEASURES, STAKEHOLDERS, CRISIS AND RISK MANAGEMENT

1. Introduction

In the last few decades, the phenomenon of global warming and related climate changes has become one of the most pressing challenges facing the modern world. The countries of the European Union, understanding the seriousness and long-term consequences of this process, are engaged in the development and implementation of complex strategies and measures to mitigate the negative effects. However, these efforts are not limited to just one or two areas; they require far-reaching changes in energy, industry, agriculture, and transport.

Carbon emissions and greenhouse gases continue to increase, creating conditions for faster warming and adverse climate events such as drought, floods, and widespread extreme weather events. Such problems require even more active adaptation and decisive action in critical sectors of the economy.

Bulgaria, as a member of the European Union, is committed to adopting and implementing similar measures. The goal is to prepare the infrastructure and society for the new climate conditions and to minimize the risks of future climate catastrophes.

In this context, adaptation and resilience become key concepts that must be integrated into every aspect of management and planning. This includes not only technological innovation but also social and cultural changes that support a more sustainable and adaptive way of life. Thus, in the conditions of rapid and irreversible climate changes, the task of adaptation and sustainability becomes increasingly urgent and complex.

The transport sector is a key industry element in terms of economic stability. Its degree of significance for the national economy of Bulgaria requires a serious development of risk prevention actions and countermeasures against its damaging components.

The request for the sustainability of the sector must necessarily include the vulnerabilities that arise from climate risks [1, 2, 3].

The first more serious steps were finalized at the beginning of 2019. Then, with a clear awareness of these challenges, with the help of experts from the World Bank, Bulgaria developed a "National Climate Change Adaptation Strategy (NCCAS) and Action Plan" [1]. The strategy sets the direction for future efforts, including an analysis of the impact of climate change on key sectors of the economy, including the Transport sector. It offers basic recommendations for overcoming barriers to adaptation, which must be implemented in the 11 years from October 2019 (the document was adopted by decision No. 621 of the Council of Ministers) until the end of 2030.

A Climate Change Adaptation Report (CCAR) has also been developed for the strategy for each sector [2]. In both types of documents, basic principles are indicated from which climate adaptation measures can be derived. Through their application, the

aim is to prevent vulnerabilities in terms of risk factors and to reduce the effects of events occurring within the "Transport" sector.

Adaptation in the context of climate change is a global set of processes, actions, or measures that societal systems adopt to cope with the pressures of climate change. The ultimate goal is to reduce their vulnerability and increase the ability of economies to withstand the impacts of climate change, i.e., to build working mechanisms to achieve such an ability in both reactive (in response to the manifested changes) and proactive (preliminary, in anticipation of the changes) form.

2. National Climate Change Adaptation Strategy status 5 years after admission

Despite the relatively high-quality and applicable adaptation policies in both documents [1, 2], already five years after their adoption, we are faced with the reality of delays and lack of active implementation of the proposed measures in many sectors, including transport.

This article is aimed at analyzing the implementation of the "National Climate Change Adaptation Strategy and Action Plan – Transport Sector" (NCCAST). Let's look at some of the reasons that led to the inactive implementation of the strategy, as well as the potential risks and losses facing Bulgaria's transport sector.

2.1 Crisis events at national and global levels concerning the backwardness of [1, 2]

The level of development of the transport infrastructure is different within the EU member states. In Bulgaria, construction and modernization are at a stage where significant investments will be needed in the long term.

Given this, in the conditions of the complicated international situation from 2020 until now, the packages of activities for implementing the strategy and its maintenance are of increased sensitivity to the consequences of these alternating events. This applies even more strongly to the creation of opportunities to implement the principles of sustainable development for the sector, and as a result, their implementation has literally been pushed back far in time.

To date, three continuous groups of crisis events in a short period have led to severe shocks in the transport construction sector (especially in the road construction sector). The series of collapses started in early 2020 with the COVID-19 pandemic, and from 2021 until now, instability of a political and economic nature has significantly damaged and devalued the positive image and funding of transport infrastructure. After February 2022, the financial turmoil that arose from the situation in Ukraine further reduced the opportunities for modern sector development.

As a result, the focus on an overall efficient and environmentally friendly transport infrastructure has shifted to "piecemeal" project implementation approaches.

In this situation, there was a vacuum in the sectoral policies of the requests to start activities according to the recommendations that the document on adaptation to climate change (ACC) [2] set at the end of 2019.

This halts the activities that should ensure the adaptability and resilience of the Transport sector. In terms of evaluating and guiding documents, [1] and [2] remained the only ones guiding adaptation measures for the transport sector of Bulgaria between 2019 and 2023. This negatively affected all the main measures for building adaptive capacity, mainly in the direction of a lack of commitment to rework the systems, documents, and methods for assessment and response in emergency situations.

2.2 Reasons for the lag and non-implementation of the strategy's recommendations

The reasons for the lag and/or complete non-implementation of the recommendations of the strategy should be sought in the accumulated deficiencies and ambiguities in the management of the transport sector. In Bulgaria, the institutions and the legal framework, which are responsible for ensuring all elements of the efficiency of the "Transport" sector, organize their activities within the framework of limited managerial autonomy.

The lack of commitment and the degradation of the understanding of the importance of transport as an economic and social subject for the development of the state and society at the national level makes it impossible to build an institutional capacity that would provide the essential part of infrastructure construction for our national economy.

This outlines the unfavorable trend that policies aimed at construction and maintenance will continue to be constrained within sectoral fragmentation and financial redistribution of resources from year to year. This makes the sector extremely susceptible to negative economic and political conditions caused by crises. Respectively, this literally stops the optimization and development of the sector in terms of technology, competitiveness, and sustainability. The latter continues to be evident in this calendar year as well when the established state of NCCAST remains unchanged compared to the 2019 base year.

3. General assessment of the recommendations and main adaptation measures proposed in the strategy.

Concerning the recommendations and the main packages of measures that are contained in the national documents for climate change adaptation (CCA) in the transport sector [1, 2], attention can be paid to the following essential points:

The positive side is the relatively in-depth study of the problems in the sector and the formation of corresponding recommendations, the implementation of which can set a perspective for real adaptability and synchronization of activities. Respectively, this should presuppose the implementation and operation of transport infrastructure in our country, which is the carrier of a safer and better service in the medium and long-term time frame.

Two large groups of activities to be optimized should be noted as weaknesses:

1) There is a need to expand the scope of the elements under the CCA compared to those proposed so far in [2].

Referring to Appendix 1 (table 23) from [2], an analysis and recommendations are prepared for increasing and refining the scope of the CCA, to be presented after the end of the project "Impact of climate change on the transport infrastructure in Bulgaria – conceptual approach for assessment of the potential impact on achieving sustainability and safety of elements of the transport sector" (funded by the Research, Consultancy and Design Centre – RCDC at the University of Architecture, Civil Engineering and Geodesy). The aim is to specify the vulnerability of transport

infrastructure to climate change, as well as adaptation measures (databases, regulatory documents, responsibilities of institutions) from an engineering-technical point of view.

2) Removal of recommendations on adaptability, which, in terms of their verification in standards and normative documents, cannot be fulfilled.

The reasons are diverse, but the main one is the lack of institutional capacity to build a unified system of legal and by-law documents with a common level of action. This is currently completely unfeasible due to the high level of fragmentation in implementing these processes at the national level.

For example, fragmentation is when multiple institutions are responsible for compiling and promulgating documentation that actually concerns the preparation of a single investment project.

Another point is that entirely independent technical (expert) committees are entrusted with preparing norms, regulations, and standards that ensure the parts of a project task. A big problem in synchronizing these different documents is the lack of instructions obliging individual instances to bring their legal acts to a single common system. This is also the reason why many of the adaptation measures are inapplicable, as recommended in [2], and hence, the principles of CCA cannot be introduced to them.

4. Recommendations for timely building of institutional capacity to CCA

In [4], it is stated that adaptive capacity develops when institutions enable actors to prepare for climate risks, changes, and effects and acquire adaptability to this complex process. Therefore, if we are looking for an application in the direction of process management, implementing this measure requires a change in the structures and activities that each national structure concerning the "Transport" sector performs.

For this to happen, targeted action at national and regional levels is needed to improve the status of several key elements. Optimizing them will provide opportunities to define institutionality regarding adaptation to climate change for the transport service. The most important of them are the following:

- **Formation of sub-sectors with direct commitments to implement CCA practices.**

This does not mean inflating the administration, but training and qualifications of the participants in the process of building adaptive capacity. In [2], it is stated that the need for training should be assessed. This is absolutely necessary at this stage of the backwardness, on the one hand, to start the processes of introduction of CCA, on the other hand, in order to use the accumulated foreign experience to speed up the work.

To learn from what has been achieved at the international level, the expertise provided by the scientometric sources and their authors should also be included. This makes the participation of scientific and educational institutions necessary, and they participate in the process of building adaptive capacity.

- **Revision of regulations and administrative-management documentation for regulation of the sector.**

With this, to initiate responsibilities and obligations under the CCA and to optimize the practices with which measures are worked on, such as data collection, processing of regulatory documents, etc. Without prescribing written procedures and the ways of their implementation, the practical implementation of the measures will again be transferred in a reduced volume and scope to the contractors in the investment process or to the traditional maintenance and operation procedures. Under such conditions, we are working at the moment, and the result is that, in practice, we do not have global working policies for the introduction of adaptive capacity.

- **The responsible units under CCA should prioritize programs to compensate for the delay, according to [1, 2].**

The compilation of available literature regarding the administration of the process is essential to its organization.

Therefore, within the responsibilities of the institution concerned, schedules of activities must be planned, and this must be tied to relevant deadlines for implementation. Competency programming will show how to compensate for the three initial missing parameters – a high degree of missing data, lack of researched and selected climate models, and lack of forecast modeling for risk assessment.

- **To eliminate inter-institutional problems by introducing the principle of joint actions.**

The authors of [4] reached similar conclusions that the lack of connectivity is the cause of unsystematic and isolated actions on adaptation measures, and in our country, the de facto results remain buffered within the governing body and its subdivisions. Reformulating the interaction between institutions in the sector will filter the barriers that result from individual administration.

The first step is within the framework of the peculiarities of the structure of the Bulgarian legislation. Because at the national level, the scope and obligations of the institutional management of the "Transport" sector are set, and therefore, the connection will be confirmed with normative acts.

Secondly, for the individual institutions to work together, the process will need a high degree of digitization. Digital approaches will most quickly and at scale provide universally accessible portals and hubs of connectivity where information is fed from all sides. At the same time, the received data will be available to all connected users of the system in real-time. This will make it possible in practice for the governing bodies to coordinate the activities for which they are responsible in a timely and regular manner. The result should be a management model where the same element of transport infrastructure can simultaneously be serviced when a problem occurs (both at the level of documentation and at the level of on-site activities by all responding parties).

- **In [2], an adaptive element "Increasing awareness" is proposed.**

Emphasis is placed there on surveying, compilation of primary general documents, analyses, and others. This practically does not complement the plans and order in which the individual institutions act but only illustrates their level of awareness.

It would be more effective to carry out work on solving specific tasks by measures such as:

- 1) drawing up documentation that indicates algorithms for drawing up the projects in the various stages, taking into account the possibility of adaptation,
- 2) implementation of maintenance and operation activities, which are already linked to adaptive activity indicators,
- 3) carrying out activities in emergencies that have real-time information, the possibility of early disclosure, and the responsible institutions coordinating their activities at the same time in the stages of the emergency.

That is, "awareness" should be understood as the practical application of specific adaptive parameters, not their theoretical knowledge within a given agency, ministry, municipality, or other governing body. This will expand users and participants who wish to receive a more sustainable service and increased CCA protection.

It should also be mentioned here the BG-ALERT system [5], which is intended for the distribution of messages to warn the population in case of dangerous events (disasters, emergencies, and others posing a threat to life, health, or property) through the networks of mobile operators to citizens' end devices (mobile

phones, tablets, and some smartwatches)¹. This system is designed to provide timely information to citizens if there is danger to them in the event of a disaster.

In the context of climate change, the BG-ALERT system can be advantageous. Climate change may lead to an increase in the frequency and intensity of extreme weather events such as floods, droughts, and storms. In such cases, BG-ALERT can provide timely information to citizens about emerging dangers and give instructions for action that can help reduce damage and protect people's lives and property.

5. Example of connectivity between institutions

Within the framework of the scientific project "Impact of climate change on the transport infrastructure in Bulgaria – conceptual approach to assess the potential impact on achieving sustainability and safety of elements of the transport sector," an example of an approach is being prepared, how the connectivity between institutions and their databases, will affect maintenance, operation, crisis management and at the same time will not require a significant financial resource.

The example is in the scope of:

- Ministry of Regional Development and Public Works [6];
- Ministry of Transport and Communications [7];
- Road Infrastructure Agency [8];
- National Railway Infrastructure Company [9];
- Ministry of the Interior [10];
- and other institutions that need to coordinate their procedures concerning the CCA.

The task is related to establishing the affected objects of the road network, for which prevention of geological risk is required, which can be provoked by occurring climatic events [11, 12].

The selection was made for landslide geological hazards from the database of the national register of landslides in Bulgaria [13]. The selected road sections are within the scope of the "Pernik" Geoprotection [14].

The aim is to show that, using the available data, with joint efforts, the institutions can join a portal that receives information from the available but is specifically related to the landslide processes concerning roads and the corresponding measures of prevention and removal of the effects.

The field survey results and survey conclusions are detailed in [15]. Establishing effective communication and coordination between various institutions and agencies is critical to overcoming the challenges facing the country with changing climate conditions. Centralized collection and analysis of data on geological and climate risks can help to better understand and manage the potential dangers they pose to the transport network. The example of the landslide geological hazard and the coordination between different institutions illustrates how, by joining efforts and optimizing the available resources, the sustainability and safety of the transport infrastructure can be improved without significant financial investment. This highlights the opportunity to achieve greater efficiency and accountability in crisis management, as well as to create a safer and more sustainable transport system in the long term.

6. Conclusions

The delay to date and lack of active implementation of the proposed measures in the NCCAS requires catching up on all elements of sustainable transport infrastructure modeling at an accelerated pace to expect the fulfillment of commitments (even in partial volume) by the 2030 deadline year.

When we talk about adaptation in a specific sector like transport, it should at least start with optimization, complementing, and reworking in three main directions:

- **Planning and strategy for managing the investment process in design and construction** – process management, regulatory documents, standards, and interconnection of all elements of the projects, which should lead to a sustainable "Transport" sector under the CCA;

- **Research and innovation** – development of new technologies and practices and digitization of processes that help transport infrastructure to function effectively under changing climate conditions [16, 17]. Here, we should simultaneously focus on climate parameter prediction modeling combined with products that allow simulations of the mutual influence of transport infrastructure and the occurring climate event.

Research and innovation should also include modernization with materials and methods at every level of the investment project and the operational life to increase sustainability and reduce the sector's sensitivity to climate change.

Last but not least, the first two recommendations must be supported by sufficiently publicized studies and scientometric results concerning CCA.

- **Risk assessment and prevention** – development of crisis management plans. There is a need for institutional connectivity, unity in actions related to crises resulting from climatic events, development of early warning systems, real-time observations, implementation of intelligent management systems, and other practices to improve connectivity with CCA.

Launching actions on the specified groups is a request for a start-up package, which a comprehensive institutional approach to climate adaptation must secure. Without a unified approach to CCA management, an adequate institutional capacity cannot be built, and the asymmetry in the measures implemented with separate isolated efforts at the national and regional level will remain the only form of adaptation of the transport and especially the road infrastructure.

- **Institutional connectivity at all stages of the transport object's life cycle.**

Coordination of activities at a given stage and on a given adaptation measure will allow simultaneous updating of all processes. On the other hand, it will significantly enhance risk management regarding climate change.

