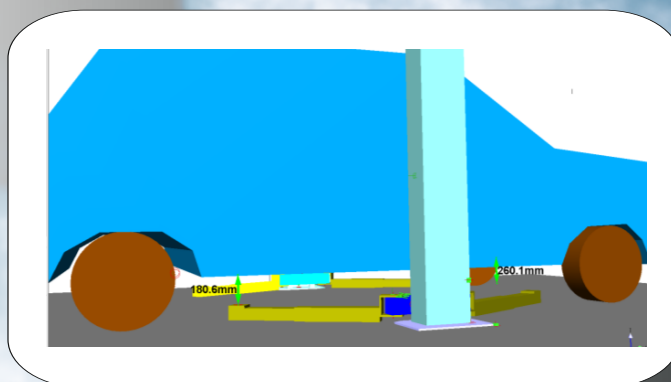


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Design of an Industry 4.0-Based, Vertically Angular Automated Line Separator

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Abstract: In this study, an original design was developed to address the issue of insufficient packaging speed, a key challenge in wet wipe production lines. A separator/distributor was developed that enables a single wet wipe machine to work with three packaging units during the transfer of products from the wet wipe preparation unit to the packaging process. The developed separator moves angularly on the vertical axis and can transfer products to conveyor groups leading to three different packaging lines. Additionally, a unique movable upper conveyor was designed to operate across a range of product heights, which applies pressure to the products during movement to prevent them from scattering. One of the primary design criteria for the conveyor is lightweight construction, and this was a key focus during development. To achieve angular motion, a servo-driven flywheel mechanism was designed. The machine is equipped with sensors for Industry 4.0 compatibility, ensuring communication between units. In case one of the packaging machines becomes inactive, the separator automatically redirects the product feeding process to the remaining packaging machines, ensuring uninterrupted production.

Keywords: WET WIPE, PACKAGING, INDUSTRY 4.0

1. Introduction

In the modern industrial environment, optimizing production lines for efficiency and speed is crucial. Wet wipe production, in particular, faces the challenge of balancing product quality with high-speed packaging processes. A key issue in wet wipe production is the limitation in packaging speed, which can lead to bottlenecks and inefficiencies.

Industry 4.0 has revolutionized manufacturing by introducing smart technologies, including the Internet of Things (IoT), sensors, and automated systems, which enable enhanced communication and coordination between machines. This paper presents an innovative solution to increase packaging efficiency in wet wipe production by designing a vertically angular automated line separator that integrates Industry 4.0 technologies.

2. Literature Review

The literature on manufacturing automation, particularly in production line optimization, emphasizes the need for efficient systems that enhance productivity and flexibility. Recent advancements have allowed for the development of automated separators and conveyors that help address the challenges posed by high-speed packaging, especially in the context of multi-line production environments where efficiency is paramount. This review focuses on automation in manufacturing, the role of vertically angular systems, Industry 4.0 integration, and recent packaging innovations, with the aim of establishing a basis for the proposed design of an Industry 4.0-compatible, vertically angular automated line separator.

2.1. Automation in Manufacturing and Packaging Lines

Manufacturing automation, a cornerstone of industrial development, has undergone several transformations, with each phase introducing technologies that reduce human intervention, streamline production, and decrease operational costs. Initially, automation focused on simple mechanized tasks, but advancements in robotics and control systems have enabled more complex operations, including real-time adjustments and multi-directional product flow. Flexible conveyor and distribution systems have become essential in modern manufacturing environments, allowing lines to adapt dynamically to changing production demands [1, 2].

Flexible conveyor systems have been identified as a solution to minimize downtime and optimize product flow. Studies reveal that traditional conveyor systems, while effective, often struggle in high-speed production environments, particularly when dealing with products of variable shapes and sizes. By integrating modular and adaptive conveyors, manufacturers can meet these demands while reducing production costs. Research on the use of robotic arms and other mechanical actuators shows that automation systems with

precise control and flexibility can effectively handle variable product dimensions, achieving reliable, repeatable separation and distribution in packaging lines. These findings support the development of systems capable of transferring products to multiple packaging units, addressing a common need in high-output industries such as consumer goods and pharmaceuticals.

2.2. Vertically Angular Systems in Manufacturing

The implementation of vertically angular motion within conveyor systems presents a significant opportunity for optimizing space usage and enhancing flexibility in product handling. Traditional conveyor setups, typically limited to horizontal movement, can occupy large areas of the factory floor and restrict the ability of a production line to handle varying product heights. By enabling angular movement along the vertical axis, manufacturers can design systems that utilize available space more effectively, particularly in facilities where space constraints are a concern.

The design of vertically angular conveyors, especially in compact environments, has been shown to reduce operational complexity and improve the flow of products through multi-line processing systems. This approach not only conserves space but also allows for more efficient utilization of resources by aligning product flow with specific line requirements, such as directing items to different packaging stations based on real-time line status. Although the vertical movement is well-documented in material handling applications, studies reveal a lack of comprehensive exploration into systems that combine vertical and angular motion, especially with industry-specific applications. This study aims to bridge this gap by integrating a servo-driven flywheel mechanism for controlled angular movement, which ensures precise product positioning and transfer across multiple lines.

2.3. Industry 4.0 Integration and Smart Manufacturing Systems

Industry 4.0 represents a paradigm shift in manufacturing, bringing smart technologies and digitalization to traditional processes. By incorporating IoT, machine learning, and real-time data analytics, Industry 4.0 enables the creation of intelligent production environments where machines communicate autonomously, adjusting operations based on sensor inputs. This real-time communication and adaptability are particularly valuable in automated packaging systems, as they enable production lines to respond instantly to fluctuations in demand or disruptions within individual units [3].

The integration of IoT technologies allows for continuous monitoring of machinery, which is essential in high-speed production environments where equipment failure can result in significant downtime. The use of real-time data not only facilitates predictive maintenance but also enables optimization algorithms to adjust production rates, manage inventory flow, and maintain

product quality. For example, real-time tracking of product movement and adaptive control can ensure seamless transitions between different sections of the production line, reducing product loss and minimizing human intervention [4].

Smart manufacturing technologies also enable efficient coordination across interconnected units, which is crucial for multi-line systems that must operate in unison to achieve optimal throughput. Predictive maintenance models powered by machine learning provide a framework for forecasting equipment failures, allowing operators to address issues before they result in production stoppages. By implementing these smart technologies, the proposed separator design aims to maintain uninterrupted product flow even if one of the packaging lines goes offline, maximizing productivity and minimizing waste.

2.4. Innovations in Packaging Systems

Packaging is a critical phase in production, particularly in high-speed environments where products must be handled with precision to prevent damage or misalignment. Modern packaging systems incorporate modular and flexible designs that allow manufacturers to adapt to changing product requirements quickly. Studies indicate that modularity in packaging equipment offers significant advantages in terms of scalability and customization, as operators can reconfigure lines to handle products of different sizes, shapes, or packaging formats without extensive retooling [5].

Automated distributors and separators designed to work in tandem with packaging machines have proven effective in enhancing line efficiency. By directing products to multiple packaging stations, these systems reduce the likelihood of bottlenecks and improve overall throughput. For industries requiring high-speed packaging, automated separators that facilitate smooth transitions between preparation and packaging stages are essential for maintaining product integrity and consistency.

Modular design is another area of focus, allowing packaging systems to adjust quickly to new product demands. Research into modular packaging line architecture has shown that reconfigurable systems can meet varying production needs with minimal downtime, which is especially valuable in fast-paced industries like consumer goods. The proposed design incorporates a movable upper conveyor to accommodate products of different heights, preventing product scattering and ensuring secure transfer to the packaging units. The lightweight construction of the conveyor also supports rapid, angular movement, providing a compact and ergonomic solution to meet production demands [6].

2.5. Gaps in Current Research

Despite significant advancements in automation and Industry 4.0 technologies, there is still limited research on integrating vertically angular motion with Industry 4.0-enabled packaging systems. Most studies focus on horizontal automation systems or isolated technology implementations, without considering integrated solutions that combine angular motion and smart manufacturing capabilities. This study addresses this gap by developing a vertically angular separator that leverages smart manufacturing systems for seamless communication, real-time monitoring, and automated adjustments [7].

The proposed design aims to create an efficient, adaptable separator capable of directing products to multiple lines based on real-time operational conditions. By combining vertically angular motion with IoT-enabled monitoring, the system promises to increase productivity and flexibility in packaging lines, meeting the evolving demands of high-output industries. This novel approach to automation, which prioritizes space efficiency, real-time adaptability, and minimized downtime, represents a new direction for research in automated packaging technology.

3. Design and Methodology

The goal of this study was to address the demand for an efficient product transfer system in wet wipe production lines, where products need to be transferred from a single production machine to three separate packaging machines. The challenge lies in meeting a high throughput requirement—up to 300 packages per minute—while ensuring each packaging machine can handle a maximum of 100 packages per minute. To meet these demands, a vertical angular automated separator was designed, with a focus on ease of adjustment, maintenance, ergonomics, space efficiency, and the ability to perform product transfer via angular motion on the vertical axis.

3.1. Separator Unit Design

The separator unit was designed to move angularly on the vertical axis, allowing it to transfer products to conveyor groups leading to three different packaging lines. The angular motion is crucial as it enables the system to handle multiple packaging lines without requiring excessive floor space, thereby improving the overall factory layout. This design also makes it adaptable to varying production needs, especially in high-speed environments where flexibility is essential [8].

The key innovation of this design is the incorporation of a movable upper conveyor that can function across a wide range of product heights. This feature allows the separator to handle products of varying dimensions without disrupting the product flow. The upper conveyor plays an essential role in ensuring that the products are maintained in a stable position during the transfer process. By applying light pressure as the product moves across the conveyor, the risk of scattering is minimized, ensuring smooth and efficient transfer to the packaging machines.

3.2. Lightweight Conveyor Design and Servo-Driven Flywheel Mechanism

The design of the conveyor system is centered on minimizing weight without compromising performance. The lighter construction of the conveyor enables faster movement, reducing wear and tear, and ensuring the longevity of the system. Additionally, this lightweight design facilitates easier adjustments and maintenance, providing the operator with a more ergonomic system for day-to-day operations.

To achieve the angular motion of the separator, a servo-driven flywheel mechanism was developed. This mechanism is designed to allow for precise angular movement while maintaining stability and reliability at high speeds. The servo drive ensures that the separator can adjust its angle quickly and efficiently, making it adaptable to various packaging line configurations. This system is crucial for achieving the required speed of 300 packages per minute while also handling the product transfer to multiple packaging lines.

3.3. Industry 4.0 Integration and System Automation

The separator unit is equipped with sensors and communication interfaces that integrate with the overall production line, ensuring compatibility with Industry 4.0 standards. This allows for real-time data exchange between the separator and the packaging machines, optimizing the efficiency of the system.

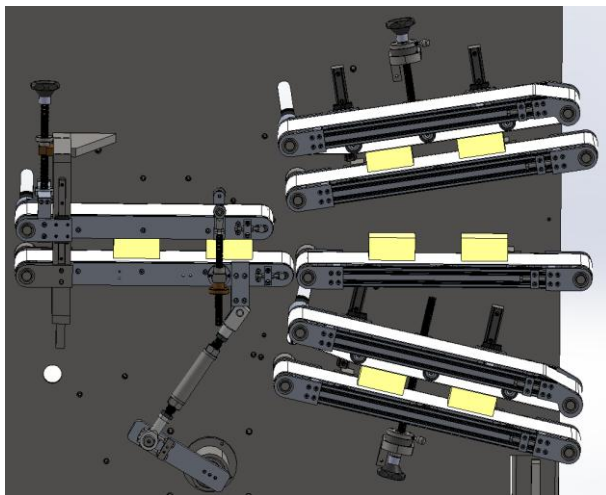
One of the key features of the design is its ability to maintain uninterrupted production. In the event that one of the packaging machines becomes inactive due to maintenance or malfunction, the separator automatically redirects the product flow to the remaining active packaging lines. This automatic redirection ensures continuous production without the need for manual intervention, thus reducing downtime and enhancing the overall efficiency of the manufacturing process.

3.4. Ergonomics and Maintenance Considerations

In addition to the technical functionality, the design emphasizes ergonomics and ease of maintenance. The system was built with user-friendly interfaces for quick adjustments and straightforward maintenance procedures. The lightweight design of the conveyors, along with their modular construction, allows for easy access to parts that require routine maintenance, reducing downtime and labor costs. The compact nature of the system also ensures that it occupies minimal space, making it ideal for factories with limited floor space.

The vertical angular movement of the separator further enhances the system's ergonomics, as it minimizes the need for large horizontal conveyors that could otherwise require more space and labor for adjustments. The angular motion system is easy to configure, and operators can quickly adapt it to meet different production requirements, making it highly versatile for various product types and packaging configurations.

The designed separator is shown in Figure 1a and the manufactured separator is shown in Figure 1b. In figure 2a the detail of design and figure 2b. detail of the manufactured separator is shown in front view. Rear view is shown Figure 3a and fig 3b.

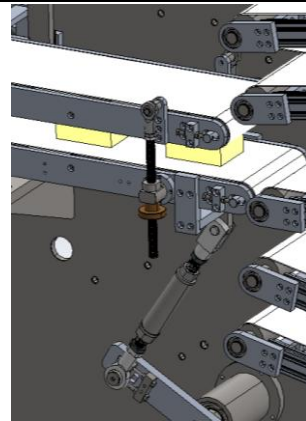


1a.



1b.

Figure 1a the designed and Figure 1b. the manufactured separator in front view

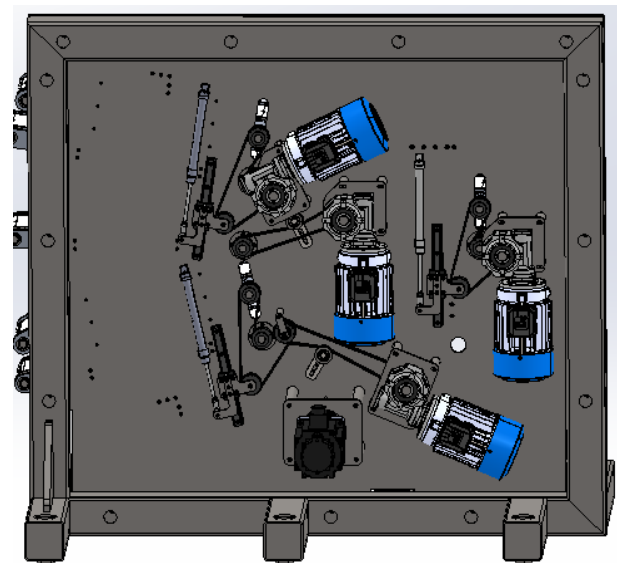


2a.



2b.

Figure 2a the detail of design and Figure 2b. detail of the manufactured separator in front view



3a.



3b.

Figure 3a-b. Rear view of designed and manufactured separator

4. Results and Discussion

The vertical angular separator was tested in a real-world wet wipe production environment to evaluate its performance in handling high-speed product transfer to multiple packaging lines. The results confirmed the separator's ability to efficiently direct products from a single production line to three separate packaging lines, each capable of handling up to 100 packages per minute. This setup allowed for a sustained throughput of 300 packages per minute, meeting the target production speed and ensuring a balanced distribution of products across the three lines.

The servo-driven flywheel mechanism proved crucial for achieving precise control over the separator's angular motion. This mechanism allowed the separator to quickly adjust to shifts in production flow and align with each of the packaging lines without delays. The lightweight conveyor design contributed to the system's ability to operate smoothly at high speeds, effectively reducing mechanical stress and wear over prolonged periods of use. By minimizing the stress on mechanical components, the design also helped extend the lifespan of the separator and reduced maintenance needs.

Integration of Industry 4.0 features was particularly advantageous. Through real-time monitoring and feedback from embedded sensors, the separator could automatically reroute product flow if one of the packaging machines went offline. This function minimized potential downtime, maintaining continuous production—a critical feature in high-output manufacturing lines where any stoppage can result in significant productivity losses.

Furthermore, a patent application has been filed for the developed system, reflecting its innovative contributions to automated packaging line technology and the novel approach to integrating vertical angular motion with Industry 4.0 capabilities. This patent application not only highlights the uniqueness of the separator's design but also establishes a basis for future developments and potential commercialization in automated production and packaging systems.

5. Conclusion

This study presents a novel design for a vertically angular automated line separator that addresses the challenges of transferring products between multiple packaging machines in a high-speed wet wipe production line. The design successfully integrates Industry 4.0 technologies to ensure seamless communication between production units and minimize downtime. With its lightweight construction, ergonomic design, and adaptability to varying product heights, the separator system provides a highly efficient and flexible solution for modern manufacturing challenges.

Further research could explore the integration of additional smart technologies, such as AI-based predictive maintenance and advanced data analytics, to further enhance system performance and efficiency.

6. Acknowledgments

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7. References

1. S. Tripathi, S. Shukla, S. Attrey, A. Agrawal, V. S. Bhadoria, "Smart Industrial Packaging and Sorting System," in: P. K. Kapur, O. Singh, S. K. Khatri, A. K. Verma (eds.), *Strategic System Assurance and Business Analytics. Asset Analytics*, Springer, Singapore, (2020). https://doi.org/10.1007/978-981-15-3647-2_18
2. M. Huang, J. Wu, Y. Tang, L. Shi, "Optimal Design of a Conveyor-Based Automatic Sorting System," 2020 IEEE 16th International Conference on Control & Automation (ICCA), Singapore, (2020), pp. 1124–1129. doi: 10.1109/ICCA51439.2020.9264520
3. J. H. Lau, "Recent Advances and Trends in Advanced Packaging," IEEE Transactions on Components, Packaging and Manufacturing Technology, vol. 12, no. 2, pp. 228–252, Feb. (2022). doi: 10.1109/TCPMT.2022.3144461
4. C. Liu, J. Fang, P. Yu, "Automatic Packaging System Based on Machine Vision," in: F. Sun, A. Cangelosi, J. Zhang, Y. Yu, H. Liu, B. Fang (eds.), *Cognitive Systems and Information Processing. ICCSIP 2022, Communications in Computer and Information Science*, vol 1787, Springer, Singapore, (2023), https://doi.org/10.1007/978-981-99-0617-8_16
5. L. Bhanwrela, J. Managre, N. Purohit, N. Gupta, "To Integrate and Optimize the Use of Programmable Logic Controller in Development of Horizontal Flow Wrap Packaging Machinery for Industry Needs," Electrical and Electronics Engineering, ATC-Factory Automation Lab-MEI, Shri Vaishnav Institute of Technology and Science, Shri Vaishnav Vidyapeeth Vishwavidyalaya, Indore, India (2024).
6. S. Haque et al., "Automatic Product Sorting and Packaging System," 2023 15th International Conference on Intelligent Human-Machine Systems and Cybernetics (IHMSC), Hangzhou, China, (2023), pp. 163–167. doi: 10.1109/IHMSC58761.2023.00046
7. L. Xiao, B. Qu, E. Shi, "Design of Automatic Packing System in Workshop Based on Programmable Logic Controller (PLC)," 2021 4th International Conference on Information Systems and Computer Aided Education (ICISCAE), (2021), pp. 2268–2272. <https://doi.org/10.1145/3482632.3484142>
8. F. Jordan, P. Schleuniger, "Detection and Synchronisation of Moving Packaging Units on a Conveyor Belt Using a Synchronised Portal," University of Applied Sciences and Arts Northwestern Switzerland (FHNW), Windisch, Switzerland (2021).

Dynamic analysis of vehicles hydraulic lift for the case of load handling

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Abstract: The paper examines the dynamic analysis of a hydraulic lift that is used for lifting and lowering vehicles. These lifts are implemented in various servicing facilities for the repair of vehicles. The lifts consist of various mechanical and hydraulic parts and besides lifting and lowering the vehicle, they need to keep the vehicle lifted for a certain amount of time. During the work operations, the lift's main parts are heavily loaded. The method of analysis consists of 3D modeling of the Hydraulic lift and carrying simulations with software. This enables to analyze the dynamics of motion, identify the forces and stresses in lift parts and the form and intensity of oscillations that can cause failures of parts and concerns about the safety. Conclusions from this paper will be useful regarding the loading dynamics on the Hydraulic Lift during lifting and lowering, and design considerations. Results will be shown in graphical form, in time dependence. The Hydraulic Lift is modeled based on the Data from the standard manufacturer. The software that will be used for modelling and analysis is SimWise 4D.

KEYWORDS: VEHICLES LIFT, LOAD LIFTING, LOAD LOWERING, OSCILLATIONS, MODELING, SIMULATIONS

1. Introduction

The type of the Hydraulic Lift taken for the study is shown in Fig.1. The study example is from a local vehicles repair workshop in Prishtina City. It is a lift mounted on the concrete ground. Main work activities of the Lift are lifting and lowering of the load, which is a vehicle or a small truck, and holding the vehicle steady in a certain height. The height H is usually around 1.8 – 2 m. The time of holding the lifted vehicle steady can vary, depending on the length of the check and repair process, and can take hours. This puts a lot of stress in the parts and mechanisms of the lift. They are devices that have a large number of elements. They have a certain lifting velocity to lift the load.



Fig.1. Hydraulic Lift for vehicles in the working environment

The type of lift is EE-6253/6254 from the Manufacturer EAE Group Companies. It is a Floor Plate, Two Post Lift with the Lifting Capacity 4000 kg. [1]. It's a type of electro-hydraulic lift. It's main technical features are shown in Tab.1.

The main parts of the lift are shown in Fig.2.

Table.1. Technical features of the Hydraulic Lift [1]

Crane Features	Value
Model	EE-6254
Capacity	4000 kg
Lifting time	50 s
Lifting height	1900 mm
Height of the lift	2827 mm
Width of the lift	3420 mm
Width between posts	2830 mm
Electromotor Power	2.2 kW

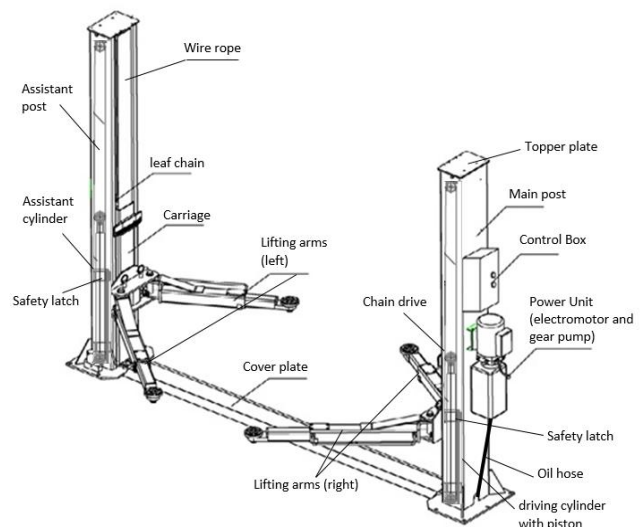


Fig.2. Hydraulic Lift main parts – Drawing view [1]

An electro- hydraulic system is used to lift the load. The working process is as follows: The hydraulic oil is delivered by the gear pump to the oil cylinders, which pushes upwards its piston. Then, the piston drives the chain to move upwards the carriage and the lifting arms (Fig.3). There is a safety latch in both posts that will automatically block with the safety teeth block in the posts in order to prevent sudden dropping-down of the load in case the hydraulic system beaks down [2].



Fig.3. Foto of the of the Main Post, Chain drive and Carriage on the Hydraulic Lift

Results of the research will be acquired for some main parts of the Lift. Forces, force moments and stress during lifting are considered main influential parameters for measuring strength and strain in the lift's parts [4], [6], [8]. To study this, analysis will be

carried for two cases of motion: lifting and lowering of the load, with capacity $Q = 4000$ kg, which is maximal loading for this lift.

Lifting velocity will be $v_{lift} = 10$ m/min and lowering velocity will be the same $v_{lower} = 10$ m/min. Results will be presented with graphs and then discussed.

Regarding the Literature review, Authors have studied Hydraulic Lifts for vehicles, shown in the References, with studies about dynamic analysis [5], [9], [10], [11], simulations [5], [12], design [4], [7], [8], investigation [6], motion control and regulation [11], [13], and Lift safety [12], [14].

2. Modeling of the Hydraulic Lift for vehicles and simulations

Modell of the Hydraulic Lift for vehicles is created with software SimWise 4D [3]. After the modelling, simulations will be carried out to get results. Analysis with simulations will be acquired using two numerical Methods, namely Finite Elements Method (FEM) and Numerical Kutta-Merson Method, which are part of the software features. Working load Q is a simplified model of the vehicle with dimensions: $Length = 2$ m, $Width = 1$ m, $Height = 1.4$ m, $Mass Q = 4000$ kg. The vehicle model is placed on the Lift arms, not constrained, ready to be lifted. (Fig.4).