The elucidated challenges and propositions underline the exigency of a consolidated, well-coordinated approach to bolster the resilience and sustainability of Bulgaria's transport infrastructure amidst the unfolding climate metamorphosis. The delay in enacting the measures envisaged in the NCCAS manifests a clear call for an accelerated impetus toward achieving a sustainable transport paradigm by 2030. This necessitates a holistic, multi-faceted strategy encompassing meticulous planning, fostering innovation, and ensuring robust risk management frameworks. Central to this endeavor is the cultivation of an institutional synergy that transcends the silos of individual agencies, enabling a conducive milieu for knowledge sharing, technological advancement, and strategic alignment with the overarching climate adaptation goals. The linchpins of this strategy – planning, research, risk assessment, and institutional connectivity – mustn't be seen as isolated tenets but as interwoven threads of a larger structure that is the climate-resilient transport infrastructure. Moreover, the infusion of digital technologies and intelligent management systems, aligned with a thorough understanding and anticipation of climate-induced risks, could significantly amplify the efficacy and responsiveness of the transport sector to climatic exigencies. This endeavor not only propels Bulgaria towards fulfilling its climate adaptation commitments but also sets a precedent of proactive, integrated, and informed action that could be emblematic of broader regional or even global climate adaptation initiatives in the transport sector.

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Climate change and its impact on long-term sustainability of the road infrastructure in Bulgaria

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Summary: Climate changes are having an increasingly strong impact on the sustainability and safety of the road infrastructure in Bulgaria. This paper analyzes how changes in climatic conditions over the last three decades affect the condition and functioning of the road network. The aim is to identify critical factors and propose methodological guidelines for design and maintenance that include adaptive strategies to address climate risks. The work emphasizes the need for a complex multidisciplinary approach combining scientific research, strategic planning, and practical implementation.

Keywords: CLIMATE CHANGE, ROAD INFRASTRUCTURE SUSTAINABILITY, LONG-TERM STRATEGIES, ROAD SAFETY, CLIMATE RISKS, MULTIDISCIPLINARY APPROACH, STRATEGIC PLANNING, ADAPTIVE MEASURES.

1. Introduction

Climate changes are having an increasingly strong impact on the sustainability and safety of the road infrastructure in Bulgaria. The country is distinguished by specific geographical and climatic features – in a relatively small territory. There is a wide variety of relief, a wide temperature range, fluctuations in precipitation, and snow cover, which are essential factors for the operational efficiency of the road network.

In recent decades, the climatic conditions in Bulgaria have changed with great intensity [1]. This creates serious challenges for road infrastructure and requires new design and maintenance strategies. As climate change progresses, these challenges are expected to deepen and become more complex.

This article analyzes how changes in climatic conditions affect the condition and functioning of the road network in Bulgaria. The aim is to identify critical factors and propose methodological guidelines for design and maintenance that include adaptive strategies to address climate risks.

This analysis is conducted in the context of growing interest and concern for the future of the country's road infrastructure due to the need to adapt to the consequences of climate change. By bringing together scientific research, strategic planning, and practical implementation, it is possible to improve the resilience of the road network, reduce losses, and protect public safety.

2. Climatic changes in Bulgaria during the last three decades

The last three decades have seen a global increase in temperatures, which has significant consequences on various climate elements. They are discussed in detail in [1, 2]. Among these key changes are:

Increase in average temperature: In Bulgaria, as well as worldwide, the average annual temperature is increasing. This has important consequences for climate and the environment, including a greater frequency of extreme weather events. In places with a moderate continental climate, the increase in the average annual minimum temperature is about 1.1 °C, and in the rest of the country – about 0.5 °C [2]. Increases in minimum temperatures during the period 1991–2020 relative to 1961–1990 are greater in hilly regions compared to plains.

Seasonal changes: Climate change leads to shifting seasons and extended periods of extreme conditions. The biggest change is noticed in the summer, which is natural, while in the winter, the change is the smallest. The reasons for these seasonal changes are to be found mainly in the circulation conditions [3, 4]. In general, the summer is getting longer, and the winter season is getting shorter and warmer, which affects the snow cover and precipitation. In turn, less snowfall leads to a higher terrestrial albedo, which in turn leads to greater amounts of solar energy absorbed by the terrain, which is converted into heat and leads to an additional increase in surface air temperatures.

Intense rainfall and drought: In recent years, cases of intense rain in Bulgaria have become more frequent [5]. This happens most often in the summer period, but the cases of intense precipitation also begin to increase during the cold part of the year. They occur more often in the eastern half of the country and the southern regions. An increase in intense rainfall can lead to floods, landslides, collapses, and infrastructure damage. At the same time, prolonged periods of drought, especially in summer, and the reduction of water resources create a risk of fires.

3. Analysis of the impact of climate change on road infrastructure

Transport infrastructure and all modes of transport are vulnerable to climate change. The more important cases of sensitivity and the corresponding significance for road infrastructure can be summarized in the following cases:

3.1 Extremely high temperatures. Prolonged periods of high to peak temperatures

Among the environmental factors, the air temperature has the most significant influence on the temperature of the asphalt pavement. Positive temperature values affect the quality of the transport infrastructure and the service provided by it in three main cases – extreme values, a wide temperature range, and prolonged periods of high average day-night temperatures [6, 7]. Within these three groups, the following climate-induced risks for the transport system are distinguished for our country:

Influence of high temperatures on asphalt coatings:

- Temperature sensitivity of asphalt mixtures: Asphalt coatings are susceptible to temperature changes. At high temperatures, which can reach 70 °C on the surface, standard (unmodified) asphalt coatings increase their plasticity (soften). This leads to a reduction in their carrying capacity and can lead to various types of damage, such as rutting, waves, shearing, and others.

- Modification of mixtures to improve their temperature characteristics: With additives in the composition of the asphalt mixture, the temperature of the surface can be lowered, usually in the range of about 60 °C. This is also positive for the cases of prolonged periods with high average day-night temperatures, which prevents the asphalt concrete from cooling. However, this increases the cost of the material.

- Temperature amplitude and mechanical stresses: Large temperature amplitudes, especially when changing low – high-temperature values, can cause block, transverse, or longitudinal cracks due to mechanical stresses resulting from the expansion and contraction of asphalt concrete coatings.

- Solar radiation and albedo: Asphalt pavements have a low albedo and absorb much of the solar radiation. This further increases the temperature of the coating and can lead to the formation of ruts, waves, and other deformations.

- Specific cases such as airstrips: the same effects are observed on the asphalt pavements of airstrips for taxiing, where the conditions for load-bearing capacity and safety are even stricter.

Impact of high temperatures on railway infrastructure and surface urban rail tracks [8]:

- Thermal expansion of rails: At high temperatures, rails can expand to impede the movement of rolling stock. This may cause traffic to stop or reduce mileage.
- Overheating of cables: High temperatures can cause catenary cables to overheat, which can interrupt rail traffic or reduce running speeds.
- Temperature amplitude: The thermal gaps of the long-welded rails track are sensitive to the variation of the temperature range, which leads to tension/pressure in the track and is directly related to its normal and safe operation.

Effect of high temperatures on fire risk:

- Correlation with periods of drought: High temperatures often coincide with periods of drought, leading to increased fire risk. They can have a destructive impact on road infrastructure, including asphalt surfaces, curb systems, and road bodies.
- Impact on structural elements: Fires can cause severe damage to some structural elements of the road structure, road accessories, and facilities such as bridges, tunnels, etc. This could lead to temporary or long-term closure of key transport routes.
- Safety and traffic issues: Fires and smoke can reduce visibility and create hazardous driving conditions. This can increase accidents, traffic disruptions, and even human casualties.
- Erosion and geological risks: Periods of drought and high temperatures can activate processes of destruction in the soil massifs, which become more susceptible to wind and precipitation erosion. This can create additional geological risks, such as landslides, rockslides, and road closures.

3.2 Rainfall, storms, and rainfall-type floods.

In a changing climate, precipitation and water conditions pose a significant risk to transport infrastructure, affecting its sustainability, safety, and functionality.

Floods and water quantities:

- Floods with a priority precipitation nature can cause flooding of various sections of the transport infrastructure.
- Flooding and undermining of bridge facilities, which can lead to the direct destruction of the substructure bridge, in which the superstructure is also compromised. Complete destruction of the bridges is also possible.

Waterlogged soil from the terrestrial body:

- The primary source of waterlogging is surface water, which can cause loss compaction, undermining, transport of particles, displacements of layers, and destruction of slopes during excavations and embankments.
- In second place are underground waters, which move along a capillary path and form wetlands and transfer particles, which also leads to deformations in them and damage to pavements, unevenness, and network-like cracks.

Hydraulic capacity and drainage systems:

- Exceeding the hydraulic capacity of drainage and small facilities (type culverts) on roads and railways.
- Overloading drainage systems in urbanized areas is especially important for the traction of pavements and the safety of car traffic.

Surface conditions and safety:

- Retention of a thick film of water on pavements can cause loss of traction and cases of aquaplaning.
- During rain, storms, and hail, visibility is impaired, which disrupts the continuity and safety of traffic.

Erosion and geological risks:

- Intensification of erosion processes, especially rain and wind erosion, in various parts of the transport infrastructure.
- Increasing the degree of geological risk, such as landslides and rockslides, especially at high wind speeds or after prolonged periods of drought.

Additional factors:

- Water retention: Water retention in road pavement cracks, which freezes and expands as temperatures drop.
- Groundwater: Prolonged retention of high groundwater levels can compromise the structural linings of underground facilities such as tunnels and subways.

3.3 Extremely low temperatures, prolonged colds with low temperatures, temperature amplitudes

The tendency is for extremely cold days (so-called "ice days") to decrease in Bulgaria. However, climate change can lead to disturbances in atmospheric conditions, resulting in extremely low temperatures in limited areas. For this reason, adaptation to climate change must necessarily include measures aimed at the consequences of very low temperatures:

Impact on road structures:

- Extremely low temperatures: In addition to the deterioration of bitumen elasticity, low temperatures presuppose the appearance of cracks and freezing of water in already existing cracks.
- Temperature cracks: With sudden temperature drops, frozen areas form in the earth's body, and temperature cracks, holes, and pits can form in the coating.

Impact on road safety:

- Black ice: Formed by a combination of low temperatures and fog and is a road safety risk.
- Icy sections: Reduced traction and increased risk to road safety.
- Freezing rain: Leads to the formation of an icy surface on road surfaces, creating a risk to road safety and infrastructure damage.

Impact on railway infrastructure [8]:

- Catenary icing: Causes problems in electrified railway lines.
- Device freeze: railroad switch (cross, connection, the combination of cross and connect) are sensitive to freeze.

Impact on bridges and other facilities:

- Water freezing in drainage elements: This may cause damage to load-bearing and non-load-bearing parts.
- Corrosion from anti-icing ingredients: This is especially risky in the presence of shortened drainage pipes and wind.
- Icing of facilities with steel structural elements.

Impact on harbors and fencing facilities:

- Icing of structures: This can lead to critical infrastructure conditions, especially in bulk breakwaters.

Additional risks:

- Retention of water in cracks in reinforced concrete and asphalt concrete elements: When temperatures drop, water freezes and widens the cracks and increases the degree of damage.

3.4 Precipitation, storms, and rainfall-type floods.

In the conditions of variable climatic factors, rainfall, storms, and rainfall-type floods pose a significant risk to transport infrastructure, affecting safety and traffic continuity.

Accumulation of snow and its consequences

- Accumulation of snow on road surfaces: During winter maintenance, it is a problem because it requires repeated regular snow removal.
- Reduced visibility during heavy snowfall: This leads to problems with transport safety and traffic continuity.
- High-speed snow drifts: This is especially problematic for roads and railways due to the deposition of large amounts of snow and the suspension of snow removal.

Influence of precipitation and wind

- Reduced visibility during heavy precipitation (snowfall): A significant risk factor in transport safety, with a priority impact on the national road network (RPM).
- Snowdrifts in stormy winds and heavy snowfall: This combination leads to significant problems with safety and traffic continuity. Road infrastructure is susceptible to these conditions.

3.5 Water level rise. Wind wave effect.

In the conditions of sea level rise, coastal transport, and port infrastructures are exposed to severe risks:

- Destruction of coastal transport infrastructure and port and coastal defense infrastructure in the presence of high water levels or wave impact. The slopes of the coastal areas are most at risk from the intensification of the erosion processes and the entire port and coastal protection infrastructure from the wave impact.
- Destruction of coastal transport infrastructure as a result of waves or combined with rain erosion of the coastline.

3.6 Other impacts with local relevance to serviceability and traffic – fog, high humidity levels, and others.

Other impacts with local relevance to serviceability and traffic include meteorological factors such as fog and high humidity levels. Fog significantly reduces visibility on the road, which can slow down traffic and increase the risk of road traffic accidents. High humidity levels can deteriorate the adhesion between the road surface and vehicle tires, cause corrosion of the steel elements of the transport infrastructure, cause deformations in the wooden sleepers of the railway superstructure, and others. These factors require special maintenance and monitoring measures to ensure the safety and efficiency of the transport system.

4. Methodological guidelines for design and maintenance

4.1 Adaptive strategies to deal with climate risks

Adaptive strategies to address climate risks in road infrastructure are vital to ensure the safety, resilience, and efficiency of transport systems in a changing climate. Here are some potential strategies that could be implemented in the coming years:

Sustainable design and construction

This includes developing sustainable and adaptive road infrastructure designs that consider climate change and extreme weather conditions. When designing, the use of materials that are resistant to climatic influences such as high temperatures, floods, and freezing should be foreseen.

Technological innovations

These could include the integration of Intelligent Transportation Systems (ITS) [9, 10], which offer real-time traffic monitoring and management, as well as warnings of hazardous conditions. This necessitates the application of weather forecasting and monitoring technologies to help respond quickly to extreme weather conditions [11]. Artificial Neural Networks (ANN) and Artificial Intelligence (AI) [12], often combined with the Internet of Things (IoT), are essential to adaptive strategies against climate risks. They help in the analysis and forecasting of climatic conditions, as well as in the automation of responses to extreme events. IoT sensors monitor parameters in real-time, while AI analyzes the data for quick response and warning.

Improved planning and management

This group includes developing risk management plans and emergency plans to address potential climate threats and ensure a rapid and effective response. This means the need to regularly reassess and update climate risk management plans and strategies based on new data and research.

A typical example of key risks is fires and floods, for which it is necessary to define safety measures and adaptation strategies, which include both technological and organizational measures for their

prevention and combating them. This may include optimization of materials and methods, early warning systems, and staff training.

Training and awareness-raising

In this regard, training and awareness-raising campaigns among the public and key stakeholders on the impact of climate change on road infrastructure are envisaged, including cooperation with local, national, and international organizations to share knowledge and resources.

Funding and Investments

Adaptation requires providing adequate funding and investment to improve the sustainability of road infrastructure and to develop new technologies.

Legislative framework

All of the above strategies require the development of legislation and regulations to support the sustainable development and adaptation of road infrastructure to climate change.

These strategies can be implemented through a coordinated effort between various stakeholders, including government bodies, local communities, industry, and the scientific community.

4.2 Integrating climate resilience into infrastructure projects

Integrating climate resilience into infrastructure projects requires a holistic approach that covers every stage of road infrastructure design and construction. This can be done as follows:

Advance planning and analysis

It is necessary to start with detailed climate risk analyses and vulnerability assessments to understand how climate change may affect the project, considering different climate scenarios and predicting possible impacts on infrastructure.

Conceptual and detailed design

Climate resilience measures should be integrated in the initial stages of design, considering future climate projections. This also includes the choice of materials and construction solutions resistant to extreme weather conditions.

Construction

In the construction phase, sustainable construction practices and materials should be used that reduce the impact on the environment and increase the project's resilience to climate risks. At the same time, risk management strategies must be implemented during construction to prevent or minimize damage from extreme weather events.

Monitoring and evaluation

It is important to verify the conformity of the predicted behavior and state of the infrastructure and its actual state during operation. This requires the development and implementation of plans to monitor and assess the climate resilience of the project after its construction, followed by the collection and analysis of data on the actual behavior of the infrastructure in response to climate conditions and the use of this information to improve future projects.

Support and management

During operation, it is essential to implement a maintenance and management plan that includes measures to maintain climate resilience long-term. This plan should be continuously updated based on new information on climate change and best practices.

By integrating these and other measures at every stage of design and construction, it can be ensured that road infrastructure can withstand the challenges of climate change and continue to serve society efficiently and safely.