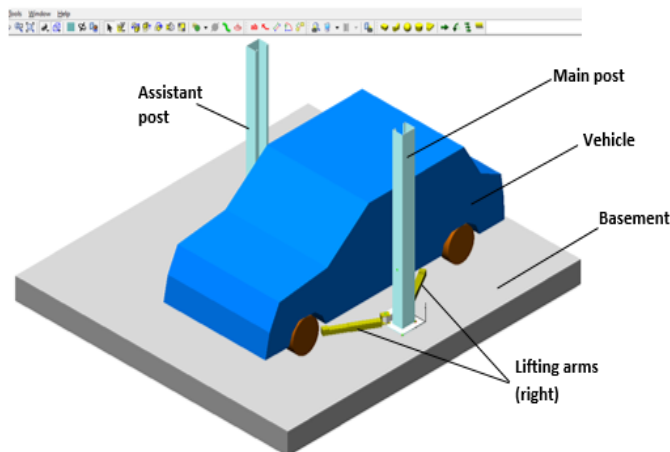


Fig. 4. Model of the Hydraulic Lift for vehicles with main parts in the software environment [3]

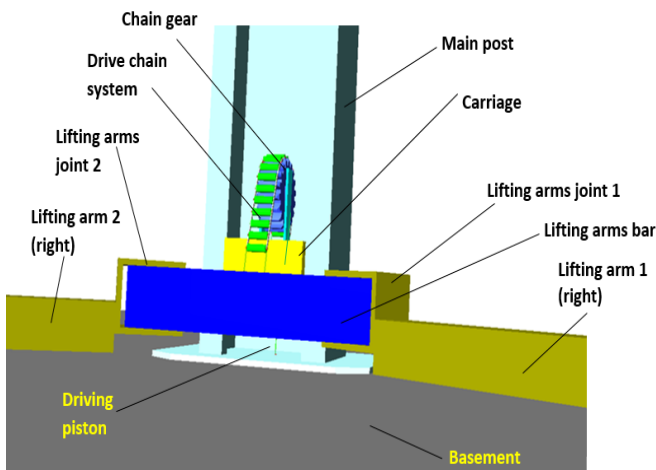


Fig. 5. Parts of the lift's drive system

For the proper analysis of the vehicle motion, simulations will be organized as close as to real occasions [11]. The piston, which is the main lifting drive is created in the model, together with the drive chain (Fig.5 & Fig.6).

The velocity of the piston for the vertical lifting is $v_l = 1900$ mm/ 50 s = 38 mm/s.

Where: $L_l = 1900$ mm – Lifting height

$t_l = 50$ s – Lifting time (Table 1).

For the analysis purposes, the right side of the lift, on the Main post is taken for the study (Fig.1). Piston will start lifting the carriage, chain and arms from time $t = 0$ s, until it contacts the vehicle chassis, which is initially at the distance of $D_1 = 180.6$ mm from the lifting arm (Fig.6 & Fig.7). The contact between lifting arms and vehicle chassis will be at time $t_{co} \approx 4.7$ s. After this time, the vehicle will be lifted. Initial distance between the basement and vehicle chassis is $D_2 = 260.1$ mm (Fig.7).

The vehicle will be lifted until the simulation time $t_{sim1} = 20$ s. After this time, the lifting will be halted, to monitor the occurrences on the vehicle [11]. During this time, the vehicle will be lifted for $D_3 = 836.2$ mm. The entire simulation will last $t_{sim2} = 21$ s.

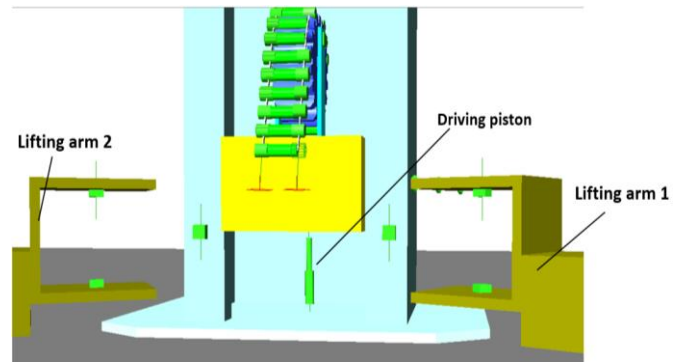


Fig. 6. Closer view of the driving piston

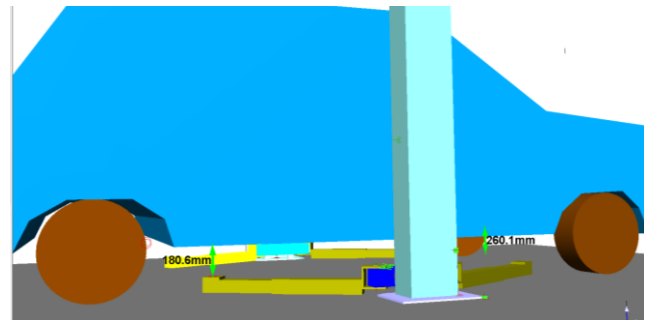


Fig. 7. Initial distance between the Lifting arms and vehicle $D_1 = 180.6$ mm, and the Basement and vehicle $D_2 = 260.1$ mm

3. Results of the vehicle lifting

Results of the analysis will be presented in the form of graphs for main dynamic parameters for some main parts of lift: Tensile Force in the chain, Forces in the pistons, stress in the lifting arms.

3.1. Tensile Force on the Drive chain

The Tensile Force acts on the Drive chain during lifting. The drive chain rolls on the chain gear (Fig.5). In one side is connected with the lifting arms bar and in other side with carriage. It lifts the arms with the load (vehicle). The usage of the drive chain is to speed up the lifting, in the proportion 2:1. On the bottom side, it is connected with the carriage, which is lifted with the piston. It is heavily loaded part. The nature of the lifting force is axial force – tension.

Results of the force in chains are in the graph in Fig.8 for the chain drive system in the Main Post. The graph of the tensile force for left drive chain is similar, and due to limitations in this paper, it will not be shown.

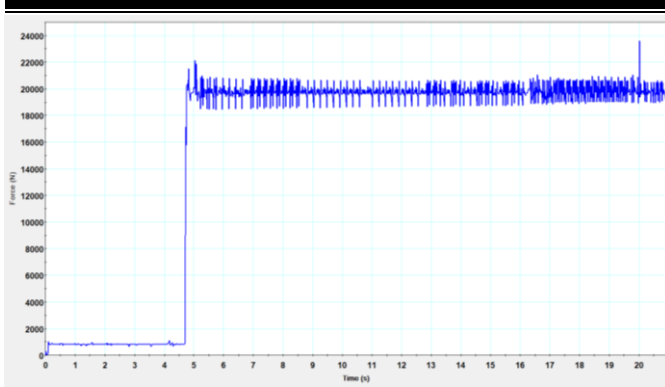


Fig. 8. Tensile force on the Drive chain in the Main Post

In the Fig.8 is given the graph of the Tensile Force on the Drive chain on the Main post F_{tch} . The curvature of the Force starts with low intensity, $F_{tch} \approx 1400 \text{ N}$ until time $t = 4.7 \text{ s}$. This is the initial process of lifting of arms without the vehicle weight. After this time, the intensity of the force jumps instantaneously at the value $F_{tch} \approx 20000 \text{ N}$, which means that the vehicle has started to be lifted. The intensity of the force does not change significantly but the nature of the curvature shows swinging and oscillations in entire process. Medium value of the force is $F_{tch} \approx 20000 \text{ N}$. Highest values of the Tension force is at the lifting start and at the lifting stop ($t = 20 \text{ s}$). Maximum value of the force is $F_{tchmax} \approx 23610 \text{ N}$, achieved after lifting stoppage at time $t = 20.05 \text{ s}$. It is caused by the short inertial motion of the vehicle after stoppage.

Important parameter for the analysis is *Peak-to-peak amplitude* λ . It is the difference between the minimal and maximal values of tension force and represents the intensity of oscillations. For the case of vehicle lifting, in time interval $4.7 \text{ s} < t < 20 \text{ s}$ the medium peak-to-peak amplitude is $\lambda_{tch} = 21000 - 18500 = 2500 \text{ N}$. Maximal value is at the time after lifting stoppage $t = 20.05$ with the value $\lambda_{tch} = 23610 - 18890 = 4720 \text{ N}$. The frequency of the oscillations during the lifting is $\nu \approx 25 \text{ Hz}$ [11].

Conclusion is that Drive chains and lifting arms are heavy loaded and with swinging and oscillations. Amplitudes are not high, but frequencies of oscillations are intense.

3.2. Force on the Pistons

In the Fig.9 is the graph of the Pressure Force F_{pp} on the piston in the Main Post. For the piston on the left side graph of the force is similar. Piston is heavy loaded part that lifts the vehicle. The force has negative values, opposite to the lifting, while it is pressure force.

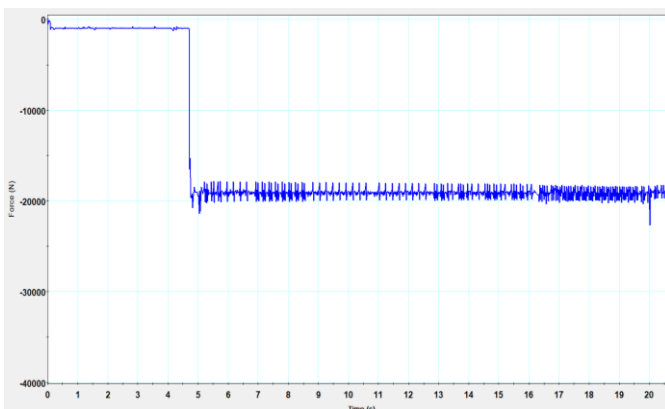


Fig. 9. Force on the piston in the Main Post

Based on the graph Fig.9, until the time $t = 4.7 \text{ s}$, the piston force is small $F_{pp} = -973 \text{ N}$. This is the initial lifting process when the piston lifts the arms and other parts of the Main Post but not the vehicle. After this time, the vehicle starts to be lifted, and the pressure force jumps to higher values $F_{pp} \approx -19200 \text{ N}$. Until the end

of the simulation, the nature of the Piston Force curvature shows swinging and oscillations in entire vehicle lifting. Short after the lifting stop, $t \approx 20.05 \text{ s}$, the pressure force reaches its maximal value $F_{ppmax} \approx -22700 \text{ N}$. Conclusion is that pistons are heavy loaded and with swinging and oscillations that results in intense amplitudes and high frequencies. *Peak-to-peak amplitude* of the pressure force in the lifting time interval $4.7 \text{ s} < t < 20 \text{ s}$, is $\lambda_{pp} = |-20200| - |-17865| = 2335 \text{ N}$. This is lower than the amplitude for the Drive Chain.

3.3. Stress on the lifting arms

Lifting arms are the parts that carries the loading (the vehicle). There are four lifting arms. We will present graphically the stress (Von Misses) on one lifting arm, on the Main Post (Fig.10). The form of the curvature of the stress is similar in form, oscillations and frequencies with the one on Drive Chain in Fig.8. Medium value of stress is $\sigma_{med} = 3.3 \cdot 10^8 \text{ Pa}$. Maximum value of the stress can reach $\sigma_{max} = 4.4 \cdot 10^8 \text{ Pa}$ occasionally due to the oscillations. The value does not exceed the material durability of the lifting arms which is $\sigma_{mat} = 4.48 \cdot 10^8 \text{ Pa}$, although the maximal values comes close.

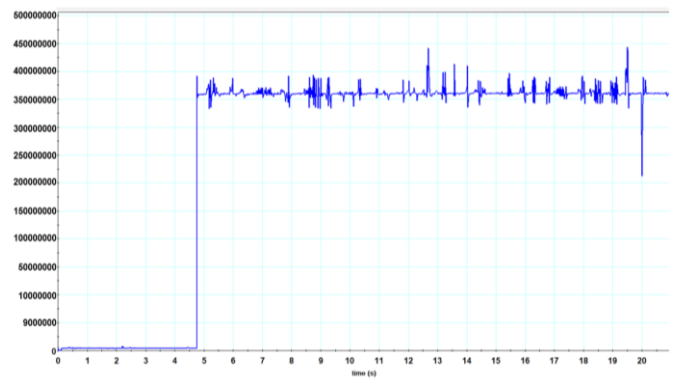


Fig. 10. Stress on the lifting arm of the Main Post

In Fig.11. is shown the dispersion of the stress in the Lifting arm on its entire volume, which is meshed and calculated using Finite Elements Method. Based on the color contrast in the arms volume, the maximal values are at the joint between the lifting arm and the lifting bar.

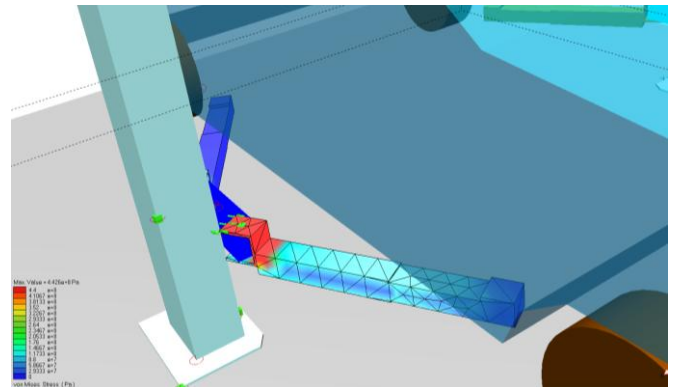


Fig. 11. Dispersion of the Stress on the lifting arm of the Main Post

4. Results of the vehicle lowering (moving down)

The simulation of the vehicle downwards motion is similar but opposite to the lifting. The main difference is that the vehicle already stands on lifting arms, meaning they are loaded from the start. The vehicle will be lowered until the simulation time $t_{sim3} = 20 \text{ s}$. After this time, lowering will be halted, but the simulation will continue until $t_{sim4} = 21 \text{ s}$ to monitor the occurrence on the vehicle. During this time, the vehicle will move down for the distance of $D_l = 740 \text{ mm}$.

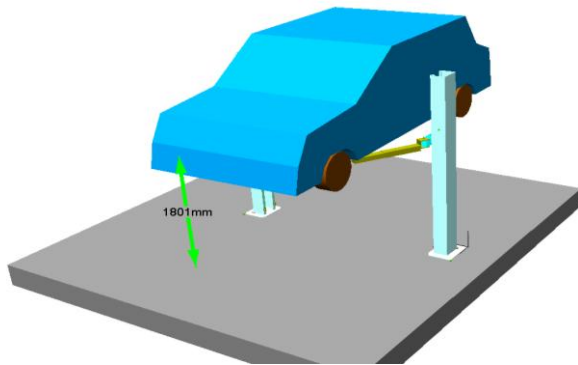


Fig. 12. Initial position of the vehicle before lowering, height $H = 1800 \text{ m}$

4.1. Tensile Force on the Drive Chain for the vehicle lowering

In the fig.13 is the graph of the tensile force on the drive chain F_{tch} during lowering. The graph of the force shows almost constant intensity $F_{tch} \approx 20000 \text{ N}$, with some oscillations at the start of the process, at the end of the process, and after the lowering stop $t_{sim3} = 20 \text{ s}$. Highest value of the tensile force is at the time $t = 0.3 \text{ s}$, $F_{tchmax} \approx 22700 \text{ N}$, but most of higher values are at the end of the process, $t > 16 \text{ s}$, and can reach up to $F_t \approx 21550 \text{ N}$. Higher values of the Force after lowering stoppage $t > 20 \text{ s}$ are caused by the short inertial motion of the vehicle.

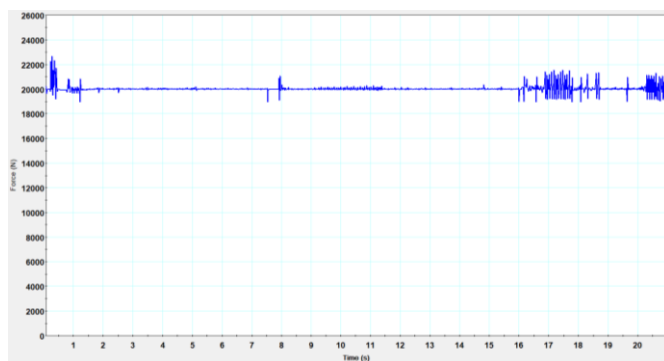


Fig. 13. Tension force on the drive chain in the main post, case of vehicle lowering

4.2. Force on the Piston for the vehicle lowering

In the fig.14 is given the graph of the pressure force F_{pp} on the piston in the main post during lowering. The intensity of the force is almost constant during the process, with some oscillations that are more present at the start and end of process, after the lowering stoppage ($t > 20 \text{ s}$). The medium intensity of the pressure force is $F_{pp} \approx -20000 \text{ N}$. Conclusion is that the lowering process has less oscillations than the lifting process.

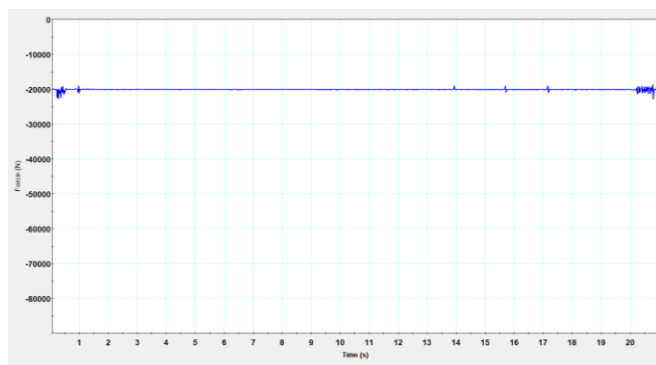


Fig. 14. Force on the piston in the main post, case of vehicle lowering

5. Conclusions

In the paper, we analyzed lifting and lowering of the load by the vehicles lift. Based on the analysis and results, we can conclude that during these motions there are oscillations present in entire duration of the process. They show small amplitudes, but high number of frequencies. This can lead to issues about the safety, which requires proper positioning of the vehicle on the lift to reduce oscillations and minimize the risk of damaging lift parts or overturning of the vehicle.

Analysis were focused in some main parts of the vehicles lift: drive chain, piston and lifting arms. The parameters acquired that best represent the dynamic response are forces and stresses present on these parts. Results of the parameters are shown in graphical form, and are discussed for each part and each case.

To achieve successful analysis and results, it is important to accurately develop 3D model that will represent as closest the real vehicle lift, and planning of the simulations that best describes the process of motion. In our case, the lifting motion has started before the vehicle lifting, and at the end, the lifting was stopped, but the simulation was carried for some additional time. This makes it possible to best represent the motion process that takes place in reality. Similar planning of the simulation was done for the lowering process, but there, the lowering needs to start with loaded vehicle.

6. References

- [1] Lift manual, Type EE-6254: <https://nordiclift.no/Images/uploaded/Brukermanualer2/EE-6253,6254.pdf>
- [2] EN Standards of elevators with platform: prEN 16719; EN 280:2013 (WI=00098021); EN 280:2013/prA1
- [3] SimWise 4D, Design Simulation, Technologies, <https://www.design-simulation.com/SimWise4D/>.
- [4] Yekinni A.A, Olaiya K.A, Badiru A.N, Omogoye O.S, *Design and Development of Motorised Vehicle Lifter*, Journal Science and Engineering Perspectives, Sep Vol. 13, 2018.
- [5] Afrim Sallahu, Shqyrtimi dinamik i liftit elektro-hidraulik për ngritjen e automjeteve, Master Diploma Work, University of Prishtina, Faculty of Mechanical Engineering, Prishtina, 2016.
- [6] S. Saravanan, R. Rajiev, K. Sunil Kumar, *An experimental investigation of car lifting mechanism using universal object interaction*, Gradiva Review Journal, volume 8 ISSUE 10 2022, ISSN NO : 0363-805.
- [7] M. Čuchor, L. Kučera, M. Lukáč, *Design of Vehicle Lifting Equipment Using Progressive Methods*, LOGI – Scientific Journal on Transport and Logistics, Vol. 12 No. 1 2021. DOI: 10.2478/logi-2021-0022.
- [8] Sh. K. Amedorme, *Design and analysis of modified four-post lift for light-duty vehicles*, Journal of Mechanical Engineering and Technology (JMET) Volume 7, Issue 1, Jan-Dec 2023.
- [9] M.Y.H. Bangash and T. Bangash, *Lifts, Elevators, Escalators and Moving Walkways/Travelators*, 2007.
- [10] Dresig, Hans, *Shwingungen mechanischer Antriebssysteme, Modellbildung, berechnung, analyse, synthese*, Springer Verlag, Berlin, 2001.
- [11] Ilir Doçi, Mirlind Bruqi, Nexhat Qehaja, *Dynamic analysis and motion control of hydraulic crane for men lifting using modeling and simulations*, Proceedings of the 27th DAAAM International Symposium, ISSN 1726-9679
- [12] Ilir Doçi, *Influentia of the stoppage - brakeing system of elevator in the elevator's studs (rails) for the case of failure*, TMT 2006.
- [13] Yan Chen and Dr. Weidong Zhu, *Dynamics and Control of Elevator Systems*, Dynamic Systems and Vibrations Laboratory, University of Maryland Baltimore, 2007.
- [14] Ilir Doçi, *Siguria e Mjeteve Transportuese I* (Safety of transportation Devices I), Book Chapter IX, Faculty of Mechanical Engineering, Prishtina, 2012.

Determination of dynamic loads during operation of a flexible screw sectional working body

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Abstract. The article presents the design of a flexible screw sectional working body that will improve the functional and operational characteristics of screw conveyors during the utilization of the removed contaminated soil layer. A mathematical model of the dynamic system of a flexible screw conveyor was created, and dynamic starting torques were calculated at the rated load of the loaded screw and when the system was braked. The analysis of the results shows that with significant damping coefficients, the startup transient process is smooth and the load reaches its nominal value without fluctuations in torque and speed.

KEYWORDS: AGRICULTURAL SOILS, CONTAMINATION, FLEXIBLE SCREW CONVEYOR, SCREW.

1. Introduction

As a result of the military actions, Ukraine's soil resources are being significantly destroyed, their quality is deteriorating, and degradation processes are intensifying, with a number of mechanical, physical, and chemical impacts on the soil cover. Such impacts lead to the destruction of the structure and functions of the soil ecosystem and deterioration of physical and geochemical properties.

Enemy aircraft and artillery have the greatest impact on agricultural land and soil cover, accounting for about 80% of the impact. As a result of missile and artillery shelling, the fields are covered with craters (craters) from the explosions of shells, mines, and missiles. The craters are of different diameters and depths [1].

The depth of the craters in the fields ranges from 30 cm (82 mm mortar) to 5 m (cruise missiles), and the soil remaining at the impact site is turbulized, subject to dynamic compaction, and contains numerous metal fragments with residues of explosive toxic substances, i.e., deterioration of physical properties of soils, changes in particle size distribution, compaction and disintegration due to a decrease in the content of agronomically valuable fractions, etc.

Other important impacts on the soil cover are the consequences of explosions, detonations, or burning of heavy machinery on agricultural land. The results of the analysis of the soil particle size distribution showed that the content of physical clay decreased in places where heavy machinery burned and fuel and lubricants leaked [2].

Therefore, restoring and ensuring the conditions for preserving the fertility of agricultural soils in Ukraine that have been destroyed by military operations is a very acute, global and urgent problem for the entire agricultural sector, which has a state priority.

In order to restore areas damaged by explosions, it is necessary to remove or clean the surface layer of soil, since in addition to chemical contamination with heavy metals, the fertile soil layer also burns out, dehydration and "sterilization" occur, killing both pathogenic microorganisms and beneficial biota [1].

To remove and clean the damaged surface layer of soil in the crater formed as a result of explosions, it is recommended to use a working tool that will allow mechanizing this process. This working tool is attached to the boom of an excavator with a hydraulic system.

To dispose of the removed contaminated soil layer, a flexible screw conveyor with a sectional auger working body can be used, which will allow it to be transferred to the truck body.

Screw conveyors are used for transportation of various types of bulk agricultural materials, including: cereals, granular seed materials, clay, sand, loose soil, mixed fodder, mineral fertilizer granules, etc. From the analysis of the literature, it can be concluded that the least resource-intensive technology for moving bulk and lumpy agricultural materials along curved routes is the use of flexible screw conveyors, which are made on the basis of individual screw sections that are hinged to each other [3]. Works [4, 5] substantiate the structural, kinematic, and technological parameters of screw working bodies in terms of their functional purpose.

However, the existing flexible screw impellers cannot fully meet the operational requirements for these types of conveyors. The use of shaftless flexible screw spirals leads to their rapid destruction when conveyors operate on curved routes due to the occurrence of alternating cyclic loads. The design of the working body in the form of a solid or sectional shaft, on which individual elements of screw ribs are located, leads to a significant complication of the design of the technological body, an increase in its material consumption, which, accordingly, causes an increase in energy consumption, as well as damage to the transported materials.

Therefore, the task of developing new designs and substantiating the parameters of flexible screw conveyor working bodies that will improve the functional and operational performance of the process of utilizing the removed contaminated soil layer is relevant.