4.3 Opportunities to optimize support

Optimizing road infrastructure maintenance is critical to improving resilience, reducing costs, and increasing road safety. One of the key opportunities for optimization is the introduction of Intelligent Transport Systems (ITS), which provide automated solutions for traffic management, road surface condition monitoring, and real-time incident response. Innovations in materials also offer opportunities to improve the durability and resilience of road surfaces

by using durable and high-performance materials that reduce the need for frequent repairs. Also, precise data from satellite and drone technologies can support the effective planning and execution of maintenance operations by providing accurate information on the condition of the infrastructure in real-time.

Another aspect of optimization is the development of effective maintenance strategies and procedures based on best practices and data analysis. An example is the application of preventive condition monitoring to identify and fix problems before they lead to severe damage or costly repairs. Integrating information and communication technologies [12] can improve coordination and communication between different units in the maintenance process and facilitate rapid response to incidents.

5. Complex and multidisciplinary approach

5.1 The importance of research and monitoring

A comprehensive and multidisciplinary approach is key to understanding and addressing the impact of climate change on road infrastructure. Scientific research plays a significant role in providing the necessary knowledge about how climate factors affect infrastructure systems, including the materials and structures most resistant to these conditions. The multidisciplinary nature of the research allows analysis of various aspects of road infrastructure, from geotechnical and material issues to traffic planning and management.

Systematic monitoring is another critical element in this comprehensive approach. Continuous monitoring and collecting real-time climate data allows engineers and governing bodies to monitor climate change and its impacts on infrastructure. This monitoring includes monitoring of atmospheric conditions, road surface conditions, and traffic. Collected data is analyzed to identify trends, predict future problems, and develop adaptation strategies, which provides a science-based basis for decision-making and rapid response to changing conditions.

5.2 The role of strategic planning and management

Strategic planning and management play a central role in adapting road infrastructure to climate change.

Strategic planning is crucial to the adaptation of road infrastructure to climate change. It helps to define long-term goals and priorities, as well as to develop a concrete framework for action. In this context, an analysis of potential risks and opportunities, as well as the necessary resources for successful adaptation, is carried out.

Strategic management allows effective coordination of the adaptation process. It includes coordination between different stakeholders, management of resources, and monitoring of progress. Ensures that decisions are scientifically sound and conform to established policies and regulations.

Strategic planning and management support a cycle of continuous learning and improvement. Through periodic reviews and evaluations, successful practices and improvement areas are identified. This allows the adaptation of strategies in response to new information or changing conditions.

6. Conclusions

In the conditions of the climate trends, the road infrastructure in Bulgaria faces several challenges, and in the future, this process will deepen. Climate change leads to adverse climatic consequences that make traffic difficult and increase the risk of accidents. Adapting these changes using research and monitoring is essential to improve knowledge of these risks and develop effective strategies to address them.

Adaptability and innovation are critical to improving the sustainability of road infrastructure. Preventive maintenance, intelligent transport systems, and new materials and technologies can help reduce the impact of climate change. Flexibility in strategic planning and management is also essential, as it allows organizations to respond quickly to changing conditions and improve their

practices based on new scientific discoveries and technological innovations.

Success in climate change adaptation requires collaboration between the scientific community, industry, and the public sector, which can accelerate the development and deployment of innovative solutions and improve coordination and resource planning in response to climate challenges. Sharing knowledge and experience between different sectors can help create a resilient infrastructure that can cope with future climate change. These findings highlight the importance of an integrated approach to climate change adaptation and innovation in infrastructure projects in Bulgaria to ensure the long-term sustainability and safety of the road network.

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Analysis of available climate data reflecting the impact of climate change on the road infrastructure in Bulgaria

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Summary: The article presents an in-depth analysis of the data related to the assessment of the impact of climate change on the road infrastructure in Bulgaria. It is necessary to systematically collect, store, and analyze territorial data on the dynamics of changes in various climatic factors such as temperature, snow cover, precipitation, winds, etc. The article examines the main sources of such information in Bulgaria, their limitations, and shortcomings. Identifying the needs and weaknesses in finding usable data is an important step on the way to building a strategy to solve this task.

Keywords: CLIMATE CHANGE, ROAD INFRASTRUCTURE, CLIMATE DATA ANALYSIS, INTENSE RAINFALL, CLIMATE RISK, CLIMATE MONITORING, ADAPTATION STRATEGIES

1. Introduction

In recent years, the public's attention and interest have been drawn to climate change, which is manifested by global warming, more frequent extreme weather events, rising sea levels, and melting glaciers. Climate change is the subject of research and analysis by a growing number of interested institutions due to its significant impact on various social and economic processes.

Observed changes in the atmosphere, oceans, glaciers, and biosphere clearly indicate that the planet is warming. The latest report of the Intergovernmental Panel on Climate Change (IPCC, 2021 [1]) reports that the average global temperature has increased by about 1.09 °C from the end of the 19th century to 2020. According to the data, the last decade, from 2011 to 2020, is the hottest since systematic meteorological observations began. Warming was felt more strongly on land, where the average temperature rose by 1.59 °C, compared to 0.88 °C over the oceans. Changes in air temperatures and indices of temperature extremes such as ice days, tropical nights, and heat waves are sources of important information in the study of climate change.

A 1 °C increase in surface temperature leads to a 7% increase in atmospheric water vapor. This affects rainfall, storms, hurricanes, and extreme weather events. In some places, precipitation decreases significantly, and dry periods become longer and more frequent. Nationally, the increased frequency of intense rainfall events results in more compromised elements of the transport infrastructure, with the republican and municipal road network being the most affected.

The increase in temperatures also affects the rise of the sea level – since the beginning of the 20th century, it has risen by approximately 20 cm, and the speed of this process is increasing. In the last century, that rate was greater than in any other century in the previous 3000 years [1].

The many changes in climate and related indicators observed in the last 50 years are occurring at a rate never before recorded in the previous 2000 years. This dynamic has a severe impact on socio-economic life and existing infrastructure. Studying these changes and their connection to different economic sectors answers many questions for the future. This highlights the importance of further research on impending climate change and its socio-economic footprint.

This publication aims to analyze the availability of meteorological and climate data relevant to the transport infrastructure in Bulgaria. With it, we continue the work of a previous publication by the same team, which describes the impact of different climate elements on the road network [2].

2. Methodology of climate data analysis

2.1 Collection and storage of climate data

Climate data collection is an important process that provides information on climate change and is essential for research, analysis, and development of climate change adaptation strategies. Here are some of the ways to collect climate data:

Climate Stations: These special weather stations are located at various locations and regularly measure climate elements such as temperature, humidity, atmospheric pressure, rainfall, and winds. This data is recorded regularly and used to analyze the climate.

Satellites and sensors: Satellites orbit the Earth and collect, with the help of various sensors and measuring devices, information about the climate – the temperature of the Earth's surface, the state of the glaciers, the concentration of greenhouse gases, and other parameters. This data is available through international agencies such as NASA and ESA.

Buoys, deep-sea probes, and floating platforms: These devices are located in the oceans and seas and measure water temperature, salinity, oxygen concentration, and sea currents. They are particularly useful for monitoring physical conditions in the World Ocean.

Aerosondes and balloons: Special aerosondes and weather balloons are used to measure parameters at altitude and observe atmospheric phenomena.

Automated systems and IoT: These enable continuous real-time data collection. This facilitates climate monitoring and provides up-to-date information.

Climate models: Climate models collect and process data from various sources, including stations, satellites, and probes, to create complex predictions of the future climate.

Global databases: Various organizations and agencies maintain global databases of climate information, such as NOAA, Copernicus, and NASA. These data are available for research and publicity.

Collecting climate data is a complex and continuous process that requires technological advances and cooperation between different institutions. This information is essential for understanding climate change and making adaptation decisions. Climate data collection needs to be systematic and consistent for several main reasons:

Understanding trends: Systematic and consistent collection of climate data allows scientists to understand trends and changes in climate over time. This process allows patterns to be drawn and future changes to be predicted.

Climate Risk Assessment: Climate data is essential in assessing the risks associated with climate change. They provide information about extreme events such as floods, droughts, tornadoes, and hurricanes that can devastate society and the economy.

Scientific research and modeling: Systematic climate data are used for scientific research and developing models that provide a better understanding of the climate and predict the future.

Planning adaptation strategies: Data are needed to prepare adaptation strategies to climate change. With their help, it can be determined what measures should be taken to reduce the vulnerability of society and infrastructure.

Informing the public and policymakers: Public and political understanding of climate change and its consequences is based on the availability of systematic data. They provide an objective basis for decision-making and policy formulation.

Comparison and coordination: Systematic data collection allows different regions and periods to be compared. This is essential for the analysis of global trends and for the coordination of measures to reduce emissions and adapt to climate change.

The long-term view: Climate change is the result of natural processes developing over millions of years and of anthropogenic activity over the past 200 years or so. Systematic data collection makes it possible to monitor the climate's long-term evolution and take action based on this long-term view.

Systematic and consistent collection of climate data is a key component in understanding and adapting to climate change and its societal and ecosystem impacts. This process provides a sound and objective basis for research, adaptation, and decision-making.

2.2 Types of climate data: temperature, snow cover, precipitation, winds, etc.

Collecting climate data to assess the impact of climate change on infrastructure requires measuring and recording various climate elements and indicators, such as:

Temperature: its measured values are essential for understanding climate change.

Snow cover: measuring its changes is important, especially in regions with snowfall.

Precipitation: information on the amount and intensity of precipitation is needed to predict flooding and erosion.

Winds: their speed and direction are essential for understanding climate conditions.

Atmospheric pressure: its measurement helps in predicting atmospheric processes and phenomena.

Humidity: it is an essential factor for climatic conditions.

Sea level and wind wave impact: these are important for areas at risk of flooding and those with coastal infrastructure.

Intensity of solar radiation: Measuring solar radiation is vital for understanding climate processes and the planet's heat balance.

Collecting this data in real-time and monitoring its dynamics is a key element for infrastructure protection and adaptation to climate change. This kind of information allows society to plan and take the necessary measures to preserve and improve infrastructure and address increasing climate challenges.

2.3 Climate Change Impact Assessment

Climate change impact assessment is a key process that helps understand how climate change affects the environment, society, and the economy. One of the first steps in this process is the analysis of climate factors and their trends. Here is how this analysis is performed:

Identification of key climate factors: The analysis begins with identifying key climate factors that can potentially influence a given region or system. These factors include temperature, precipitation, humidity, winds, sea level, etc.

Data collection: To perform the analysis, it is necessary to collect data on climatic factors. This may include information from weather stations, satellite observations, marine measurements, and other sources. The data must be systematic and reliable.

Time series and trends: After the data is collected, time series are created that show the dynamics of climate factors over the years. This analysis allows the identification of trends such as an increase in average temperature or an increase in precipitation.

Statistical analysis: To assess the degree of influence of climate change, mathematical-statistical methods are used. This may include correlations between climate factors and various parameters such as flood counts, average sea surface temperatures, etc.

Modeling: Some assessments require climate models that simulate future climate scenarios. These models are based on analyzing current trends and are used to predict future changes.

Interpretation of the results: The final step in analyzing climatic factors and their trends is interpreting the results. This

includes determining the possible environmental, economic, and societal impacts.

Analysis of climate factors and their trends is a fundamental step in determining the risks and opportunities associated with climate change. It provides a scientific basis for decision-making and policy formulation for adaptation and mitigation of climate risks.

2.4 The relationship between climate factors and road infrastructure

Climatic factors have a major impact on road infrastructure's design, construction, maintenance, and adaptability. The following more important aspects can illustrate this:

Temperature: The extreme temperatures and the wide temperature range negatively affect a significant group of characteristics and design parameters of the road infrastructure, respectively, the quality of the service it provides. Given the density and characteristics of roads, it is the mode of transport most affected by temperature limits in terms of durability, serviceability, and sustainability of service, compared to rail, water, and air.

Precipitation and flooding: This group of factors affects roads in a wide range of effects – from retention of surface water and reduction of traction through an increase in soil water quantities to local damage, defects, or destruction of roads and their facilities. They are important for the development of erosion-induced conditions and for increasing the geological risk in the area of landslides and collapses. The reason is reduced visibility (throughput), increased risk of road accidents, and forced traffic stops.

Snow cover and icing: These factors affect winter maintenance, traffic continuity, and durability of materials subjected to anti-icing additives. Cases of ice, "black ice," and snow cover are significantly relevant to road safety.

Extreme winds and storms: Within the scope of the routes, they can cause damage to the contact network of electrified transport, the power grid, and other damages. They are related to traffic safety and in cases of combination with hail, rain, and others. They are a prerequisite for fire risks. They increase the degree of surface wind erosion.

Sea level rise and wind wave impact: If the sea level rises due to climate change, coastal roads and bridges may be at risk of flooding. This aspect is particularly important for coastal regions. Under certain wind conditions, transport, port, and coastal protection facilities can be destroyed due to wave action.

Intense heat waves: Prolonged periods of high to peak temperatures affect the durability and wearability of road surfaces. They overdry the surface of the slopes, as a result of which they increase the surface weathering and the prerequisites for accelerated erosion. They are a prerequisite for fires and damage to the infrastructure resulting from the sensitivity of the building materials.

3. Sources of meteorological and climate data in Bulgaria

3.1 National climate networks and stations

The initial information for the climatic changes is the meteorological data – raw data from observations in more than 30 first-class synoptic stations in Bulgaria, with data submission every three hours in the international exchange. The stations that participate in the research must fulfill two criteria: 1) the possibility of public access to meteorological information, and 2) reflect the physical-geographical diversity of our country to the maximum extent. Nine stations meet these two conditions at the moment in the non-mountainous territory of our country, four of which are in Northern Bulgaria – Vidin, Lovech, Razgrad, and Varna and five in the South – Sliven, Kardjali, Sandanski, Burgas, and Sofia.

There are also several private sites where information from automatic weather stations can be accessed, but they do not always meet the requirements for representativeness and correctness of the data.

Meteorological information can also be obtained from the archives of the stations located at some of the civil and military airports and the Executive Agency for Maintenance and Research of the Danube River.

A distinction must be made between meteorological and climate data. The former focuses on short-term atmospheric conditions. Climatic data are averaged weather data collected over long periods and serve to analyze long-term climate trends.

3.2 Climate prediction models

Climate prediction models are implemented in computer programs and systems that simulate and predict climate conditions in the future. These models use mathematical equations, statistical data, and physical parameters to predict temperature, precipitation, winds, humidity, and other climate characteristics of specific localities and regions.

Climate prediction models are based on scientific research and gather information about current climate conditions and their changes over time. They can be used to analyze climate trends, make short-term and long-term climate forecasts, and assess the impact of climate change on various sectors such as agriculture, energy, and infrastructure.

Copernicus and NASA are most often used, adapted using different methods for the territory of our country. In some institutions such as NIMH, UACEG, SU, TU, etc., mathematical models with a regional orientation are being developed, which can forecast climatic conditions and analyze their consequences on the buildings and road infrastructure in the country.

3.3 International organizations and activities

Several international institutions, programs, and initiatives are engaged in collecting, analyzing, and sharing climate data and climate change information. These organizations and activities facilitate cooperation between different countries and regions to understand climate change and manage its consequences. Some of them are:

International Panel on Climate Change (IPCC [3]): This is an essential scientific organization that collects and evaluates scientific data on climate change and provides assessments and projections of its effects.

World Meteorological Organization (WMO [4]): It plays a key role in collecting and disseminating climate data and meteorological information on a global scale.

The United Nations Convention on Climate Change (UNFCCC [5]): This convention promotes international cooperation on climate change issues and requires countries to provide data and information on their climate action.

European Union projects and programs: The EU funds a number of climate-related projects and programs (e.g., PVGIS [6]) and collects data on climate change in the region.

These international organizations and activities can be important sources of information that are used for analyses and strategies for adaptation to climate change in the Balkans and Bulgaria.

4. Limitations and shortcomings of available data

The limitations and shortcomings of available climate data are important factors to consider in their use and analysis.

4.1 Issues with data limitations and deficiencies

When analyzing and interpreting climate data, it is important to understand their limitations and shortcomings:

Insufficient spatial coverage: In some cases, climate data may only be collected from a limited number of weather stations or regions. This means that there are places for which no data are available, and their climate dynamics remain unknown.