2. Results and discussions

To improve the performance of flexible screw conveyors, a design of a screw sectional working body was developed, which is shown in Fig. 1. It contains sections 1 of equal diameters and lengths, which are made in the form of welded structures of tubular blanks 2, to one conditional inner end of which a cylindrical sleeve 3 is rigidly fixed. The latter is made with a system of axial parallel grooves 4, which are placed evenly around the circumference, for example, four, and are parallel to the axis of the tubular blank and which are in interaction with rolling elements 5. On the other side, the rolling elements 5 are in contact with the spherical recess 6 of the spherical body 7 with the possibility of axial and angular rotation of the spherical rod 8. In addition, from above, the cylindrical sleeve 3 is in rigid interaction with the spherical body 7, in which the inner sphere 6 is in interaction with the outer surfaces of the rolling elements 5, and at the free inner end of the spherical body 7 there is a cylindrical ring with an outer triangular profile 9, which is in rigid interaction with a similar recess 10 of the cylindrical sleeve 3, which is made at its free end outside. From the other end of the welded cylindrical section, a connecting sleeve 11 with an internal square or shaped hole 12 is rigidly installed in the inner hole perpendicular to the axis, which is in interaction with the corresponding end of the spherical rod of the neighboring section and rigidly fixed in a known way. Four jumpers 13, for example, are welded to the outer diameter of the connecting sleeve 11 evenly around the circumference at one end, and at the other end the jumpers are welded to the outer diameter of the cylindrical sleeve 3. A screw section 13 is rigidly welded to the outer diameter of the cylindrical section 2, which is actually a continuation of the helical spirals of the neighboring sections, a recess 14 is made in the center of the spherical rod 8, which is in contact with the lubricant, which in turn is connected to the rolling elements 8 by a system of holes, and a central hole is made at the free end of the rod, which is connected to the recess 15 and an oiler is screwed at its end.

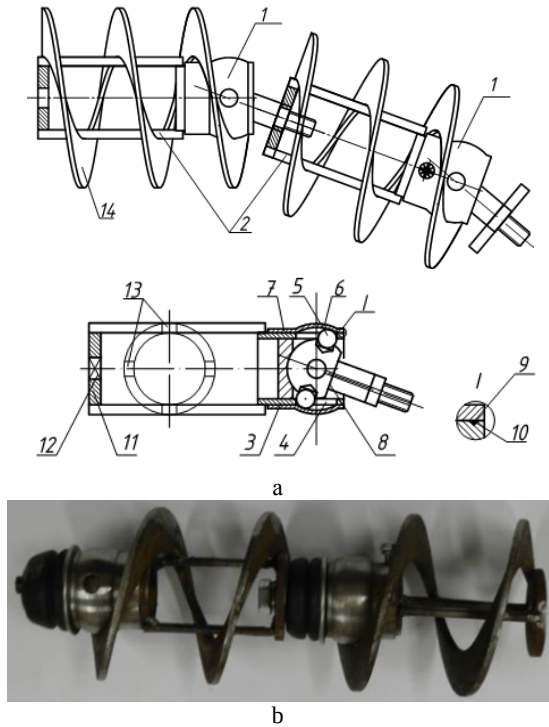


Figure 1. Constructional diagram (a) and general view (b) of the screw sectional working body

The operation of the screw working body is as follows. During the rotation of the spiral section 14, the rotational motion is transmitted through the rolling elements 5 to the spherical linkage 7 and the adjacent sections of the screw working body.

In order to estimate the maximum loads that occur in the elements of a flexible screw conveyor during the transient processes of starting and braking, we will create its dynamic model and analyze the resulting solution.

The simplified dynamic model will be written in the form of an elastic three-mass rotating system subject to external torques from the motor and the transported material. The dynamic model is shown in Fig. 2.

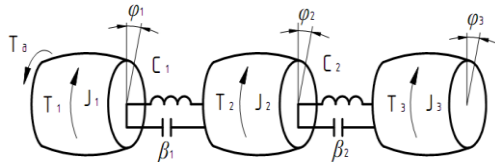


Figure 2. Scheme of the dynamic model

The first rotating mass J_1 represents the combined mass of the drive mechanism (motor, gearbox, coupling). It is affected by the torque of the motor's electromagnetic forces T_d , reduced to the screw's axis of rotation, and the force T_1 of friction in the drive mechanism. The second rotating mass J_2 – is the combined mass of the first link of the flexible screw conveyor together with the mass of the transported material. It is subjected to a moment of resistance, which can be represented as the sum of two components – a constant dry friction moment T_2 and a viscous friction moment that depends on the speed of movement. Similarly, J_3 the following corresponds to the combined mass of the next link of a flexible screw conveyor.

Obviously, if there are several conveyor links, the number of rotating masses should correspond to their number. However, in models that study transient processes, due to the presence of significant friction forces of bulk material, which causes damping of oscillations of subsequent links, it is possible to replace a long chain of links with a reduced torque of resistance T_3 , applied to the link by mass J_3 , as well as a certain viscous friction moment. This

assumption significantly reduces the complexity of the system analysis, with virtually no effect on the determination of the maximum dynamic loads that occur in the drive mechanism and the first link of the screw. Therefore, for the purpose of the study, we will limit ourselves to a dynamic system consisting of three characteristic rotating masses.

Each link is connected to the next elastic element, the combined stiffness of which is determined by the elastic properties of the screw link and the hinge mechanism.

The dynamic model shown in Fig. 2, the dynamic model is described by a system of three differential equations of motion. Each equation describes the motion of the corresponding rotating mass:

$$\left. \begin{aligned} J_1 \ddot{\varphi}_1 &= T_d - c_1(\varphi_1 - \varphi_2) - \beta_1 \dot{\varphi}_1 - T_1 \operatorname{sgn}(\dot{\varphi}_1); \\ J_2 \ddot{\varphi}_2 &= c_1(\varphi_1 - \varphi_2) - c_2(\varphi_2 - \varphi_3) - \beta_2 \dot{\varphi}_2 - T_2 \operatorname{sgn}(\dot{\varphi}_2); \\ J_3 \ddot{\varphi}_3 &= c_2(\varphi_2 - \varphi_3) - \beta_3 \dot{\varphi}_3 - T_3 \operatorname{sgn}(\dot{\varphi}_3); \end{aligned} \right\} \quad (1)$$

where $\varphi_1, \varphi_2, \varphi_3$ – rotation angles of rotating masses J_1, J_2, J_3 accordingly; c_1, c_2 – rigidity of the connecting elements; $\beta_1, \beta_2, \beta_3$ – coefficients of viscous damping forces acting on the respective masses.

The torque of a motor is described by its mechanical characteristic, which relates rotational speed and torque. The simplest is the static mechanical characteristic of an electric motor, which does not take into account electromagnetic processes in the motor. As a drive motor, an asynchronous electric motor with a squirrel-cage rotor is most often used without a starting current and speed control circuit, i.e., the motor is directly connected to the mains. In this case, its mechanical characteristic can be written as:

$$T_d = \frac{2T_k}{\frac{s}{s_k} + \frac{s_k}{s}}. \quad (2)$$

The values in expression (2) are determined by the following formulas:

$$s_k = \frac{\omega_0 - \omega_k}{\omega_0} \text{ – critical slip of the electric motor;}$$

$$s = \frac{\omega_0 - \dot{\varphi}_1}{\omega_0} \text{ – running sliding of the electric motor,}$$

where ω_0 – synchronous rotor speed of the electric motor;

ω_k – critical rotor speed of the electric motor;

T_k – critical torque of the electric motor.

The last three values are determined from the motor's tabulated parameters and must be reduced to the screw's axis of rotation.

The system of differential equations (1) is nonlinear, so its analytical solution is difficult, and therefore we will use a numerical method based on transforming the system of second-order differential equations into a system of first-order differential equations with twice as many of them. To do this, we will make the appropriate substitutions and replacements. As a result, we get the following system of equations:

$$\left. \begin{aligned} \varphi_1 &= u; \\ \dot{u} &= \frac{T_d - c_1(\varphi_1 - \varphi_2) - \beta_1 \dot{\varphi}_1 - T_1 \operatorname{sgn}(\dot{\varphi}_1)}{J_1}; \\ \varphi_2 &= v; \\ \dot{v} &= \frac{c_1(\varphi_1 - \varphi_2) - c_2(\varphi_2 - \varphi_3) - \beta_2 \dot{\varphi}_2 - T_2 \operatorname{sgn}(\dot{\varphi}_2)}{J_2}; \\ \varphi_3 &= w; \\ \dot{w} &= \frac{c_2(\varphi_2 - \varphi_3) - \beta_3 \dot{\varphi}_3 - T_3 \operatorname{sgn}(\dot{\varphi}_3)}{J_3} \end{aligned} \right\} \quad (3)$$

To solve system (3), it is advisable to apply the Runge-Kutta numerical method, which has proven to be convenient and reliable for solving systems of equations describing dynamic models of oscillating mechanical systems.

During the startup, the system of masses was at rest at the beginning of the movement, so the initial conditions are written in the form:

$$\left. \begin{aligned} \varphi_1(0) &= 0; \\ \varphi_2(0) &= 0; \\ \varphi_3(0) &= 0; \\ u(0) &= \dot{\varphi}_1(0) = 0; \\ v(0) &= \dot{\varphi}_2(0) = 0; \\ w(0) &= \dot{\varphi}_3(0) = 0 \end{aligned} \right\} \quad (4)$$

In order to analyze the influence of certain system parameters on the magnitude of dynamic loads during the startup period, we will perform the calculation by assuming the following numerical values of mass, power, and elastic coefficients:

- Rotating mass of the drive $J_1 = 2 \text{ kg m}^2$;
- Rotating masses of 1 and 2 screw links $J_2 = J_3 = 0.01 \text{ kg m}^2$;
- Rigidity of drive elements $c_1 = 2000 \text{ N m}$;
- Rigidity of the 1st link elements $c_2 = 1000 \text{ N m}$;
- Coefficient of viscous friction of the drive mass $\beta_1 = 0.5 \text{ N m s}$;
- Coefficients of viscous friction of 1 and 2 links $\beta_2 = \beta_3 = 5 \text{ N m s}$;
- Torque of the drive elements $T_1 = 10 \text{ N m}$;
- Moment of resistance of 1 link $T_2 = 20 \text{ N m}$;
- Resistance torque 2 links $T_3 = 200 \text{ N m}$;
- Rated speed of the drive $\omega_0 = 10 \text{ s}^{-1}$;
- Critical sliding $s_k = 0.25$;
- The critical torque $T_k = 500 \text{ N m}$.

The values of friction moments and critical torque are selected for the calculated rated power of the electric motor of 2.2 kW. In order to increase the starting torque, which is necessary when starting the screw conveyor under load, we choose an asynchronous motor with increased slip. The second, particularly loaded case of flexible screw conveyor movement is its sudden braking due to material jamming or accidental entry of a certain object into the transportation zone. At this point, the system, which has been rotating at a constant speed, begins to brake, increasing the braking torque until the drive comes to a complete stop. Mathematically, applying certain assumptions, this can be written as a linear increase in torque T_3 in time t from the initial value T_{30} to the maximum value when the movement of the rotating mass J_3 is stopped:

$$T_3 = T_{30} + Mt, \quad (5)$$

where M – braking torque growth factor.

The value M determines the braking speed of the drive. In real systems, the braking time can last from 0.1 s to 5 s. A short time is typical for incompressible bulk materials (sand, dry grain materials), and a long braking time is typical for the transportation of compressible media (soft grain materials, feed, seeds, chaff). The conveyor movement during braking can be divided into 2 stages. The first is braking until the rotating mass J_3 stops. At this stage of motion, the system is described by the same equations (1-3), but with different initial conditions that correspond to the final values of the angles and their velocities in steady-state motion before the start of braking at time t_1 , and the braking torque is determined from expression (5):

$$\left. \begin{aligned} \varphi_1(0) &= \varphi_1(t_1); \\ \varphi_2(0) &= \varphi_2(t_1); \\ \varphi_3(0) &= \varphi_3(t_1); \\ u(0) &= \dot{\varphi}_1(t_1) = \omega_1; \\ v(0) &= \dot{\varphi}_2(t_1) = \omega_2; \\ w(0) &= \dot{\varphi}_3(t_1) = \omega_3 \end{aligned} \right\} \quad (6)$$

The second stage of motion is the oscillation of masses J_1 and J_2 , connected through elastic elements c_1 and c_2 to the stopped

mass J_3 . At the second stage, the elastic system is described by a system of two differential equations:

$$\left. \begin{aligned} J_1 \ddot{\varphi}_1 &= T_d - c_1(\varphi_1 - \varphi_2) - \beta_1 \dot{\varphi}_1 - T_1 \operatorname{sgn}(\dot{\varphi}_1); \\ J_2 \ddot{\varphi}_2 &= c_1(\varphi_1 - \varphi_2) - c_2(\varphi_2 - \varphi_3) - \beta_2 \dot{\varphi}_2 - T_2 \operatorname{sgn}(\dot{\varphi}_2) \end{aligned} \right\} \quad (7)$$

Accordingly, after substitution, we obtain a system of four first-order differential equations:

$$\left. \begin{aligned} \dot{\varphi}_1 &= u; \\ \dot{u} &= \frac{T_d - c_1(\varphi_1 - \varphi_2) - \beta_1 \dot{\varphi}_1 - T_1 \operatorname{sgn}(\dot{\varphi}_1)}{J_1}; \\ \dot{\varphi}_2 &= v; \\ \dot{v} &= \frac{c_1(\varphi_1 - \varphi_2) - c_2(\varphi_2 - \varphi_3) - \beta_2 \dot{\varphi}_2 - T_2 \operatorname{sgn}(\dot{\varphi}_2)}{J_2} \end{aligned} \right\} \quad (8)$$

with the corresponding initial conditions, which are final for the moment of time t_2 of the mass J_3 stopping:

$$\left. \begin{aligned} \varphi_1(0) &= \varphi_1(t_2); \\ \varphi_2(0) &= \varphi_2(t_2); \\ u(0) &= \dot{\varphi}_1(t_2) = \omega_2; \\ v(0) &= \dot{\varphi}_2(t_2) = \omega_2; \end{aligned} \right\} \quad (9)$$

Thus, a mathematical model of the dynamic system of a flexible screw conveyor was obtained, and dynamic starting torques were calculated at the rated load of the loaded screw and when the system was braked.

On the basis of the created mathematical model of the dynamic system of a flexible screw conveyor, we calculated the dynamic starting torques at the rated load of the loaded screw. The calculation results are shown in Fig. 3 – 6. The graphical results of calculating the dynamic loads during braking of the system described by Fig. 5–9 are shown in Fig. 7 – 10.

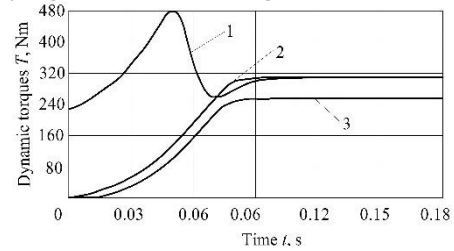


Figure 3. A change of the dynamic torques of the drive and in the elastic sections of the conveyor with significant external damping $\beta_2 = \beta_3 = 5$: 1 – T_d ; 2 – $c_1(\varphi_1 - \varphi_2)$; 3 – $c_2(\varphi_2 - \varphi_3)$

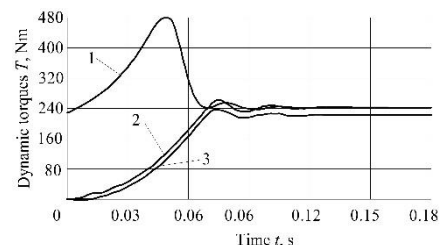


Figure 4. A change of the dynamic torques of the drive and in the elastic sections of the conveyor with small external damping $\beta_2 = \beta_3 = 1$: 1 – T_d ; 2 – $c_1(\varphi_1 - \varphi_2)$; 3 – $c_2(\varphi_2 - \varphi_3)$

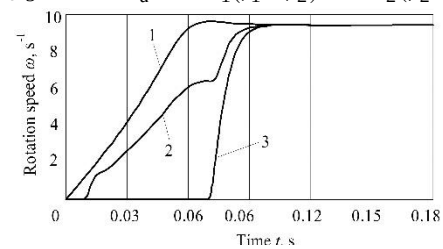


Figure 5. The rotation speeds of masses with significant external damping $\beta_2 = \beta_3 = 5$: 1 – ω_1 ; 2 – ω_2 ; 3 – ω_3

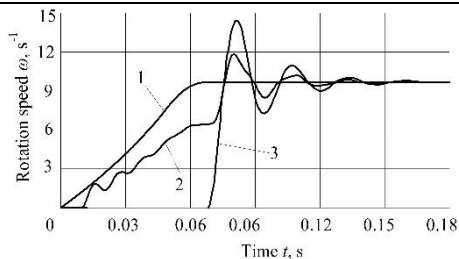


Figure 6. The rotation speeds of masses with small external damping $\beta_2 = \beta_3 = 1$: 1 – ω_1 ; 2 – ω_2 ; 3 – ω_3

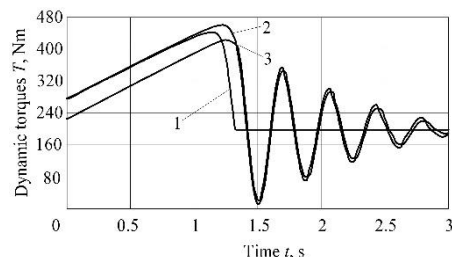


Figure 7. Dynamic torques in the sections of the conveyor during slow braking (1 s): 1 – T_d ; 2 – $c_1(\phi_1 - \phi_2)$; 3 – $c_2(\phi_2 - \phi_3)$

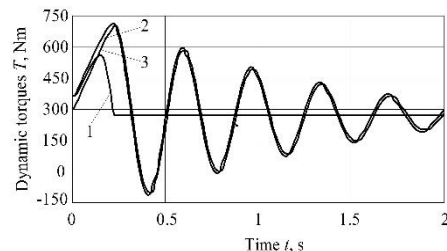


Figure 8. Dynamic torques in the conveyor sections during fast braking (0.2 s): 1 – T_d ; 2 – $c_1(\phi_1 - \phi_2)$; 3 – $c_2(\phi_2 - \phi_3)$

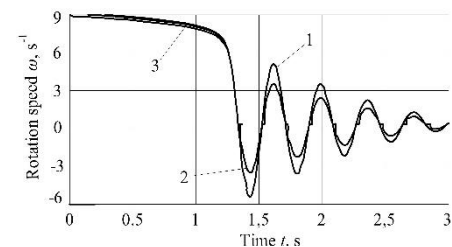


Figure 9. The speeds of the conveyor sections during slow braking: 1 – ω_1 ; 2 – ω_2 ; 3 – ω_3

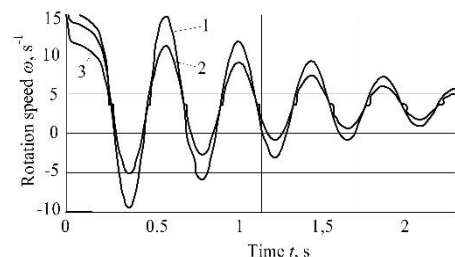


Figure 10. The speeds of the conveyor sections during fast braking (0.2 s): 1 – ω_1 ; 2 – ω_2 ; 3 – ω_3

The analysis of the results shows that with significant damping coefficients, the start-up transient process is smooth and the load reaches its rated value without fluctuations in torque and speed. At low damping, a certain transient oscillatory process is observed, but the dynamic loads do not exceed 20% of the nominal value.

The cases of slow and fast braking are considered. The analysis of the graphs shows that fast braking significantly increases dynamic loads, which can significantly exceed the maximum critical torque of the electric motor (on average by 50-70%) and

the rated load torque (by 2.5-3 times). To ensure the strength of the screw links during braking, it is necessary to provide safety elements (clutches) with an actuation torque not exceeding 1.5 times the nominal torque.

The analysis showed that the dynamic loads during system startup are not critical, and in case of jamming, they significantly exceed the permissible values.

3. Conclusion

Based on the analysis of literature sources and patent search, a flexible screw sectional working body has been developed and manufactured, which will improve the functional and operational characteristics of screw conveyors. On the basis of the created mathematical model of the dynamic system of a flexible screw conveyor, the dynamic starting torques were calculated at the rated load of the loaded screw. The analysis of the results shows that at significant damping coefficients, the startup transient process is smooth and the load reaches its nominal value without fluctuations in torque and speed. At low damping, a certain transient oscillation process is observed, but the dynamic loads do not exceed 20% of the nominal value.

The analysis of the results of calculating the dynamic loads during braking of the system shows that rapid braking significantly increases the dynamic loads, which can significantly exceed the maximum critical torque of the electric motor (on average by 50-70%) and the rated load torque (by 2.5-3 times). To ensure the strength of the screw links during braking, it is necessary to provide safety elements (clutches) with an actuation torque not exceeding 1.5 times the rated torque.

4. References

1. Electronic resource: Even the flight of a rocket affects the harvest." How war destroys Ukrainian soils. Retrieved from <https://www.rbc.ua/rus/news/navit-prolit-raketi-vplivae-urozhay-k-viyna-1715344389.html>
2. Balyuk S.A., Kucher A.V., Solokha M.O., Solovei V.B., Smirnov K.B., Momot G.F., Levin A.Ya. (2022). The influence of armed aggression and military actions on the current state of the soil cover, damage and loss assessment, restoration measures. Kharkiv: FOP Brovin O.V., 2022, 102 p.
3. Hevko R.B., Rozum R.I., Klendiy O.M. (2016). Development of design and investigation of operation processes of loading pipes of screw conveyors. INMATEH: Agricultural engineering, 50(3), 89-96.
4. Hevko R.B., Klendiy M.B., Klendii O.M. (2016). Investigation of a transfer branch of a flexible screw conveyor. INMATEH: Agricultural Engineering, 48(1), 29-34.
5. Hevko R.B., Dzyura V.O., Romanovsky R.M. (2014). Mathematical model of the pneumatic-screw conveyor screw mechanism operation. INMATEH – Agricultural engineering, 44(3), 103-110.

Technologies for additive manufacturing of metal structures

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Abstract: Additive manufacturing (AM) of metal structures is transforming industries by enabling the creation of complex, efficient, and customizable components. This article explores key AM technologies for metals, including Powder Bed Fusion (PBF), Directed Energy Deposition (DED), Binder Jetting, Metal Extrusion, and Sheet Lamination. Each is analyzed in terms of principles, strengths, limitations, and applications. A comparative evaluation highlights factors like precision, scalability, cost, and environmental impact to identify optimal technologies for various industries. Despite its advantages, challenges remain in material quality, process reliability, cost, and certification. Emerging trends such as hybrid manufacturing, AI-driven process optimization, advanced materials, and sustainable practices hold promise for overcoming these barriers. By examining current technologies and future opportunities, this article provides valuable insights for advancing metal AM in diverse applications.

Keywords: ADDITIVE MANUFACTURING, METAL STRUCTURES, POWDER BED FUSION (PBF), DIRECTED ENERGY DEPOSITION (DED), BINDER JETTING, METAL EXTRUSION, SHEET LAMINATION, HYBRID MANUFACTURING, SUSTAINABLE MANUFACTURING

1. Introduction

Additive manufacturing (AM), commonly known as 3D printing [1-3], has emerged as a transformative technology in modern manufacturing, enabling the layer-by-layer construction of complex and intricate geometries directly from digital models. This approach contrasts with traditional subtractive methods, offering significant advantages such as material efficiency, design flexibility, and reduced lead times. Over the past two decades, AM has advanced beyond its initial use for rapid prototyping and evolved into a robust method for producing functional components across various industries.

Metal additive manufacturing [4-7], in particular, has gained prominence due to its ability to produce high-performance parts with superior mechanical properties and lightweight designs. Industries such as aerospace, automotive, medical, and construction have embraced AM for metals to address demanding requirements for strength, durability, and precision. In aerospace, AM enables the production of lightweight but structurally strong components, reducing fuel consumption. Automotive manufacturers leverage AM for rapid design iterations and custom parts, while the medical sector benefits from personalized implants and prosthetics. In construction, metal AM offers solutions for creating complex architectural structures and infrastructural components with minimal waste.

This review aims to provide a comprehensive exploration of key additive manufacturing technologies specifically tailored for metal structures. It examines their working principles, advantages, limitations, and suitability for various applications. Technologies covered include Powder Bed Fusion (PBF), Directed Energy Deposition (DED), Binder Jetting, Metal Extrusion, and Sheet Lamination. A comparative analysis highlights the strengths and weaknesses of each method across critical performance metrics such as precision, scalability, cost, and environmental impact.

The article also discusses the current challenges faced by metal AM, including material quality, process reliability, certification, and economic constraints. Emerging trends such as hybrid manufacturing, artificial intelligence (AI) integration and sustainable practices are explored as potential solutions to these barriers. By focusing on the present state and future directions of metal AM, this article seeks to guide researchers and industry professionals in advancing the adoption of this transformative technology across diverse fields.

2. Classification of AM Technologies for Metals

The development of additive manufacturing (AM) technologies for metals [4-7] has led to a range of methods optimized for specific applications. These methods enable the creation of metal components with varying complexity, precision, and performance. AM technologies for metals can be classified based on material

type, energy source, and process flow, offering a systematic understanding of the available approaches.

1. Classification by Material Type

AM methods for metals are designed to handle different forms of feedstock, including:

- **Powders:** Common in Powder Bed Fusion (PBF) and Binder Jetting, where metal powder is fused or bonded layer by layer.
- **Wire:** Used in Directed Energy Deposition (DED) processes that employ wire as the primary feedstock for building parts.
- **Filaments:** Found in metal extrusion techniques, where a metal-polymer composite filament is extruded and subsequently sintered.
- **Sheets:** Utilized in Sheet Lamination, where thin metal sheets are bonded and shaped layer by layer.

Each material type offers unique advantages, such as high material utilization (powder and wire) or cost efficiency (sheet and filament-based methods).