Insufficient time span of data: To analyze climate trends and changes over time, long-term information is required. Lack of data over a long period can make analysis and forecasting difficult.

Errors and inaccuracies: Every measuring instrument and method has its own errors and inaccuracies. This can result in data that does not always accurately reflect actual climate conditions.

Lack of standardization: Different weather stations and data sources may use different methods and tools, making data comparison and analysis difficult.

Heterogeneous data: Climate information is collected from various sources, including weather stations, satellite observations, climate prediction models, and more. Integrating this disparate data can be challenging due to different formats and collection methods.

Unforeseen omissions: In rare cases, data may contain unforeseeable omissions or information gaps, making analysis and forecasting difficult.

All of these issues and limitations must be considered in data analysis to improve the accuracy and reliability of analyses and predictions.

4.2 Problems with access to climate data in Bulgaria

A common practice when seeking meteorological information for various needs, including government departments and problem-solving institutions requiring such information, is to request it from the authority that manages, maintains, and is responsible for meteorological observations in the country. In most countries, this is done by the national weather service. In Bulgaria, it is the National Institute of Meteorology and Hydrology (NIMH [7]). For much of the operational work related to the operation of the meteorological network, the institute receives a government subsidy. Unfortunately, the institute does not present the detailed results of the station measurements in the public space. Only data from measurements in synoptic conditions are freely available, and only for part of the synoptic stations are available [8]. The data is superficial, with rounded values, and there is no information, such as extreme temperature, wind, precipitation, etc.

Due to the lack of archival information on the official page of NIMH, in any force majeure circumstances, such as disruption of road infrastructure, the concerned services and persons should request meteorological information through an official way from NIMH. They, in turn, decide if, when, and what information to provide, often for a fee. Information containing a time series with a longer range is also needed for some needs. NIMH can then provide the so-called "raw data" [9]. They are not provided immediately and in complete form, but multiple visits to the NIMH archive are required, which consumes an enormous amount of time and resources. A fee is also required for some of the information, which can sometimes be prohibitive for the concerned authority. For some needs, such as organizing fieldwork, planning repair, and construction activities, as well as several outdoor activities for better planning, climatic information is needed, such as the number of days with precipitation, amount of precipitation per month and years, average monthly temperatures, temperature extremes, etc. Such summary information cannot be found on NIMH pages, and published climate reference books contain information based on data from the middle of the last century [10].

It should be noted that NIMH makes publicly available monthly and annual summaries in which limited information can be found on average and extreme values of temperature, precipitation, wind, and other elements for a relatively small number of stations after 2007 [11]. In Bulgaria's neighboring countries, access to meteorological information is wider, and data can be found for many stations for at least 60 years. Serbia [12] and Romania [13] are leading meteorological services in this regard, which can provide a range of freely available climate and meteorological information on request. Climatic information for the last 60 years can be freely accessed on the websites of the meteorological services of most European countries. However, everyday information requires more specialized communication with the service in question, and most countries only provide such information for a fee. However, for some stations that are in the international exchange of the World Meteorological Organization [14], the daily data can be found on different sites, such as [15] or [16]. Information about some extreme data can be found

on the pages of meteorological yearbooks (such as those published in Bulgaria until 1982), statistical yearbooks, and publications in the media. Unfortunately, collecting information this way is not always successful, as it usually covers a small number of stations, has many missing data, and sometimes includes many errors.

The need for meteorological information to solve road infrastructure problems is paramount. Therefore, easy access to it will facilitate teams working on infrastructure projects.

5. Importance of quality climate data for transport decisions

In light of the challenge of accelerating climate change, developing and implementing a climate data collection and analysis strategy is of great importance. This strategy should be based on collecting, analyzing, and disseminating accurate and reliable climate-related data to support the sustainable and effective management of road infrastructure and road safety.

Without extensive and up-to-date information on climate conditions, we are powerless to address the impacts of climate change on road infrastructure. This data provides us with the necessary basis for:

Forecasting and planning: with the correct data, we can predict climate risk and plan infrastructure changes and improvements to address the challenges ahead.

Vulnerability assessment: we can assess the vulnerability of the road network and facilities, such as bridges and tunnels, to climate change and identify where investments in remediation and renovation are needed.

Improving safety: with data on climate risks, we can develop more effective road safety strategies, including warnings and infrastructure changes, to prevent disasters.

Resource optimization: by using climate information, we can optimize the use of resources such as salt, snow-, and ice-cleaners.

The current and future generations of designers, engineers, and builders must commit to creating and implementing strategies to improve climate data collection in transportation infrastructure areas. This includes support for national and international climate networks and stations, investment in climate prediction models, and active participation in international climate-related organizations and initiatives.

The real meaning of this commitment is manifested in our ability to protect our transport and infrastructure from the adverse effects of climate change and ensure sustainability and safety for future generations. A strategy to improve climate data is not just necessary; it is the key to the next successful steps for sustainable development and preserving the infrastructure that will serve us well in the future.

6. Conclusion

Climate data analysis is critical to road infrastructure and its resilience to the challenges posed by climate change. We have examined various aspects of this analysis in this text and highlighted its key role. It is clear from the exhibition that climate change has an impact on many aspects of infrastructure, including roads and bridges. Rising temperatures, intense rainfall, changes in winds, and other climate phenomena can lead to damage and serious damage to infrastructure.

The presentation examines the types of climate data needed to analyze the impact of climate change. This includes data on temperature, snow cover, precipitation, winds, and other parameters that can be used to assess climate risk to infrastructure. Climate data sources, including national climate networks and stations, climate prediction models, and international organizations, were also considered important sources of information.

The conclusion of this study emphasizes the need to continue and strengthen efforts in the field of climate data analysis for road infrastructure. In light of the growing challenges of climate change, this kind of research and monitoring is proving critical. We need to

invest in better systems for collecting and analyzing climate data and develop models to predict climate risk. This will allow us to create a more resilient infrastructure and prepare for future climate challenges.

Furthermore, the importance of collaboration between the scientific community, the public sector, and industry should be emphasized. We can only create innovative solutions and strategies for adapting to climate change through the combined efforts of all these sectors.

In conclusion, climate data analysis of road infrastructure is vital to maintain its functionality and resilience to climate challenges. Our commitment to these efforts will define the future of infrastructure and its ability to cope with climate change.

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Energy policy in the service of the climate – status and trends

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Abstract: Despite the efforts of the world community to limit global warming by reducing the greenhouse gas emissions emitted by societies, studies show that the levels continue to rise, and this hides a number of consequences for people's lives. The European Union, with its 8% share of generated global emissions, is not among the leaders in emitting harmful greenhouse gases, but it is among the leaders in pursuing a systematic and strict policy of climate neutrality. A European Climate Act for a green transition was introduced in 2021, setting a binding target for EU countries of net zero greenhouse gas emissions by 2050, with an intermediate target of 55% by 2030 compared to 1990 levels. **The purpose of this report** is to follow the policy of the Union, the state and trends in the field of energy from renewable sources and energy efficiency and the participation of Bulgaria in the progress towards achieving the set goals.

Keywords: ENERGY EFFICIENCY, RENEWABLE ENERGY SOURCES, CARBON EMISSIONS

1. Introduction

With the 2015 Paris Agreement, world leaders renewed their commitment to continued climate action and limiting global warming to below 2°C compared to pre-industrial levels and working to limit it to 1.5°C. Greenhouse gas emissions are considered the main cause of global warming. The trends and forecasts for the emitted greenhouse gases on the planet are presented in fig. 1.[1]

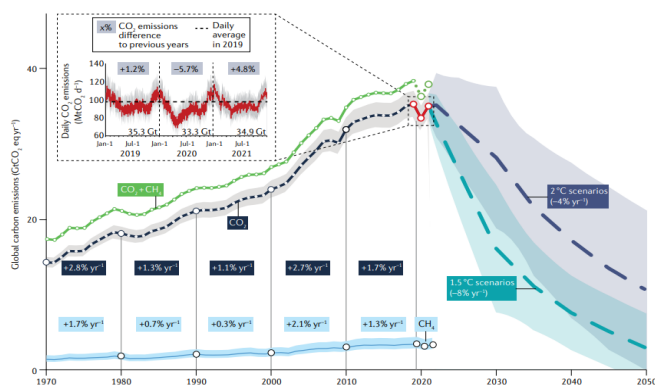


Fig. 1. Global CO2 and CH4 emission trends

Source: <https://www.nature.com/articles/s43017-022-00285-w>

The European Union is not among the leaders that emit harmful greenhouse gases. The EU accounts for only 8% of global greenhouse gas emissions. The largest emitter are the countries from the East Asia region with 27%, followed by the North America region with 12% and Latin America and the Caribbean with 10%.

Although not a major emitter of greenhouse gases, the EU is a leader in pursuing climate neutrality policies. In 2021, the EU adopted a European Climate Act. It sets a binding EU target of net zero greenhouse gas emissions by 2050, with an interim target of reducing net emissions by 55% by 2030 compared to 1990 levels. In support of this ambition, on 14 July 2021 the European Commission made legislative proposals under the „Fit for 55“ package. The main elements in the package are summarized in Fig. 2 [2,13]

Among the main highlights of the package is the setting of more ambitious targets in the field of energy from renewable sources and energy efficiency. In this regard, in May 2022 the Commission adopted a REPowerEU plan in which it proposed to increase the energy efficiency target by 2030 from 39% to 42% and the share of renewable energy from 40% to 45% by 2030.

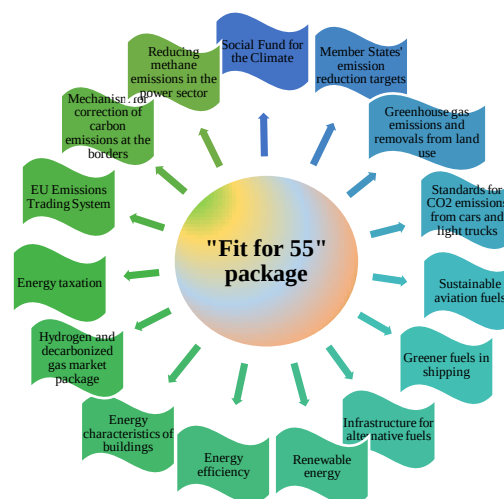


Fig.2. Key elements in the „Fit for 55“ legislative package

On 30 March 2023, a political agreement was reached to increase the share of energy from renewable sources to 42.5% by 2030, with an additional expected increase of 2.5% to reach a level of 45%, and in July 2023, the Energy Efficiency Directive was adopted as part of the „Fit for 55“ package. The new energy saving targets are presented in Fig.3. [3]

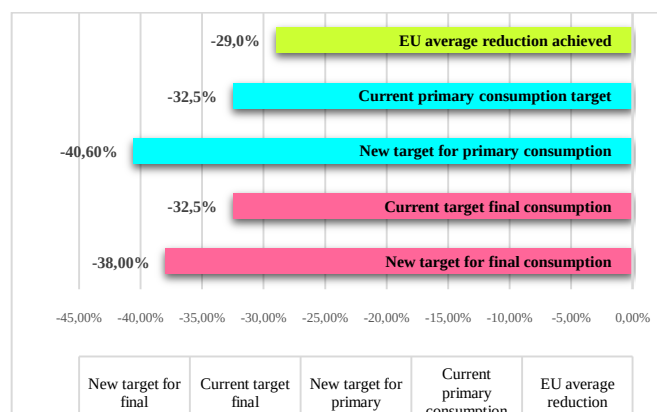


Fig. 3. Changes in targets for primary and final energy consumption

According to the new rules, an additional reduction of primary energy consumption by 8.1% (from -32.5% to -40.6%) and final energy consumption by 5.2% (from -32.5% to -38.0%) by 2030 compared to 1990 levels.

To meet the new targets, Member States must gradually increase their energy savings until 2030. On average, final consumption savings must increase by 1.49% of total annual consumption, reaching by the end of 2030 1.9%. [Fig.4]

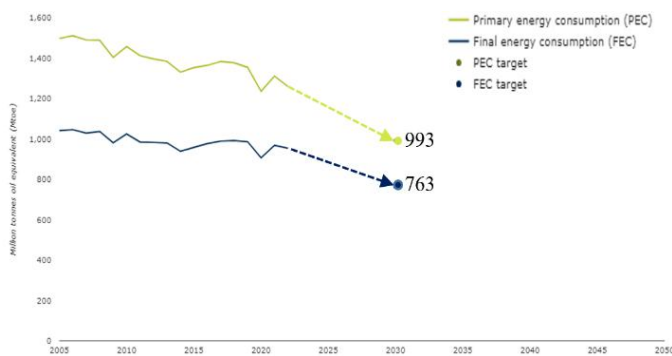


Fig. 4. Primary and final energy consumption in the EU (in megatons of oil equivalent) for the EU-27 [4]

Source: <https://www.eea.europa.eu/indicators/primary-and-final-energy-consumption>

The final consumption limit is set at 763 million tonnes of oil equivalent for EU members and 993 million tonnes for primary consumption. The limit on final consumption is binding and the limit on primary consumption is indicative.

2. Literature review

The concept of energy efficiency is associated with the amount of product that is produced in a given process from a unit of energy. In the energy intensive products directive 2005/32/EC, [5] the concept is defined as "ratio between the result of a given performance, service, good or energy and the amount of energy input". It covers the amount of energy consumed for the production of a unit of output. It is defined as a set of actions to reduce the energy consumed while maintaining the level of services offered. It represents a ratio between the output amount of productivity of a good, service or energy and the input amount of energy.[14] The smaller the amount of energy input for the production of the same amount of output, the higher the energy efficiency. [6] Energy efficiency (EE) is determined by the formula:

$$EE = \frac{\text{expended energy}}{\text{number of manufactured products}} = \frac{\text{imported energy} - \text{exported energy}}{\text{manufactured products and services}}, \text{ GJ/t} \quad (1)$$

Improving energy efficiency is defined as „increasing the efficiency of the final consumption of energy as a result of technological, behavioral and/or economic change“. [7] From the definition it follows that the increase in efficiency can be expressed as: [6,8]

- Obtaining the same amount of output with reduced energy consumption, or
- Obtaining a greater amount of output with constant energy consumption, or
- Obtaining such an amount of production that in relative units exceeds the increased energy consumption.

The main purpose of introducing energy efficiency indicators is to monitor the improvement of the energy efficiency of a given industrial enterprise and production cycle in order to establish the impact of implemented measures to improve energy efficiency on the energy characteristics of the production process or enterprise.

The energy can be used efficiently or inefficiently. Energy efficiency (and conversely inefficiency) can be seen as:

- **Result obtained from the energy input.** It cannot be 100%, due to the objective laws of thermodynamics. However, it is necessary to look for opportunities to reduce losses.
- **Careful (efficient) use of energy when it is used in optimal amounts.** Inefficient energy use results from poor design, operation and maintenance; operation of equipment "idle" (lighting, running processes at a higher temperature than necessary; lack of adequate energy storage, etc.)

When energy is converted from primary to useful form, losses occur along the entire path of transformation. (fig. 5)

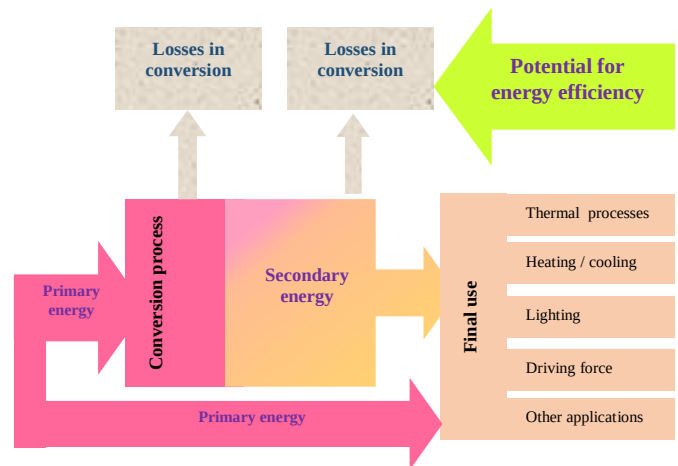


Fig. 5. Energy conversion [6]

Primary energy is energy in the form in which it is found and obtained from nature. It can be exhaustible (oil, gas, coal) and inexhaustible (solar, wind, water, geothermal biomass).

Secondary energy is the form in which primary energy is converted for more convenient use (charcoal, oil refining products, gasoline, kerosene, etc.)

Final energy is the energy that is input to a conversion device at the point of final consumption.

The supplier and the consumer have control over these exchange processes, which means that they can make an effort to improve efficiency and reduce energy resource losses.

Any form of energy that can be used without depletion is considered renewable (solar, wind, hydro, geothermal, bioenergy from biomass and waste). Fossil fuels such as oil, coal and gas are non-renewable.

An energy efficiency index (EEI) is used to reflect changes over a period of time

$$EEI = \frac{\text{Average energy consumption (ref)}}{\text{Average energy consumption}} \quad (2)$$

An increase in EEI reflects an increase in energy efficiency and vice versa.

Understanding the efficient use of energy is not associated with the imposition of deprivations or restrictions to meet production or personal needs. It represents the satisfaction of energy needs, without affecting the level of comfort and safety, by directly saving resources and financial means. Expectations of the benefits of reduced energy consumption for the environment are associated with:

- Reduction of greenhouse gas emissions;
- Reduction of pollution;
- More affordable energy for people and businesses;
- Reducing dependency on fossil fuel imports.

3. Research and discussions

Among the main focus in the "Fit for 55" Package are: increasing the share of renewable energy sources in final energy consumption and increasing energy efficiency to reduce emissions in all sectors of the Union economy. Each Member State will determine its indicative national contributions depending on specific national characteristics. According to the data of EU countries have achieved the overall target both in terms of the share of energy produced from renewable sources (20%) for 2020 (22.1% reported for 2020) (see Fig. 6) and the energy efficiency target (Fig. 8)[9]



Fig. 6. EU target on the share of energy from renewable sources
Source: https://www.eca.europa.eu/ECAPublications/SR-2023-18/SR-2023-18_BG.pdf

The contribution of each of the countries in the Union is presented in fig.7. [8]

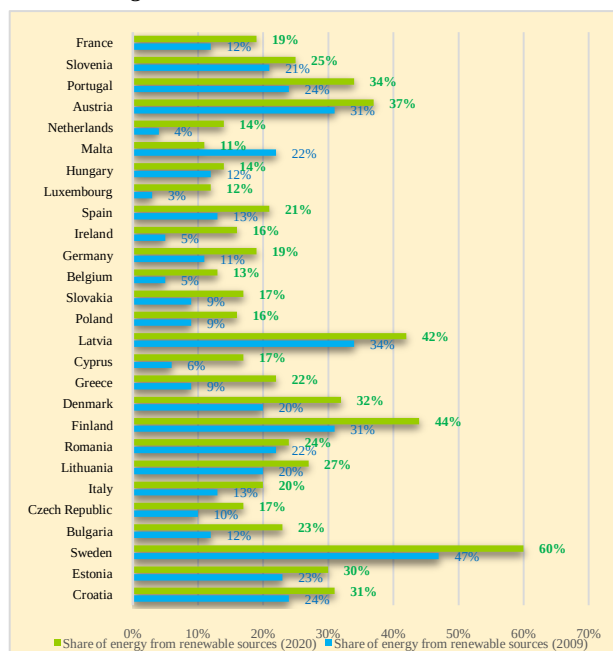


Fig. 7. Progress of EU-27 countries towards national targets for share of energy from renewable sources, 2009-2020

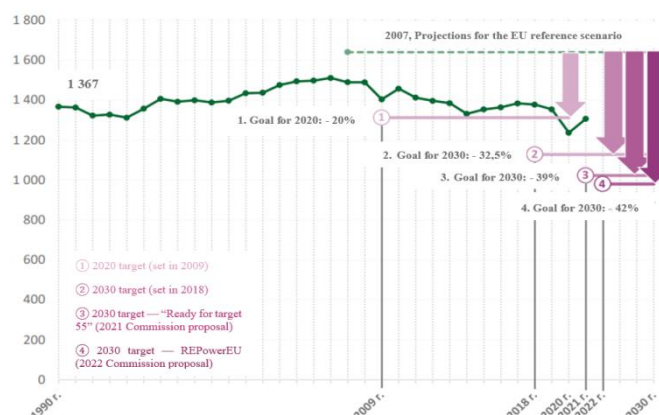


Fig. 8. EU target for energy efficiency, expressed as energy consumption, in million tonnes of oil equivalent [8]

In fig. 9 shows the change in the amount of greenhouse gas emissions generated as a result of the long-term efforts of the EU member states. The change in emissions in the Union, as a result of long-term efforts for the period 1990-2019, shows impressive results. Emissions for the EU-27 decreased by 26%, in Russia the decrease was by 33%, and in Japan – by 5%. The remaining countries registered an increase in emissions. For China - a growth of 259% was reported, for India - a growth of 166%, and for the USA - 2%.

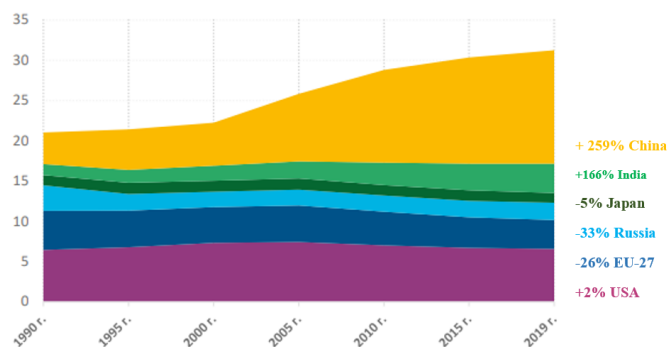


Fig. 9. Change in global emissions for the period 1990-2020 [8]

The policies of Bulgaria in the field of sustainable energy development are determined by the Integrated Plan in the field of energy and climate of the Republic of Bulgaria 2021 - 2030. [10] The total gross domestic energy consumption by 2022 marks a historical peak for the period 2001-2021, equal to 19,295.4 ktoe. (Fig. 10)

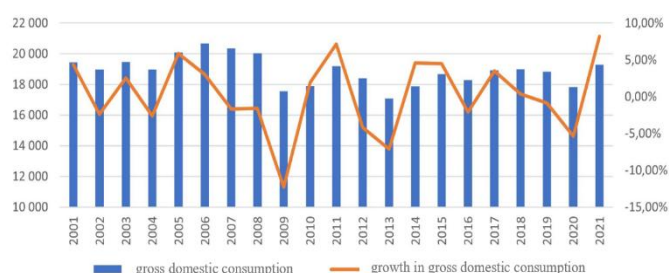


Fig. 10. Gross domestic energy consumption, ktoe, 2001-2021
Source: <https://www.seea.government.bg>

Data on the distribution of final energy consumption to 2022 by sector reflects growth in the post-pandemic period in all four groups. Compared to the levels of 2001, consumption in the transport, trade and services sectors has increased and decreased in the industry sector. [11] (Fig. 11).

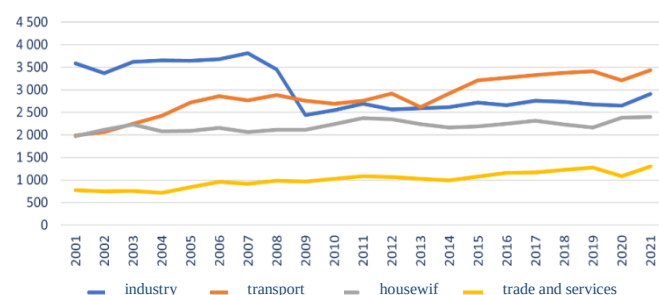


Fig. 11. Final energy consumption by sector, 2001-2021 [11]

Source: <https://www.emi-bg.com>

The change in energy efficiency in the Bulgarian economy for the period 2008-2020, measured by the energy efficiency index - ODEX shows the average results by sector: (Fig. 12) In the "Industry" sector - a significant increase in energy efficiency by over 19% for the period:

- In the "Transport" sector, energy efficiency in 2020 is deteriorating. The index is 5.5% above the 2008 level.
- In the "Households" sector, the ODEX index reported 11% above its 2008 level.
- In the Services sector, the index in 2020 exceeds the 2008 level by more than 33%.



Fig. 12. Change in the ODEX index by sector, 2008-2020, indices 2008=100%. [10]

Source: <https://www.seea.government.bg>

In the four sectors during the period of the Covid crisis, a drop in the values of the index was observed, which indicates an improvement in energy efficiency in them, but the general trend for the period 2008 - 2021 reflects the most pronounced deterioration of the index in the sectors - transport and households, services [15]. Only the Industry sector has lower values of the index compared to 2008, which testifies to the improvement of energy efficiency.

Regarding the consumption of energy from renewable energy sources, the data shows a growth for the period 2020-2022 of 1.34%. The trend of energy consumption in the country is presented in fig. (Fig.13). [12, 16] The country's energy and climate plan envisages the share of renewable energy in final consumption to grow to 27.09% by 2030, which is nearly 4% above the value noted in EU Regulation 2018/1999.

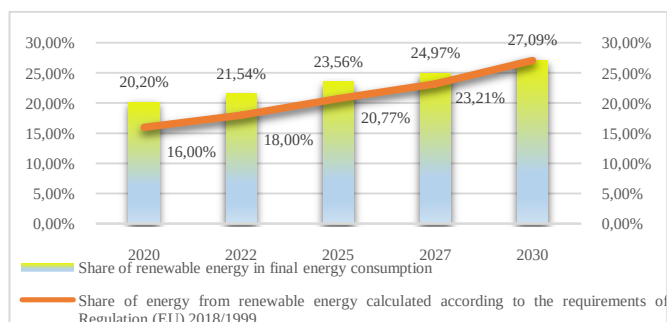


Fig. 13. Share of renewable energy in the gross final energy consumption in Bulgaria for the period 2020-2030

The distribution of the types of renewable energy in relation to the total amount of energy consumption shows that solar energy is only 1.2%, wind energy is 1.1%, biofuels are 1.4%, and heating and cooling through heat pumps is only 1% (Fig.14). [12]

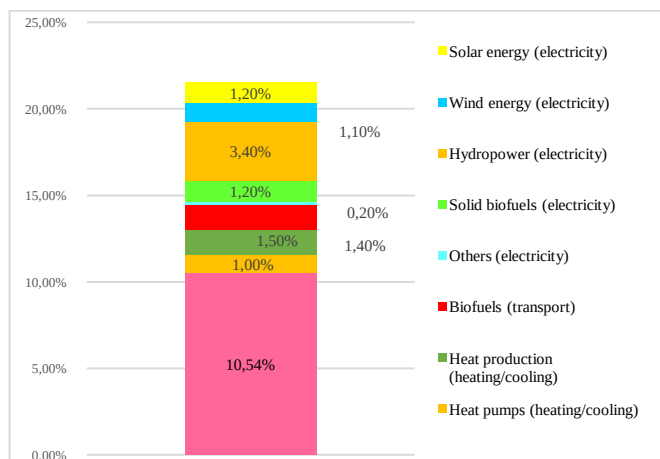


Fig.14. Share of renewable energy in total energy consumption, 2022

4. Conclusion

The EU has achieved its main climate and energy targets by 2020 – greenhouse gas emissions have been reduced, the share of energy from renewable sources has increased and energy efficiency has been improved in the Union. The achieved results serve as an incentive to set a new, more ambitious goal – achieving climate neutrality by 2050.

The process of transition to energy with low levels of harmful emissions requires increasing energy efficiency, increasing the use of energy from renewable sources in the gross final energy consumption, improving energy management, developing energy infrastructure, building an internal market and developing various concepts and implementation of new technologies and services.

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Challenges to the analysis of available data on crisis events and their effects on transport infrastructure under climate change

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Abstract: *The article focuses on issues related to the assessment and interpretation of existing data on crisis events in the context of transport infrastructure. In the face of global climate change, analyzing these data becomes increasingly complex and requires in-depth consideration. The main challenges the paper addresses include the lack of comprehensive and up-to-date data, limited opportunities to analyze causal relationships between climate events and their impact on transport infrastructure, and shortcomings in existing analysis methodologies. The authors call for the development of new, more efficient methods of data collection and analysis that can serve as a basis for future strategic decisions.*

Keywords: CLIMATE CHANGE, TRANSPORT INFRASTRUCTURE, CRISIS EVENTS, CAUSAL RELATIONS, STRATEGIC DECISIONS, ADAPTATION MEASURES

1. Introduction

In the conditions of global climate change, the sustainability and adaptability of transport infrastructure is becoming increasingly relevant and requires in-depth analysis. Climatic events such as heavy rains, storms, floods, and temperature anomalies can have a significant impact on the operation and reliability of transport systems. However, existing data on these crisis events are often insufficient or limited, making their analysis difficult and sometimes inadequate.

Transport infrastructure is vital to the day-to-day functioning of society and the economy, providing connectivity and access to critical resources and services. At the same time, it is exposed to various climatic risks that can affect its functionality, safety, and efficiency. The consequences of climate change, such as the increasing frequency and intensity of extreme weather events, lead to an increase in the exposure of transport infrastructure to risks. Accordingly, analyzing the impact of climate change on transport infrastructure and developing adaptation strategies becomes essential.

The purpose of this paper is to explore the critical challenges associated with the assessment and interpretation of available data on crisis events and their impact on transport infrastructure in Bulgaria. In particular, we address the problems stemming from the lack of comprehensive and up-to-date data, the limited ability to establish causal relationships between climate events and their impacts, and the shortcomings of existing analysis methodologies. At this stage, it is imperative to develop new, more efficient methods of data collection and analysis that can serve as a basis for future strategic decisions in transport infrastructure and climate resilience. These new methods may include the use of modern technologies such as the Internet of Things (IoT), geographic information systems (GIS), and artificial intelligence (AI) to improve data collection and real-time analysis.

The article calls for the urgent need to develop new, more efficient methods of data collection and analysis that can serve as a basis for future strategic decisions in transport infrastructure and climate resilience.

The problem of climate adaptation of transport infrastructure is technical but also institutional and organizational. Although technological innovations can offer new avenues for data collection and analysis, successful adaptation also requires coordinated efforts between the various institutions and agencies responsible for managing and maintaining transport infrastructure. Establishing inter-institutional partnerships and collaborative platforms can improve understanding and response to climate risks while stimulating the sharing of knowledge and resources.

Furthermore, educational and research institutions can play a key role in developing new methodologies and tools for climate risk assessment and transport infrastructure adaptation. Research and

training of specialists in the field of climate resilience and transport infrastructure can contribute to the development of innovative solutions and sustainable practices. In the long term, introducing educational programs aimed at climate adaptation of transport infrastructure can prepare future professionals for the challenges associated with global climate change.

In conclusion, to achieve a successful adaptation of transport infrastructure to climate change, a comprehensive approach is needed that includes technological innovation, institutional and organizational cooperation, as well as investment in education and research. Creating solid partnerships between the public and private sectors, academia, and civil society can accelerate progress towards a more sustainable and adaptive transport sector in the face of ongoing climate change.

2. Analysis of available data on crisis events and their effects on transport infrastructure

According to the "UN Framework Convention on Climate Change" [1], "adaptation" to climate change can be defined as "the adaptation of a natural or human system in response to climate risks."

To prevent the consequences of climate change, the Member States of the European Union have prepared packages of strategic documents. The Bulgarian package for "National Climate Change Adaptation Strategy and Action Plan (2019 - 2030)" was approved in October 2019. The main document for the Transport sector is Annex No. 7 of [2-4].

According to "Climate change adaptation - assessment of the transport sector" [2], in the medium and long term, the most critical risks for the Bulgarian transport system that can be expected as a result of the predicted climate changes are:

- Extreme heat: the forecasts are for a continued increase in temperatures and the duration of the situations that occurred;
- Blizzards and snowfall: long-term forecasts for the annual amount of snowfall predict a decrease (the latter is visible for the period 2020-2022), but in the short and medium term, the events that occur as a result of snowstorms will make it difficult for all modes of transport in certain areas;
- Landslides: Precipitation factors are the primary enablers of landslides and rockslides, such as due to the expected increase in the frequency of extreme rainfall events;
- Flooding: increased frequency and impact of flooding under all climate change scenarios.