2. Classification by Energy Source

The energy source plays a crucial role in determining the process mechanisms and applications of metal AM technologies. Key categories include:

- **Laser-Based Systems:** Common in PBF (Selective Laser Melting, SLM) and DED, lasers provide high precision and control for melting or sintering metal feedstock.
- **Electron Beam Systems:** Used in processes like Electron Beam Melting (EBM), electron beams deliver high energy levels for melting metal powders in a vacuum environment.
- **Arc-Based Systems:** Often used in wire-based DED, electric arcs provide a cost-effective and scalable energy source for metal deposition.
- **Binder and Chemical Processes:** Found in Binder Jetting, where binding agents solidify metal powder layers without requiring direct melting.
- **Ultrasonic Energy:** Utilized in Sheet Lamination, where ultrasonic welding bonds metal sheets into a cohesive structure.

Each energy source offers trade-offs in terms of precision, build speed, energy efficiency, and part quality.

3. Classification by Process Flow

The workflow of AM technologies for metals can be categorized into distinct stages, affecting the final part's quality and application. Key classifications include:

- **Powder Bed Processes:** Methods like PBF involve spreading a layer of powder over a build platform, followed by selective fusion using lasers or electron beams. These processes are known for high precision and excellent mechanical properties but have slower build rates.
- **Directed Deposition Processes:** DED and similar methods deposit material directly onto a surface in a controlled manner, offering versatility in repair and large-scale applications.

- **Binder-Based Processes:** Techniques like Binder Jetting use a liquid binder to join metal powder particles layer by layer, with sintering or infiltration required to achieve final part strength.
- **Extrusion-Based Processes:** Metal extrusion methods rely on the deposition of a composite filament, followed by debinding and sintering steps to create functional parts.
- **Sheet-Based Processes:** Sheet Lamination techniques involve bonding and cutting metal sheets layer by layer, offering high speed and material efficiency but limited geometrical complexity.

By organizing metal AM technologies into these categories, we can better understand the trade-offs and applications of each approach, laying the groundwork for selecting the most suitable method for specific industrial needs.

3. Key Technologies

Additive manufacturing (AM) for metals includes various key technologies designed to meet specific needs in material properties, precision, and application. These methods allow for the production of complex metal structures, offering design flexibility and material efficiency, though they also present challenges in cost, speed, and scalability. Below is an overview of the main technologies used in metal AM.

3.1. Powder Bed Fusion (PBF)

Techniques: Selective Laser Melting (SLM) - Uses a laser to melt and fuse metal powder particles, producing fine details and excellent mechanical properties; Electron Beam Melting (EBM) - Uses an electron beam to melt metal powders, effective for high-melting-point metals like titanium. **Mechanisms:** Metal powders are spread across a build platform, melted layer by layer by a laser or electron beam, bonding them to the layer below. **Applications:** Used in aerospace, medical implants, and automotive industries for producing complex geometries. **Advantages and Limitations:** Advantages - High precision and complex part production; Limitations - High equipment costs, slow build rates, and need for post-processing.

3.2. Directed Energy Deposition (DED)

Techniques: Laser-Based DED - Uses a laser to melt metal powder or wire, forming the structure layer by layer; Arc-Based DED - Uses an electric arc to melt metal wire, depositing it onto the build surface. **Mechanisms:** Energy is directed at the material, melting it and allowing it to deposit layer by layer. **Applications:** Used for large parts, such as turbine blades, and for repairs in aerospace and defense [8-12]. **Advantages and Limitations:** Advantages - Flexibility in material use and part size; Limitations - Lower resolution and surface finish compared to PBF.

3.3. Binder Jetting

Mechanisms: Metal powder is layered, with a binder selectively applied, followed by sintering to remove the binder and fuse the metal. **Applications:** Ideal for medium-sized parts in industries like automotive and aerospace. **Advantages and Limitations:** Advantages - Fast and cost-effective, suitable for complex geometries; Limitations - Lower strength and density compared to PBF and DED, requiring additional post-processing.

3.4. Metal Extrusion

Techniques: Bound Metal Deposition (BMD) - Metal-polymer composite filament is extruded, followed by heating and sintering; Fused Filament Fabrication (FFF) - Similar to BMD but uses a metal filament mixed with polymer binder. **Mechanisms:** The filament is extruded layer by layer, followed by debinding and sintering to achieve full metallization. **Applications:** Primarily for prototyping and low-volume production of metal parts. **Advantages and Limitations:** Advantages - Cost-effective, simple setup, suitable for prototyping; Limitations - Limited material options, requires post-processing.

3.5. Sheet Lamination

Techniques: Ultrasonic Additive Manufacturing (UAM) - Uses ultrasonic welding to bond metal sheets layer by layer. **Mechanisms:** Metal sheets are bonded together and machined to achieve the desired shape. **Applications:** Used for lightweight structural components in aerospace and automotive industries. **Advantages and Limitations:** Advantages - Fast and low-cost for

large parts; Limitations - Limited material options and lower resolution.

These key technologies serve different industrial needs, based on factors such as material, part complexity, and production speed. Understanding the advantages and limitations of each method is critical for selecting the most appropriate technology for specific applications.



Fig. 1 An image of a metal turbine blade

Figure 1 shows an image (made by AI) of a metal turbine blade designed for aerospace applications, manufactured using additive manufacturing. The intricate cooling channels and polished surface demonstrate the advanced engineering and precision achievable with this technology.

4. Comparative Analysis

Selecting the appropriate additive manufacturing (AM) technology for metal structures requires evaluating performance metrics, application suitability, and environmental impact. This section compares key technologies based on accuracy, material properties, build speed, cost, scalability, and environmental factors.

Performance Metrics

- **Accuracy:** PBF (Selective Laser Melting and Electron Beam Melting) provides high precision, suitable for complex geometries; DED offers lower resolution but is ideal for large-scale parts or repairs; Binder Jetting and Metal Extrusion have lower accuracy, often requiring post-processing.

- **Material Properties:** PBF delivers parts with superior mechanical properties (high tensile strength); DED is good for repairs but lacks the precision of PBF; Binder Jetting and Metal Extrusion produce parts with lower mechanical strength, requiring post-processing.

- **Build Speed:** DED has the fastest build times for larger parts; Binder Jetting is also quick for medium-sized parts; PBF is slower due to the scanning process; Metal Extrusion and Sheet Lamination are the slowest.

- **Cost:** PBF has high upfront and operational costs due to expensive materials and equipment; DED is more affordable than PBF but still involves high costs for equipment; Binder Jetting is cost-effective for medium volumes, using cheaper materials; Metal Extrusion and Sheet Lamination are the least expensive but have trade-offs in material properties.

- **Scalability:** DED is highly scalable for large parts or repairs; PBF is best for low to medium-volume, high-precision production; Binder Jetting scales well for medium-volume production of less-critical parts; Metal Extrusion and Sheet Lamination are better for low-volume or prototyping.

Application Suitability

- **Aerospace:** PBF is ideal for lightweight, high-performance parts; DED suits large components and repairs; Binder Jetting is used for prototypes but not for high-strength parts; Metal Extrusion and Sheet Lamination have niche uses in lightweight structures.

- **Automotive:** PBF is used for high-performance parts with complex geometries; DED works for larger automotive components and repairs; Binder Jetting is suitable for prototypes and medium-

sized parts; Metal Extrusion and Sheet Lamination are used for low-volume production and lightweight parts.

- **Medical:** PBF is favored for biocompatible implants and prosthetics; DED is used for repairs and custom prosthetics; Binder Jetting is less common due to material limitations; Metal Extrusion and Sheet Lamination are not widely used in medical applications.

Environmental Considerations

- **Energy Consumption:** PBF requires high energy for laser or electron beam melting; DED is more energy-efficient, especially with arc-based systems; Binder Jetting is the most energy-efficient; Metal Extrusion and Sheet Lamination are relatively low in energy use.

- **Waste Generation:** PBF generates excess powder, but it can be recycled; DED produces minimal waste, mainly excess material; Binder Jetting and Metal Extrusion also create waste, but recycling is possible; Sheet Lamination generates minimal waste from cutting and machining.

- **Recyclability:** PBF and DED can recycle unused powder or wire; Binder Jetting parts can be fully recycled post-sintering; Metal Extrusion and Sheet Lamination are harder to recycle due to binder content.

In conclusion, the choice of AM technology for metal structures depends on factors like performance, cost, scalability, and environmental impact. PBF and DED are ideal for high-precision and large-scale parts but come with higher costs, while Binder Jetting and Metal Extrusion offer cost-effective solutions for lower-performance applications. Environmental considerations, such as energy consumption and recyclability, should also influence the selection process.

5. Challenges and Limitations

Additive manufacturing (AM) for metal structures offers promising advancements but faces several challenges across technical, economic, environmental, and regulatory domains. These factors affect its broader adoption, particularly in industries demanding high precision and performance.

5.1. Technical Challenges

Material Availability and Quality: Limited availability and inconsistent quality of metal powders and filaments are significant hurdles. Properties like particle size and flowability impact part integrity and performance, with variations leading to defects.

Process Reliability and Repeatability: Ensuring consistent outcomes across production runs is challenging due to variability in machine calibration, material quality, and environmental conditions. Reliable process control is critical for applications in aerospace and medical fields [13-15].

Resolution and Surface Finish: Some methods, like Powder Bed Fusion (PBF), offer high resolution but often require post-processing for better surface finish. Technologies like Directed Energy Deposition (DED) or Metal Extrusion have lower resolution, adding to the overall time and cost.

5.2. Economic Challenges

High Costs: Metal AM requires significant upfront investment in machines and materials. Technologies like PBF and DED are expensive, both in capital and operational costs, limiting accessibility for smaller companies.

5.3. Environmental Challenges

Energy Use and Material Waste: Energy-intensive processes, particularly PBF, require high-powered lasers. While some metal powders are recyclable, not all are recoverable, leading to material waste. Efficient recycling and waste management remain key concerns.

5.4. Regulatory Challenges

Certification and Standardization: Obtaining certification for metal AM parts is a slow and costly process, especially in industries like aerospace and healthcare. The lack of established standards complicates regulatory approval and industrial adoption.

In summary, AM for metal structures faces challenges including material quality, process reliability, high costs, environmental impact, and regulatory hurdles. Addressing these issues requires ongoing innovation and collaboration across industries.

6. Emerging Trends and Future Directions

Additive manufacturing (AM) of metal structures continues to evolve, driven by advancements in materials, integration with other manufacturing methods, automation, and a growing emphasis on sustainability. These emerging trends are shaping the future of AM, enabling broader applications and improving its efficiency and environmental impact.

New Materials [18]

- **Alloys and Composites:** The development of specialized metal alloys tailored for AM processes, such as lightweight titanium-aluminum alloys or high-strength steel, is expanding the range of applications. Advanced composites combining metals with ceramics or polymers are being introduced to enhance properties like wear resistance, thermal stability, or conductivity.

- **Advanced Metals:** Efforts are underway to create functionally graded materials (FGMs) that offer varying properties within a single part, enhancing performance in critical applications like aerospace and energy.

Hybrid Manufacturing

- **Integration with Subtractive Methods:** Hybrid manufacturing, which combines AM with traditional machining methods, is gaining traction. For example, AM can produce complex geometries, while CNC milling provides high-precision finishing. This integration allows manufacturers to leverage the strengths of both techniques, enabling faster production cycles and improved part quality.

- **Repair and Retrofit Applications:** Hybrid systems are increasingly used to repair and refurbish high-value components, such as turbine blades, where AM builds new material onto worn areas, followed by precision machining for final touches.

Automation and AI

- **Process Automation:** The integration of sensors, robotics, and automated control systems is streamlining the AM process, reducing human intervention, and ensuring consistent quality. Automated powder handling and part removal systems are improving throughput in high-volume production environments.

- **AI-Driven Optimization:** Artificial intelligence (AI) and machine learning algorithms are enhancing design optimization, defect prediction, and real-time monitoring. AI can help identify optimal process parameters, reducing trial-and-error experimentation and improving efficiency.

Sustainability Initiatives

- **Eco-Friendly Practices:** Efforts to reduce the environmental footprint of AM include developing recyclable metal powders, minimizing energy consumption, and improving powder recovery systems. Binder jetting and metal extrusion processes are increasingly recognized for their energy efficiency compared to more intensive methods like PBF.

- **Green Materials:** Researchers are exploring the use of bio-derived binders and low-energy sintering techniques to reduce environmental impact. Additionally, closed-loop recycling systems for unused powders are becoming standard practice in AM facilities.

Large-Scale Additive Manufacturing

- **Construction and Infrastructure:** Large-scale AM technologies are moving beyond aerospace and automotive applications into the construction sector. Techniques such as Wire Arc Additive Manufacturing (WAAM) are being used to fabricate structural components like bridges and building frameworks, offering faster build times and reduced material waste compared to traditional methods.