In drafting the project [2-4], the main points that need to be worked on to obtain results in the specified period were determined. The more important of these, which have not been effectively defended to date and form the basis of the analysis in this publication, are the dysfunctionality of the underlying policies and the insufficient

capacity to adapt. Regarding the institutional framework, the following problem points stand out:

- Short-term vision and information-level fragmentation of the leading direct climate change risks and vulnerabilities facing the transport sector.
- Local analyses and risk assessments, respectively, show the impossibility of a comprehensive evaluation of the vulnerability of the transport sector as indicated in [2] and corresponding to the summary in Fig. 1.
- Climate change adaptation activities for the transport sector. On this point, it was concluded that stakeholders prepare strategic documents within the one-way impact, namely from transport on the environment. Adverse impacts (the impact of changed climate conditions on transport infrastructure) are practically not amenable to long-term analysis and planning, and issues are limited to the ongoing management of problems arising from short-term impacts.
- The lack of quality data to analyze and enable the creation of long-term strategies by responsible institutions forms a global low adaptive capacity of the sector.

Climatic phenomenon	Vulnerability of transport infrastructure						Mitigation
	transport infrastructure			Attitude towards transport safety			Stages of prevention: ①- Level standards ②- Performance ③- Operational support
	Roads (streets)	Rail roads	Transport facilities, incl. airstrips	Car roads	Rail roads	Transport facilities	
High temperatures							① ② ③
Low temperatures							① ② ③
It's raining							① ② ③
Storms (wind, hail)							① ② ③
Snowfall							① ② ③
Droughts							① ② ③
Fogs							① ② ③
Snow storms							① ② ③
Sea level rise - excitement							① ② ③

Climatic phenomenon	Sustainability	Mitigation	Impact on the user and consequences
	Attitude towards maintenance and traffic management	Stages of prevention: ①- Level standards ②- Performance ③- Operational support	
High temperatures	☑	① ② ③	TOTALLY NEGATIVE for traffic continuity and road safety
Low temperatures	☑	① ② ③	
It's raining	☑	① ② ③	
Storms (wind, hail)	☑	① ② ③	
Snowfall	☑	① ② ③	
Droughts	☑	① ② ③	
Fogs	☑	① ② ③	
Snow storms	☑	① ② ③	
Sea level rise - excitement	☑	① ② ③	

Fig. 1 Vulnerability ranking of Bulgaria's transport infrastructure to the effects of climate change. **Legend:** highest sensitivity – red color / lowest sensitivity – green color.

Regarding the possibilities for building adaptive capacity, [2] points out several omissions in providing the basic options for adaptations that are still relevant today:

- Adaptation capacity – insufficient available information in terms of volume and quality with which to create management systems;
- Adaptation activities - most activities are aimed at crises and lack long-term effectiveness due to a lack of a systematic approach.

To justify a framework to parameterize these two indicators, it is necessary to expand the discussed national database with an additional resource. It should include elements of investment design (project preparation, design standards), operation and maintenance, emergency response, institutional capacity building, and data collection.

It is important to note that data collection is essential and accompanies all other aspects as a basis for their implementation. Given the backlog in implementing the recommendations, it is imperative to start a discussion and proposals for the collection and use of databases (climatic and transport infrastructure conditions) to accumulate a basis for concretization within the medium-term plan (5-7 years) opportunities for adaptation. Without improving data collection practices that are open enough to be used to process and complement climate model algorithms and interactions, the sector's climate event analysis and prevention methodology will not be justified. Accordingly, it is stated that vulnerability risk assessment for this sub-sector through a working model will not be possible until the 2030 deadline.

In [5], it is noted that work should begin on the application of adaptation parameters, and this should follow a principled algorithm to create a system that takes into account current and projected climate changes and links them to transport infrastructure, reducing its sensitivity to them, respectively, to improve its durability and serviceability, safety and continuity of movement.

In [5], it is stated that the main difficulties in the overall adaptation of the transport infrastructure to climate risks are the lack of awareness of climate patterns (as a consequence of the interaction of different possible behavior of humanity and the planetary climate), combined with the scope of change of each climate norm in which the parameters of the transport object are set. For Bulgaria, the task is complicated by insufficient publicly available and up-to-date data on the impact source and the recipient.

This makes it difficult to implement projects that solve adaptation tasks in the transport sector. To create an environment for research, monitoring, visualization, and response, the basic sustainable principles in construction must be respected - for example, introducing conditions to apply the concept of "life cycle" for the field of transport construction by analogy with that of buildings. This will enable a methodical approach to work on the main areas such as design norms, data collection for all stages of the investment project, preparation at the design level, operation and maintenance, and actions in emergencies already recommended in [6]. In second place is the gradation of the significance of the events and the possibilities for building adaptive capacity. In this case, the main problem for Bulgaria is the lack of data (missing, incomplete, irregular, unavailable) about the climate, the climatic phenomena that have occurred, and, accordingly, their consequences concerning the current state of the transport infrastructure.

Significant neglect of database collection leads to a lack of statistical parameters. This complicates the research work regarding adaptation and makes inapplicable the most modern methods of modeling (neural networks, artificial intelligence, etc. [7]) of the processes and their use for predictive analysis in the medium and long term.

Based on [6], we analyzed the significance of extreme climate events concerning the main parameters of transport (infrastructure

and traffic). The preliminary analysis of the actuality of the problem and the need for its step-by-step solution shows that there are levels of vulnerability in all elements of the transport infrastructure, with the road infrastructure being the most sensitive, which is summarized in Fig. 1. This was a prerequisite for the team to focus on checking the quality and quantity of the data that make up the available information base and its accessibility and visibility concerning the road infrastructure.

3. Sources of publicly available data on crisis events and their impact on transport infrastructure

The directions in which the search was directed were climate data, extreme events that occurred, and effects on the road network. For this purpose, within the framework of the project, sources with publicly available data were studied. Such are the National Statistical Institute (NSI) [8], Road Infrastructure Agency (RIA) [9], National Civil Protection Service (NCPS) [10], local sources at the district and municipal level, and information in the media. The latter is not an official source of data. Still, due to the high degree of missing data, fragmentation of the available data, or inconsistency in the registers of the mentioned national institutions, it was necessary to overlay all publicly available information.

Despite the efforts and complementary media-type elements, survey results are sparse, inconsistent, and difficult to track.

On the NSI website [8], statistics are available on climate crises for the period 2004–2021, and for the territory of the country for specific periods, the information is summarized in a form that is difficult to compare, from which to track and derive dependencies by area for types of climate risks and the territory of Bulgaria. As for the Republican Road Network (RRN), there are aggregated data for the entire country on the affected infrastructure by year for the period 2004–2008, and for each year, the data were provided by different respondents (RIA, NCPS, regional road administrations, etc.). In this case, it is impossible to determine the degree and significance of the impacts, but only the total number of those RRN objects that were the subject of direct budgetary costs for restoration.

A partial information base is maintained in the RIA, which refers to crisis events (according to data from the regional road administrations) by years after 2013 and separate announcements until 2022 for planned ongoing and/or major repairs on the state road network.

In this project, an attempt has been made to combine data from the RIA with information from NSI, NCPS (partial accident bulletin for the period 2009–2023), and the media on climate crises that are the cause of emergencies, traffic disruptions, and damage to the republican road network to derive a principle algorithm. Still, the quality of the databases is insufficient in quantitative and qualitative terms.

4. Results of the survey of available publicly available information

The conducted study confirmed the expectations that the possibilities of connecting climatic events with the current and subsequent state of the transport (for the needs of the road project) infrastructure could not be realized with the available publicly available information. Accordingly, a lack of adaptive capacity in these measures (database collection and organization) has been demonstrated, and the creation of a real-time verification program system with high predictive capacity cannot be ensured at the current stage of the project.

The data show that the climatic phenomena with priority in terms of the roadworthiness of the RRN and the continuity and safety of traffic are the following - heavy rains and the floods caused by them (Fig. 5), an increase in the geological risk of erosion (abrasion) in terms of precipitation factor, including combined with another occurrence component, snowfall from blizzards (except for the years 2020–2022, which had dry winters).

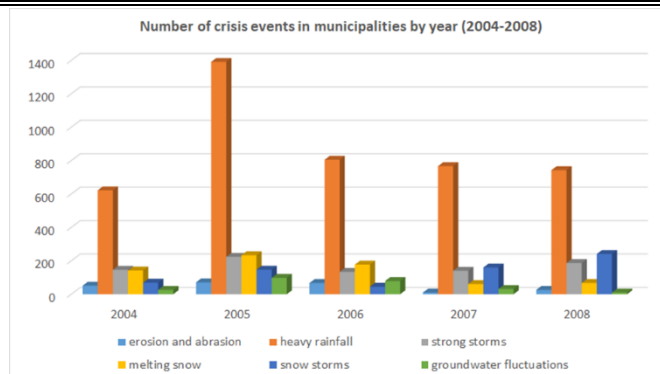


Fig. 2 Number of crisis events in municipalities by year (2004 - 2008) by type. Data source – NSI [8]

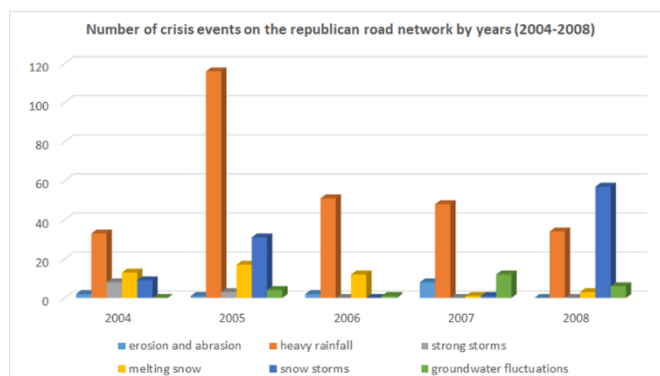


Fig. 3 Number of crisis events by type for the republican road network of Bulgaria by year for 2004–2008. Data source – NSI [8]

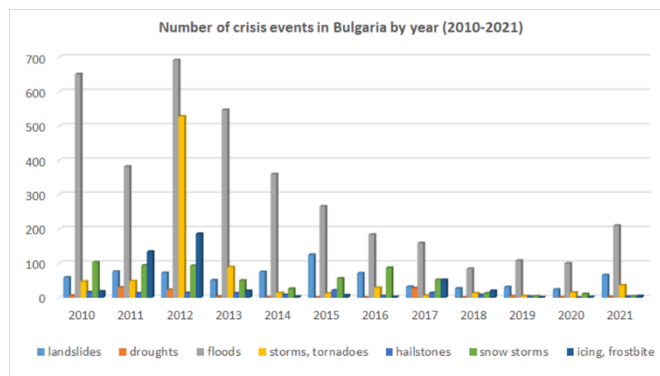


Fig. 4 Number of crisis events by type in Bulgaria by year for 2010–2021. Data source – NSI [8]

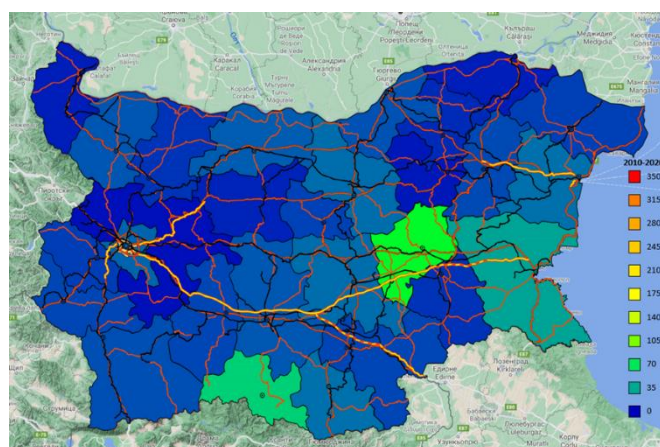


Fig. 5 Map of the regions in Bulgaria with the average number of floods per year for 2010–2020. Data source – NSI [8]

Nevertheless, the tracking of statistics made it possible to draw several more essential conclusions about the overall severity of the main climate crises in Bulgaria for 2004–2023. Figures 2, 3, and 4 show that most crisis phenomena in municipalities and RRN are caused by heavy rains, according to NSI statistics from 2004 to 2021. This often leads to floods (Fig. 5), landslides (Fig. 6), etc.

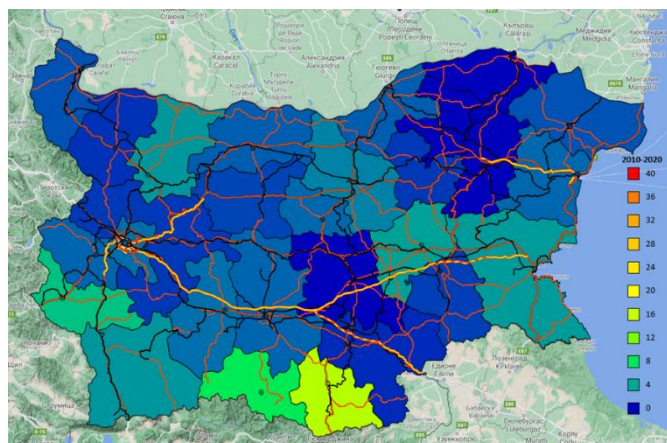


Fig. 6 Map of regions in Bulgaria with the average number of landslides per year for 2010–2020. Data source – NSI [8]

Figures 5 and 6 present a visualization of the average annual number of floods and landslides in different regions of Bulgaria for the period 2010–2020, based on data from the National Statistical Institute in Bulgaria (NSI). According to the statistics shown, it can be seen that heavy rains are the main catalyst for floods and landslides in the country, and the consequences of these crisis phenomena significantly affect the transport infrastructure. The distribution of floods and landslides by region highlights regional differences in exposure to such risks. The analysis of this data is essential as it helps to identify vulnerable areas and allows for better planning and implementation of measures to prevent and address the effects of climate change. Furthermore, the analysis of this geographic data can serve to improve crisis management and infrastructure adaptation strategies, which are essential to maintain the functionality and safety of the country's transportation systems.

5. Conclusions

Within the scope of the study, it was established that the building of adaptive capacity according to the principles laid down in the climate change adaptation will require an enormous human and financial resource from related institutional units and the immediate launch of measures to implement the specified adaptive practices.

At this stage of the research, we found that, apart from the huge delay (from 2019 to the present), the primary problem is the lack of collected, archived, applicable, processed, and accessible databases relating to the status of the impact on the Transport sector. The second fundamental problem is that at the national level, a coordination model for creating appropriate archives has not been developed and, therefore, does not function. At the moment, every instance and/or institution responsible for certain sectoral policies and possibly required to keep an archive maintains some level of it, which is usually unavailable, incomplete, and out of sync with other transport-related agencies.

Therefore, the legal framework and regulations for its implementation must first be worked on to create a multidisciplinary data archive. Thus, given the level of technology development, all institutions will be able to count on having access to a dynamic platform where they can enter the information they are responsible for. It will be constantly updated, and with the help of a model for the AI to work with, it will be possible to connect events and facts that can be processed to correctly assess the risk and its consequences (from a short-term to a long-term perspective).

It is thus expected that in addition to point-in-time data (for climate events, traffic disruptions, accidents, and the need for repair and restoration of transport infrastructure, for accidents and others), these data will presuppose a relevant link between climate change and the occurrence of extreme climate an event that led to a crisis on the transport (road) infrastructure, traffic violations and damage to the transport infrastructure, respectively the subsequent recovery measures and, as a result, a realistic forecast model for the prevention of a subsequent similar situation.

The presented problems and recommendations emphasize the importance of creating an integrated data collection and processing system to support the prevention and management of crises in the Transport sector, especially in climate change. Developing a legal framework and guidelines for effectively implementing the principles of adaptation to climate change is key to building adaptive capacity and sustainability of the transport infrastructure. The establishment of a multidisciplinary data archive and the creation of a dynamic platform for the exchange of information between different institutional units will allow a faster and more accurate analysis of the risks and consequences of climate events. Also, it will support the development of precise forecasts and effective crisis prevention and response plans. Implementing these recommendations requires a concerted effort by all parties concerned, as well as a commitment to continuously update and optimize data collection and processing systems in line with the latest technological developments and climate change adaptation requirements.

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Design and construction based on climate scenarios and regional climate models

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Abstract: The application of old climate data in the design of buildings and transport infrastructure that will be used in the future is problematic because of climate change. On the other hand, it is currently unknown what the success of human actions to limit them will be. This leads to some uncertainty about the exact parameters of the climate until the year 2100. This requires a new approach to design and construction in the context of climate change. The article examines the impact of RCP (Representative Concentration Pathway) climate scenarios and regional climate models based on them, on design and construction for energy efficiency and sustainability. The significance of different RCP scenarios and the need for spatiotemporal scaling of climate data are discussed. The disadvantages of using a static representative climatic year (as it is in the Bulgarian regulatory documents for energy efficiency) are analyzed compared to its dynamic and adaptive variant.

Keywords: CLIMATE RCP SCENARIOS, ENERGY EFFICIENCY, ADAPTATION AND OPTIMIZATION, REPRESENTATIVE CLIMATE YEAR

1. Introduction

The term “climate change” refers to long-term changes in the weather conditions of our planet. These changes relate to temperature, precipitation, wind, and other climatic factors. In principle, they could be the result of both natural processes and human activity. Research in recent decades indicates that at the moment, there are no significant natural causes (for example, a substantial increase in solar activity, changes in the Earth's orbit, etc.), but there are significant anthropogenic causes – the population of the planet grew to 8 billion in just 50 years [1], and the preferred energy source is fossil fuels, which emit carbon emissions when burned. This leads to an increase in the concentrations of greenhouse gases in the atmosphere, mainly carbon dioxide (CO₂), methane (CH₄), and nitrous oxide (N₂O), emitted by transport, industry, agriculture and other human activities.

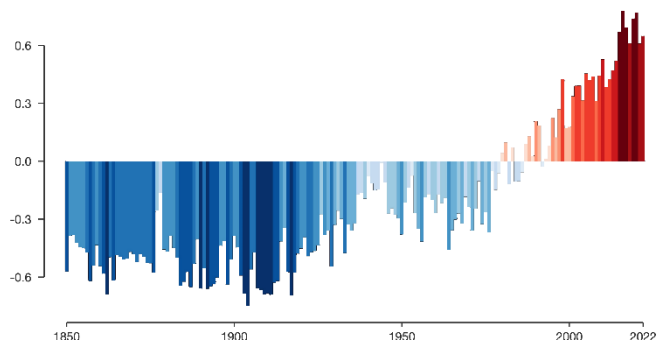


Fig. 1 Relative temperature changes for the world from 1850 to 2022 compared to the average for 1971 – 2000 in °C [2].

One of the most significant manifestations of climate change is the increase in global temperatures (Fig. 1). This, in turn, leads to more frequent and more intense extreme climate events such as hurricanes, storms, floods, drought, sea level rise, inundation of fertile land, loss of biodiversity, etc. Some of them have catastrophic proportions and serious socio-economic and political consequences.

Tackling climate change has two sides. The first of them is proactive; it aims to limit the causes of climate change by reducing greenhouse gases in the atmosphere to acceptable levels. This aims to restore the so-called “infrared window” [3] in the Earth's infrared radiation spectrum through which it cools, radiating heat to space. This will help to restore the energy balance of the planet and gradually reduce CO₂ over decades’ temperatures will also begin to decrease, which will restore the planetary balance in a more favorable temperature range for humanity and life.

The other significant action to deal with climate change that humanity must undertake is adaptation to the changes already occurring and their consequences. This means that they should be studied and modeled so that they can be predicted and actions taken

to limit losses from their impact. This involves looking at different climate scenarios (and which will occur depending on humanity's behavior and activities).

There are many human activities whose results are directed towards the future. Such are the design and construction of buildings and facilities that will be operated in the future, as we already know, under other climatic conditions.

Currently, when designing buildings to determine their energy balance, climate data from past 30-year periods (for example, from 1961 to 1990, from 1991 to 2020, etc.) are used, and the climate values for them are set as average for the period. In Fig. 1, however, it can be seen that significant temperature changes occurred after 2005. They partially affect the climate values for the period 1991 to 2020, but not enough because of the upward trend if they will be used to design buildings and facilities that will operate in the future.

In Ordinance No. RD-02-20-3 of November 9, 2022, on the technical requirements for the energy characteristics of buildings [4], climatic data are used, which were published for the first time in Ordinance No. RD-16-1058 of 10.12.2009 d. on energy consumption indicators and energy characteristics of buildings [5]. The new Ordinance No. RD-02-20-3 is used for the design of buildings and facilities that will be used for at least the next 50 years, under different climatic conditions. If the normative life of buildings is increased to 100 or 150 years (in connection with applying the principles of the circular economy), then the climate will be important in their design not only for the next 50 years but for 100-150 years.

In conditions of rapid climate change, using old climate data from past periods leads to inadequate buildings, facilities, and infrastructure for the future climate. Buildings will need much more energy for cooling than we can calculate from data determined from measurements over the previous 30-40 years. The materials we use must be resistant to higher temperatures in order not to destructure. This applies both to the construction of buildings and to the construction of transport infrastructure. Some thermal insulations (for example, ETICS) are damaged by very high temperatures and high solar radiation values on their surface [6-8]. The same applies to asphalt road surfaces, the softening of which leads to the accumulation of deformations and damages (ruts, waves, bumps, bulges, etc.). Analogous cases of compromise are observed in the asphalt pavements of airplane taxiways. The behavior of different asphalt pavement mixtures at high temperatures should be investigated to make more adequate choices for future climatic conditions [9].

2. Climate scenarios for the future

The multifaceted manifestation of climate change leads to different impacts on buildings and infrastructure. Buildings, facilities, and infrastructure must be prepared not only for higher temperatures but also for droughts, floods, stormy winds, tornadoes,

hurricanes, and other extreme climatic phenomena, which, according to scientists, are becoming more frequent [10]. Among the European countries, Bulgaria has the sharpest increase in cases of extreme weather [11].

Modeling the future of our planet's climate involves an element of uncertainty that comes primarily from the uncertainty of how well humanity will recognize the problem, plan measures to solve it, and how successful those measures will be. Therefore, in 2014, the Intergovernmental Panel on Climate Change (IPCC) developed various RCPs (Representative Concentration Pathways) scenarios for the future of the Earth's climate [12]. These were provided in her Fifth Assessment Report. The scenarios are four in number and represent model trajectories of greenhouse gas concentration (Fig. 2) and radiation pressure [12], which are used in climate models. Radiation pressure is the difference in W/m^2 per unit of time (hour) between incoming and outgoing radiation in the atmosphere and is the primary driver of climate change.

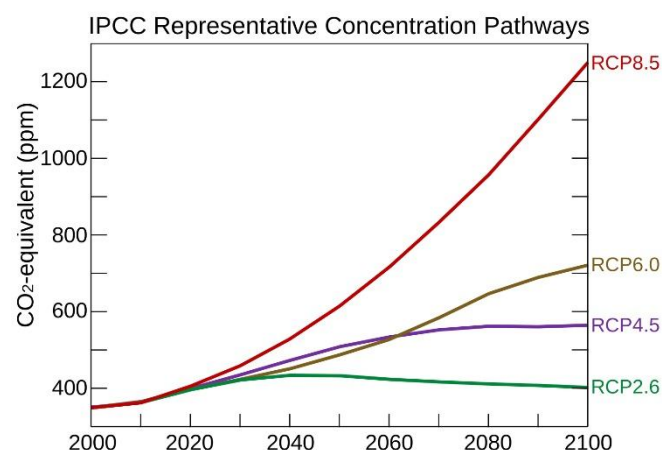


Fig. 2 Model trajectories of greenhouse gases translated into carbon equivalent under the four climate scenarios from 2000 to 2100 [12]

Here is a brief overview of these scenarios and their significance:

RCP 2.6 – this is the most optimistic scenario for radiation pressure of 2.6 W/m^2 , which assumes a sharp reduction in greenhouse gas emissions and stabilization of concentrations by the middle of the century. This scenario is associated with strict emission reduction policies and intensive adaptation measures. In this scenario, it is possible to limit global warming to below 2°C relative to pre-industrial levels.

RCP 4.5 – a scenario with a moderate reduction in emissions, which, however, fails to stabilize greenhouse gas concentrations by 2100. This scenario assumes significant but achievable efforts to reduce emissions, which could lead to more moderate warming (by $2\text{--}3^\circ\text{C}$).

RCP 6.0 – a scenario in which emissions continue to rise until mid-century and then begin to decline, but the total concentration of greenhouse gases continues to rise until 2100. In this scenario, moderate to large warming (by $2\text{--}4^\circ\text{C}$) would require significant adaptation measures.

RCP 8.5 – the most pessimistic scenario in which emissions continue to rise throughout the century without any significant restrictions. Extreme and continued exponential warming (by $4\text{--}6^\circ\text{C}$ or more) would have catastrophic consequences for the climate and require aggressive and desperate measures for adaptation and survival.

Understanding and using these climate scenarios is important for planning long-term adaptation and emission reduction strategies. They also help analyze the risks and opportunities associated with climate change. Global and regional climate models and strategies are developed on their basis.

3. Global and regional climate models

3.1 Global climate models

Global Climate Models (GCM) [13] are computer models for simulating the Earth's climate. They are key to climatology and are used to study various aspects of the climate, including how it may change under the influence of human activity and greenhouse gases.

Global models are based on the fundamental laws of physics, chemistry, and fluid dynamics and integrate multiple sub-systems of the climate system, for example, atmospheric processes (such as cloudiness and precipitation), ocean currents, ice cover, vegetation, etc.

These models are used to create climate forecasts at different temporal and spatial scales, from decades to centuries and from global to regional scales (Fig. 3).

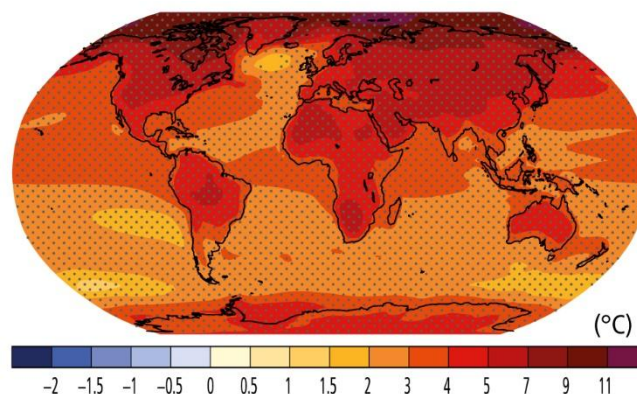


Fig. 3 Increase in average surface temperatures for the period 2081-2100 compared to the period 1986-2005 under climate scenario RCP 8.5 [14]

Global climate models suffer from insufficient accuracy of some parameters, limited resolution, and uncertainty related to factors such as cloudiness or human activity. Therefore, the results of these models are usually represented as probability distributions and scaled spatially and temporally to regional climate models for more detailed predictions.

3.2 Regional climate models

Regional climate models (RCM) are created based on the GCM, taking into account the specifics of each region.

Regional Climate Models (RCMs) [15] are computer models that provide detailed information about climate conditions in specific geographic areas under different climate scenarios, offering higher spatial and temporal resolution. This is important because climatic conditions can vary dramatically over short distances due to factors such as location, topography, and microclimatic effects. RCMs have the following applications:

- **Scenario development:** Using RCMs in combination with RCP scenarios allows scientists and policymakers to develop more specific climate scenarios for different regions.
- **Adaptation and Resilience:** Thanks to more accurate regional forecasts, RCMs are useful in planning climate change adaptation measures, defining sustainable development strategies, and disaster risk management, where local factors matter greatly.
- **Energy efficiency:** In the context of architectural and building design, RCMs can provide valuable information in building and facility design and urban planning.
- **Resource management:** Detailed climate forecasts help manage water, agriculture, and other natural resources, allowing regions to prepare and adapt to future conditions.

Regional climate models play a key role in understanding and adapting to climate change at the regional level. They are tools that can turn global scenarios into practical and usable regional strategies and solutions. Therefore, they are indispensable in creating future climate forecasts, for example, for Europe (Fig. 4), necessary for sustainable development planning.

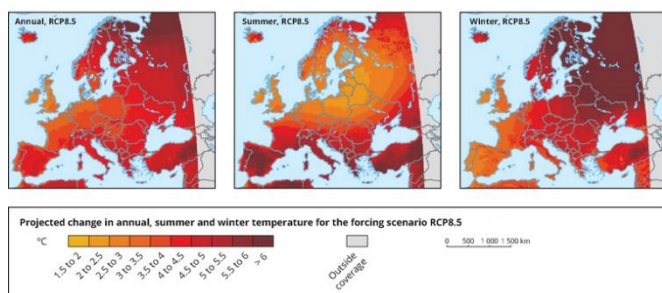


Fig. 4 Increase in mean surface temperatures in Europe for the period 2071-2100 compared to the period 1971-2000 under the RCP 8.5 climate scenario [16]

3.3 Relationship between global and regional climate models.

The methodology by which global climate models are adapted to local conditions is called spatio-temporal scaling (downscaling). It results in regional climate models.

Spatial scaling focuses on increasing the geographic resolution of models. Global climate models usually have a coarse spatial resolution and do not consider local factors, for example, topography, water bodies, cities, etc. Spatial scaling allows the modeling of climate parameters over much smaller geographic areas.

Temporal scaling refers to the precision of the time intervals over which climate forecasts are made. For example, while a global model may provide a forecast of decadal mean temperature, a regional model may provide a forecast of temperature conditions at shorter intervals – daily, hourly, etc.

A comparison can be made between global and regional climate models by various criteria:

- **Resolution:** Global models have a lower spatial resolution and usually cannot provide accurate information about specific regions. Regional models have higher resolution and can provide more accurate data for specific locations.
- **Parameters and Variables:** Global models focus on global variables such as Earth's average surface temperature, concentration of greenhouse gases, etc. Regional models include additional variables specific to a region, such as local winds, topography, etc.
- **Complexity and computational resources:** Global models are generally more complex and require more computational resources. Regional models are simpler but focused and can be run with less computing power.
- **Accuracy and reliability:** Although global models are useful for general trends, they can have errors when modeling regional climate phenomena. Regional models tuned for specific local conditions are often more accurate in this regard.

Understanding these differences and interrelationships between global and regional climate models is key to their effective use in various scientific and practical tasks.

4. Comparison of the static and dynamic approaches to the representative climatic year

4.1 Criticism of using the static approach

The existing methodology for using a static representative climatic year has serious drawbacks:

- **Insufficient predictive accuracy:** Static representative climate years are based on historical data and do not account for the impact of future climate change. This can lead to insufficiently accurate predictions of energy efficiency or other climate-dependent aspects of projects.
- **Lack of adaptability:** This approach does not allow easy adaptation to changing conditions. For example, buildings designed based on old climate data may be inadequately insulated or conditioned for future conditions.
- **Limited spatial resolution:** Static climate years are usually based on old, low-resolution models that cannot capture the microclimate features of specific locations.

4.2 Advantages of a dynamic and adaptive approach.

The dynamic approach has the following advantages:

- **Flexibility and adaptability:** This approach allows for a design that can adapt to future climate conditions, such as temperature changes, solar radiation, humidity, or winds.
- **Spatial and temporal accuracy:** Such models can be much more accurate because they are created by spatiotemporal scaling of climate data. This enables microclimatic analysis and precise design.
- **Resource optimization:** Dynamic models can help optimize energy consumption, material selection, and other aspects of the construction process. This can lead to the creation of more sustainable and energy-efficient buildings.
- **Improved response to extreme events:** An adaptive approach can include extreme weather scenarios, making buildings and infrastructure more resilient to disasters such as floods, droughts, or heat waves.

The use of a dynamic and adaptive approach in design and construction is not only desirable but imperative, especially in the context of a rapidly changing climate. This approach allows designers to make informed decisions based on specific climate conditions at the construction site. This may include material selection, building orientation, energy efficiency, and other aspects critical to the sustainability and functionality of the project.

4.3 Examples of using the new methodologies

Effective urban planning in response to climate risks requires reliable climate forecasts adapted to urbanized areas. Analysis in [17] combines climate modeling and data-driven approaches to offer global multi-model urban climate projections in the 21st century. Under the RCP 8.5 scenario, some cities in the United States, the Middle East, North Central Asia, Northeast China, and interior regions of South America and Africa are expected to experience significant warming of more than 4 °C until the end of the century. The research highlights the critical need for multi-model global projections of urban climate and supports the idea of green infrastructure investment as an effective way to mitigate urban heat stress on a large scale. Green infrastructure (parks, green roofs, and facades) can help alleviate the effects of urban warming, improving the comfort and quality of life of city dwellers in a changing climate.

The plan for adaptation to climatic changes in the Lyulin area in the city of Sofia, based on a digital counterpart of the territory, developed by scientists in the Department of “Cartography and GIS” at the Faculty of Geology and Geography of the University of Sofia is in the same direction. They use two climate scenarios (RCP 4.5 and 8.5) for three future periods (2021-2050, 2046-2075 and

2071-2100). Guidelines for regional climate changes until the end of the 21st century for the Balkan Peninsula and Bulgaria, in particular, can be found in [18].

A study of the impact of climate change on the energy efficiency of existing buildings in Greece until 2100 was done in [19], focusing on non-residential buildings, using data from about 2500 energy audits. RCP 4.5 and 8.5 scenarios were investigated. Future climate data has been generated for 62 cities in Greece, analyzing how these changes will affect the heating and cooling needs of buildings and their energy consumption. Projections show that the average annual temperature in Greece will increase by 1.5 °C under the RCP 4.5 scenario and by 1.9 °C under the RCP 8.5 scenario in 2050 (the Mediterranean Sea moderates the temperature increase because it absorbs some of the heat). In 2090, these increases are expected to reach 1.7 °C and 4.2 °C, respectively. If buildings are not modernized, this will lead to a reduction in energy consumption for heating by 22-26% in 2050 and by 23-52% in 2090. On the other hand, energy consumption for cooling is expected to increase by 24-30% in 2050 and by 28-66% in 2090.

A European study [20] shows that Bulgaria, as a country with a continental climate, will experience a significant increase in cooling degrees until the end of the 21st century, leading to a more substantial growth in energy needs for cooling.

5. Conclusions

Based on the research, the following conclusions can be formulated:

Applying old climate data to the design of buildings and transport infrastructure is inappropriate in the context of current and impending climate change. This creates a risk of incorrectly designed and unsustainable construction sites in the future.

Uncertainty about future climate conditions and the success of global climate change mitigation efforts necessitates a new, adaptive approach to design and construction.

RCP (Representative Concentration Pathway) scenarios and the regional climate models based on them provide an essential toolkit for adapting the design to the assumed climate conditions by 2100.

Spatio-temporal scaling of climate data is a critical factor for properly integrating RCP scenarios in projects, especially in terms of energy efficiency and sustainability.

The disadvantages of using a static representative climate year (as provided for in the Bulgarian regulatory documents) make this approach unsuitable for dealing with the dynamic nature of climate change and does not allow adequate adaptation of design and construction.

It is recommended to review and update the existing Bulgarian regulatory documents for energy efficiency to include dynamic and adaptive climate models and data.

The successful implementation of the new methodologies requires the active participation of all interested parties – from the scientific community to politicians and industry.

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The irrigation regime of tomatoes grown in glass unheated greenhouses using an ecological and water-saving irrigation technique

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Abstract: The research was conducted to determine the irrigation regime of greenhouse tomatoes in 2022 on the MVCRI- Plovdiv experimental field in an unheated steel-glass greenhouse of the Venlo type. The experiment was carried out in three irrigation modes: optimal, reduced, and increased, respectively - 100%, 75%, and 125% using water-saving technology.

The size of the irrigation norms has been determined, i.e., the number of waterings for the growing season and their distribution by phases of development for soil and climatic conditions of the Plovdiv region.

The results obtained for irrigation of the greenhouse tomatoes show that 18 waterings were implemented for the growing season to maintain the soil humidity between 85-100% of the MFMC for the conditions of Plovdiv from the beginning of May to the end of July. The size of irrigation norms by modes varies from 14.9 to 24.7 mm, and irrigation from 268 to 447 mm. The maximum irrigation rates during the most significant water consumption period can be applied in 3-4 days and satisfy the needs of the plants. The obtained results are the basis for determining the design irrigation regime and predicting the culture's irrigation time.

Introduction

A decisive role in the cultivation of vegetable crops, including greenhouse tomatoes, is the correct combination of the individual factors from the agro-technological complex (variety, irrigation, fertilization, heat, light, treatments, etc.), which condition the very technology of growing a given type of vegetable crop under certain soil-meteorological conditions. (Delibaltov, 1972).

Tomatoes are a crop sensitive to the water regime of the soil. (Mitova Iv., Hr. Stoikov, 2008) They have the ability to develop a sizeable above-ground mass that forms many fruits with a high-water content, a relatively weak root system located at a shallow depth, and covering a relatively small volume of soil. There is a close relationship between the amount and distribution of the tomato root system and the layered use of water from the soil (Kireva, 2020). It was established that 58-75% of the 0-20 cm-lay roots cause 50-52% depletion of soil moisture, respectively. Based on the biological characteristics and requirements of the plants, the author believes that it is best to maintain higher soil moisture in the upper soil layers (0 - 20 cm) through frequent watering and low watering rates that reduce fluctuations in soil moisture, i.e., it remains at a relatively constant level. This same layer is the richest in nutrients. (Kireva, 2020).

From the conducted research related to the irrigation of greenhouse tomatoes, irrigation regimes were developed with optimal water supply and water deficit in biological and economic terms for the conditions of the Sofia field (Aboamera M. 1992; Kireva, Aboamera1991; Kireva R.,2020; Kireva R. 2009) and St. Zagora (An. Stoyanova, G. Kostadinov, M. Moteva, 2020; Stoyanova, A., Kuneva, V., Valchev, N. 2019.)

The influence of water deficit on flowering, fruit formation and productivity in different tomato genotypes was studied in MVCRI. It was proven that genotypes with indeterminate growth types are more sensitive to the applied stress, where it was found that more than 60% brushing of flowers leads to an average of more than 65% decrease in productivity (Ganeva et al., 2018, 2019; Grozeva et al., 2018; Pevcharova et al., 2018, 2019).

Greenhouse tomato cultivation relies solely on an irrigation system to supply the necessary irrigation water. For this reason, questions related to its practical use are essential. A preferred water-saving method is drip irrigation, which allows water to be delivered directly to the root system and irrigated at lower irrigation rates. This method fully meets sustainable agriculture and ecological fruit production requirements, including ensuring high yields and product quality and reducing unwanted side effects. (Bucks et al., 1982).

The study aims to establish the irrigation regime of greenhouse tomatoes, with drip irrigation for the soil and climatic conditions of the Plovdiv region.

Materials and methods

Experimental studies were carried out in an unheated steel-glass greenhouse of the Venlo type at the experimental field of MVCRI - Plovdiv under conditions of early production to establish the irrigation regime of greenhouse tomatoes in 2022. The sowing of the seeds took place in the middle of January, and the picking at the end of February. The mulch film was laid on the beds before planting the plants in the greenhouse permanently. In the second ten days of April, when the temperature of the soil in the greenhouse at a depth of 10 cm rose permanently above 10°C, the tomato plants were planted in the budding phase at a density of 3.5 plants/m².

The experience was carried out with three irrigation modes - optimal, reduced, and increased accordingly - 100%, 75%, and 125% of PPV using water-saving irrigation technologies. The optimal irrigation rate (100% of PPV) was calculated according to the formula:

$$m = [10H.\alpha.(MFMC - \delta)].K,$$

where m is the irrigation rate, mm;

α – the bulk density of the soil, gr/cm³;

H – the depth of the active soil layer, m;

MFMC – the marginal field moisture content in % relative to the absolute dry weight of the soil;

δ – the pre-irrigation soil moisture in % relative to the absolute dry weight of the soil;

K – the coefficient of reduction of the irrigation rate, taking into account the area occupied by the plants in 1 dka, in the experiment K = 0.66%, i.e., 66% of the site is irrigated.

Watering is carried out when the moisture in the soil drops to 85% of the PPV. From the obtained results of the soil moisture, the size of the irrigation rates was determined. Soil samples were taken in the variant with a 100% irrigation rate of 0.0–0.40 m through 0.10 m to follow the soil moisture dynamics, which were processed by the weight-thermostat method. The limit values of the individual elements of the tomato irrigation regime were established experimentally.

With drip irrigation, the amount of the entire irrigation rate is not given, as with other watering methods. A reduction is required at the expense of the non-irrigated area. For this purpose, the formula of (Frecman B., Carzoli. 1980) was used, considering the planting scheme. After calculating the irrigation rate for the option with mode irrigation of 100%, the rates of the other modes were determined based on their size.

Results

The climatic conditions of each region are essential for the normal vegetative development of plants and for obtaining high yields with excellent product quality. They are also a determining factor for drawing up and applying an irrigation regime. In this regard, a climatic characteristic of the growing season 2022 has been developed for the region of Plovdiv in terms of average day-

night air temperature ($^{\circ}\text{C}$) and the amount of precipitation for the period May - September - precipitation (mm).

For this purpose, a 65-member statistical series covering 1957 – 2022 was compiled. A theoretical collateral curve was calculated by averaging the empirical points (Fig. 2) with the following parameters: $T_{cp} = 3183.0^{\circ}\text{C}$, $C_v = 0.0425$ and $C_s = 0.0955$. The trial year is warm with a margin of 10.0% and a May-September temperature sum of 3366.0°

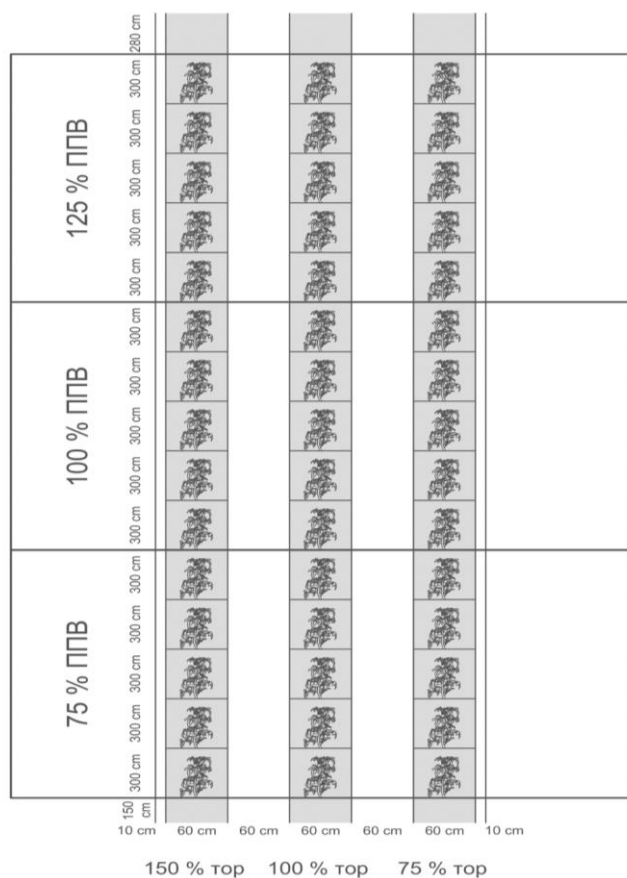


Figure 1. Scheme of the experiment

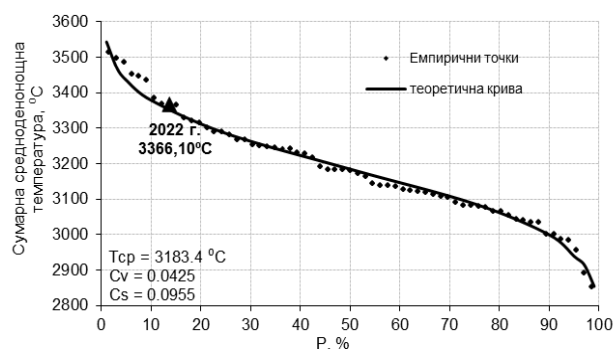


Figure 2. Guarantee of the average day and night air temperature for V - IX 2022

The Plovdiv region was characterized in terms of the amount of precipitation for May - September. For this purpose, a 65-member statistical series was compiled for the period 1957-2022, based on which the theoretical collateral expressed as a curve was calculated and the empirical collateral of all data (Fig. 3). The theoretical curve averages the empirical points at N average = 242.7 mm, $C_v = 0.399$, and $C_s = 0.672$. The experimental year is characterized as average with collateral $P = 64.0\%$ and an amount of precipitation of 232 mm

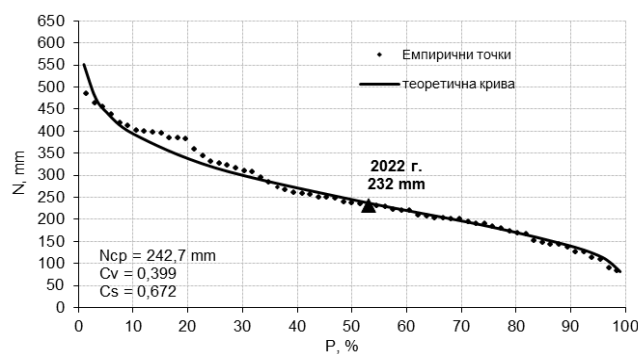


Figure 3. Rainfall guarantee for V – IX 2022

The results of the realized irrigations for greenhouse tomatoes show that to maintain the soil humidity in the range of 85-90% of PPV when growing tomatoes in glass unheated greenhouses, 18 irrigations with an average irrigation rate of 19.5 mm are needed, which are realized through different interval depending on plant development, the stress of meteorological factors and irrigation rate 357 mm. (Table 1). The conditions of Plovdiv were realized for the period from the beginning of May to the end of July (table 2).

According to modes, the dimensions of the irrigation norms vary from 14.9 to 24.7 mm, and the irrigation norms vary from 268 to 447 mm. The maximum irrigation rates during the most significant water consumption period can be applied in 3-4 days and satisfy the needs of the plants. At 1.5 atmospheres of pressure, they are realized in 2-3 hours.

The irrigation period for the active vegetation of greenhouse tomatoes grown under greenhouse conditions for the Plovdiv region covers the time from the first ten days of May and continues until the end of the fruiting period - the first ten days of August (Table 2).

It is recommended to apply frequent irrigations with low irrigation rates, which reduce fluctuations in soil moisture proceeding from the biological characteristics and requirements of tomatoes for soil moisture, i.e., it remains relatively constant. This ensures a uniform plant water supply, which is also achieved using drip irrigation technology.

Table 1. A number of waterings and irrigation rates of greenhouse tomatoes on experimental field MVCRI - Plovdiv for the growing season of research 2022.

Modes	Number of waterings	Irrigation rate (mm)	Irrigation norms (mm)
125%M	18	24.7	446
100%M	18	19.8	357
75%M	18	14.9	268

Table 2. Distribution of waterings according to stages of development of tomatoes grown under greenhouse conditions on an experimental field of the MVCRI - Plovdiv

Phases of development	Number of waterings	Irrigation period
Sowing	-	3rd ten days of January
Pricking	-	2nd ten days of March
Planting	Catch irrigation	1st ten days of April
Increased growth	1-2	1st ten days of May
Beginning of flowering, Full flowering	3-4	2nd ten days of May 3rd ten days of May
Ripening and harvesting of the fruit. Fruiting	4-5	1st week of June 3rd week of June
Active fruiting Harvesting	7-8	1st ten days July August

Conclusion (Achieved Results)

The research carried out is of essential importance because, for the first time, the irrigation regime of greenhouse tomatoes was investigated for the region of the city of Plovdiv, where greenhouse production is the most widespread due to the favorable weather conditions for growing the crop;

- The amount of irrigation and irrigation norms, number of irrigations for the growing season of greenhouse tomatoes for the soil and climatic conditions of the city of Plovdiv has been determined;

- The distribution of waterings according to the stages of development of tomatoes grown under greenhouse conditions at the experimental field of the Maritsa Agricultural Research Center, Plovdiv was determined;

- A climatic characteristic has been developed for the region of the city of Plovdiv in terms of air temperature and the amount of precipitation for the period May - September 2022;

The obtained results are the basis for determining the design irrigation regime and predicting the time for irrigation of the culture.

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