- **Energy Sector Applications:** AM is being applied to produce large, high-performance parts for wind turbines, pipelines, and other infrastructure, where cost-effectiveness and customization are critical.

In conclusion, the future of metal additive manufacturing is being shaped by advancements in materials, hybrid manufacturing approaches, and the integration of automation and AI. Emphasis on sustainability and scalability is further expanding its applications, positioning AM as a transformative technology across industries.

7. Conclusion

Additive manufacturing of metal structures represents a transformative shift in manufacturing, offering unparalleled design freedom, material efficiency, and the ability to produce highly customized and complex parts. Key technologies such as Powder Bed Fusion (PBF), Directed Energy Deposition (DED), Binder Jetting, Metal Extrusion, and Sheet Lamination each bring distinct advantages and limitations, making them suitable for specific applications across industries such as aerospace, automotive, and healthcare.

Despite its promise, the broader adoption of metal AM is hindered by persistent challenges. Technical obstacles, including material quality, process reliability, and surface finish, remain critical concerns. Economic barriers, such as the high initial investment and operational costs, particularly for advanced machines and specialized materials, further limit accessibility. Environmental impacts—notably high energy consumption and material waste in some processes—require continued innovation to align with global sustainability goals. Additionally, regulatory challenges, particularly in the standardization and certification of AM processes, pose hurdles for industrial use in critical applications.

Overcoming these challenges necessitates a coordinated effort among researchers, industry stakeholders, and policymakers. Investment in the development of new materials, hybrid manufacturing approaches, and sustainable practices will be crucial. Furthermore, collaboration between industry and academia can drive innovation, while harmonized standards and certification frameworks can accelerate adoption in regulated sectors.

In conclusion, while the technologies for metal additive manufacturing have achieved significant milestones, addressing the remaining technical, economic, and regulatory challenges will be pivotal for its broader application. By fostering collaboration and investing in research, the potential of AM to revolutionize manufacturing can be fully realized, unlocking new opportunities for innovation and growth.

8. References

1. I. Gibson, D. W. Rosen, B. Stucker, et al., *Additive manufacturing technologies* (17, 160-186, Cham, Switzerland: Springer, 2021)
2. I. Gibson, D. Rosen, B. Stucker, *Additive manufacturing technologies: 3D printing, rapid prototyping, and direct digital manufacturing*. (2015)
3. I. Jin, X. Zhai, K. Wang, et al., Big data, machine learning, and digital twin assisted additive manufacturing: A review, *Materials & Design*, p.113086. (2024)
4. D. Herzog, V. Seyda, E. Wycisk, et al., Additive manufacturing of metals, *Acta Materialia*, **117**, 371-392, (2016), <https://doi.org/10.1016/j.actamat.2016.07.019>
5. Z. Liu, D. Zhao, P. Wang, et al., Additive manufacturing of metals: Microstructure evolution and multistage control, *Journal of Materials Science & Technology*, **100**, 224-236, (2022), <https://doi.org/10.1016/j.jmst.2021.06.011>
6. L. Yang, K. Hsu, B. Baughman, et al., *Additive Manufacturing of Metals: The Technology, Materials, Design and Production*, (Springer, 2017)
7. G. R. Kumar, M. Sathishkumar, M. Vignesh, et al., Metal additive manufacturing of commercial aerospace components—A comprehensive review, *Proceedings of the Institution of Mechanical Engineers, Part E: Journal of Process Mechanical Engineering*, **237**(2), 441-454 (2023).
8. F. Careri, R. H. Khan, C. Todd, et al., Additive manufacturing of heat exchangers in aerospace applications: a review, *Applied Thermal Engineering*, 121387 (2023).
9. G. R. Kumar, M. Sathishkumar, M. Vignesh, et al., Metal additive manufacturing of commercial aerospace components—A comprehensive review. *Proceedings of the Institution of Mechanical*

- Engineers, Part E: Journal of Process Mechanical Engineering*, **237**(2), 441-454 (2023).
10. C. Radhika, R. Shanmugam, M. Ramoni, et al., A Review on Additive Manufacturing for Aerospace Application. *Materials Research Express* (2024).
 11. V. Mohanavel, K. A. Ali, K. Ranganathan, et al., The roles and applications of additive manufacturing in the aerospace and automobile sector. *Materials Today: Proceedings*, **47**, 405-409 (2021).
 12. H. A. Colorado, C. A. Cardenas, E. I. Gutierrez-Velazquez, et al., Additive manufacturing in armor and military applications: research, materials, processing technologies, perspectives, and challenges *Journal of Materials Research and Technology*.---JMRT, (2023), <https://doi.org/10.1016/j.jmrt.2023.11.030>
 13. S. Rouf, A. Malik, N. Singh, et al., Additive manufacturing technologies: Industrial and medical applications. *Sustainable Operations and Computers*, **3**, 258-274 (2022).
 14. A. Haleem, M. Javaid, 3D printed medical parts with different materials using additive manufacturing, *Clinical Epidemiology and Global Health*, **8**(1), 215-223 (2020).
 15. S. Boopathi, P. Kumar, Advanced bioprinting processes using additive manufacturing technologies: Revolutionizing tissue engineering. *3D Printing Technologies: Digital Manufacturing, Artificial Intelligence, Industry*, **4**, 95 (2024).
 16. Z. Wawryniuk, E. Brancewicz-Steinmetz, J. Sawicki, Revolutionizing transportation: An overview of 3D printing in aviation, automotive, and space industries, *The International Journal of Advanced Manufacturing Technology*, 1-23 (2024).
 17. S. G. Sarvankar, S. N. Yewale, Additive manufacturing in automobile industry, *Int. J. Res. Aeronaut. Mech. Eng.*, **7**(4), 1-10 (2019).
 18. A. Bhatia, A. K. Sehgal, Additive manufacturing materials, methods and applications: A review, *Materials Today: Proceedings*, **81**, 1060-1067 (2023), <https://doi.org/10.1016/j.matpr.2021.04.379>

Possible energy savings in passenger elevators

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Abstract: Paper deals with determining the possible savings of electrical energy in a passenger elevator. After carrying out calculations with a set number of floors of an administrative building and number of passengers according to a proven and widely used methodology in Bulgaria, an appropriate three-phase squirrel-cage induction motor has been selected to drive the considered elevator system. Calculations have been also carried out on the possible recovery, i.e. returning electrical energy back to the supply power grid when the driving rotating electrical machine is switched to generator mode. Variants with different number of passengers and movement of the cabin in upward and downward directions were theoretically studied. The active power, time to work in recovery mode and the active energy returned to the power grid are defined for each specific case. Calculations of possible electrical energy return in generator mode would be of interest to specialists dealing with these technical facilities.

Keywords: INDUCTION MOTORS, ELECTRIC DRIVE, ENERGY CONSUMPTION, POWER GENERATION, POWER GRID

1. Introduction

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 [1, 2].

Elevators are stationary lifting devices with periodic action, intended for raising or lowering people or various loads 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.

Elevators save us the endless and tiresome climbing of stairs in tall buildings. They were used as early as 2600 years ago, but of course they were quite different from modern ones. The first electric passenger elevator was made by the German company *SIEMENS* in 1888. It rose to 22 m in just 11 seconds. The first *OTIS* electric elevator was installed in a skyscraper in New York in 1889.

Currently, the situation in Bulgaria regarding elevators is as follows. As of 16 September 2024, according to the information system of the State Agency for Metrological and Technical Surveillance (SAMTS) for the facilities with increased danger, which also includes information about the elevators registered by the technical supervision authorities, their number is as follows: registered 90905 elevators, of which 80905 are in operation, and licensed persons have registered 69873 elevators, of which 64117 are in operation. There are 11,122 units in public buildings, which are under the supervision of SAMTS, and 69,873 units are in residential and industrial buildings and they are under the supervision of companies with a license issued by SAMTS to inspect them [3].

A large part of the elevators that left the factories count them as being in service. But there are many buildings in which there are 3 or 4 elevators, but only one is actually functioning. The technical condition of the old elevators is getting worse every year. They are becoming more and more dangerous and still not maintained according to European safety requirements and standards. The average age of elevators that were manufactured before 1992 is now almost 40-45 years. Periodic repairs must be carried out, which are necessary and stipulated by the manufacturers of the respective lifts. All who maintain elevators are obliged to comply with the instructions of the factories that produced them and to carry out functional inspections, technical services: small, medium and capital repairs.

An elevator is a means of transport like a car. It has even been proven that globally, elevators carry the most people in the world, even more than cars. Because many people today will travel by car, by subway, by bus, but they will also take an elevator in a building. So this is an extremely important facility that the owner

must manage properly so that its safety is not compromised. Just as if a car fails technical inspection, its owner is penalized, so if an elevator in an apartment or administrative building fails technical inspection, the owner of the building is penalized [3].

By purpose, elevators are divided into the following types: passenger, hospital, cargo. Elevators are divided by the size of the nominal speed also: low-speed - with nominal speed up to 1 m/s for buildings up to 15 floors; speed - with a nominal speed up to 2.5 m/s for buildings with a height of up to 24 floors; high-speed - with a nominal speed above 2.5 m/s for buildings with a very high height and with a large flow of passengers.

The main parameters that characterize the qualities of individual elevators are: speed, load capacity (the maximum weight of payload or passengers), lift height (the distance from the lowest to the highest service level of the elevator) and number of stops (usually the number of stops overlaps with the number of floors).

Most often, induction motors (IMs) - single-speed and two-speed - are used to drive elevators. Two-speed IMs provide motion at rated and reduced speed. The nominal (high) speed is used for transport between floors, and the low (reduced) speed is used for positioning and precisely stopping the cabin relative to the set floor. Unlike general-purpose IMs, those for elevators have an increased starting torque.

It has been estimated that IMs are used in seventy to eighty per cent of all industrial drive applications [2, 4]. In turn, 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.

The electrical control schemes for passenger elevators that are still widely used are relay-contactor control systems. To improve the operation of elevators and to improve the automation of their management, control systems based on programmable logic controllers (PLC) can be used.

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 [1, 2].

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 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.

2. Details according to the passenger elevator under consideration

The elevator, the subject of this paper, has been designed for an office building with 10 floors. The flow of passengers in the morning is high, up direction, boarding a full cabin and descending an empty cabin, and in the late afternoon it is the opposite – ascending an empty cabin and disembarking passengers afterwards.

When choosing the power of electric motors (EMs) for elevators, the method of successive approximations is used. It consists in the following – on the basis of static loads or statistical data for similar mechanisms, a preliminary power of the EM is determined. With the static load data and the data of the pre-selected motor, calculations have been made and a static and dynamic load diagram has been drawn out for a full cycle. This chart checks the pre-selected motor for warm-up and short-term overheat conditions.

The average power loss method or equivalent quantity methods are used to check the EM for heating. If these checks are not passed, the next higher power motor from the standard power range is selected and the checks are carried out again.

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 [5, 6]. The first three modes (S1, S2 S3) are adopted as the main operating modes of EMs: continuous, short-time and periodic duty. Modes S4 – S10 are introduced to simplify the puzzle of random mode equivalents by rated load, by expanding the nomenclature of the latter. 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.

The duty cycle type of the elevators is Intermittent Periodic Duty (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 [2, 7].

Selected and successfully passed the checks is an EM with specific output data, some of them are:

- ✓ Rated load capacity $G_{RATED} = 3200 \text{ N}$ – i.e. 4 passengers weighing 80 kg ($\approx 800 \text{ N}$) each
- ✓ Cabin travel speed $V = 1 \text{ m/s}$
- ✓ Cabin weight $G_{CABIN} = 5100 \text{ N}$;
- ✓ Guide wheel diameter $D = 0.58 \text{ m}$
- ✓ Transmission ratio of the gear $i_g = 27.32$
- ✓ Number of floors – 10;
- ✓ Floor height $h = 3.6 \text{ m}$;
- ✓ Nominal efficiency of the system $\eta = 0.75$.

Some technical data of the drive EM are given in the Appendix.

In elevators with electric drive, a feature of the mechanical system is the presence of the so-called a counterweight that balances the weight of the cabin plus part of the load.

The weight of the counterweight is determined by the formula:

$$G_{CW} = G_{CABIN} + \alpha G_{RATED}, N \quad (1)$$

where

G_{CW} – weight of the counterweight

α – equalization coefficient, takes values from 0.3 to 0.6, i.e. balancing 30-60% of the rated load capacity. We accept $\alpha = 0.5$.

$$G_{CW} = 6700 \text{ N}$$

The acting resistance forces F_i and their corresponding moments of resistance are determined for each of the possible stops, as well as the travel times and the acting accelerations.

In terms of resistance forces, they are greatest when a loaded cabin with a nominal load starts up from the lowest floor and when an empty cabin descends from the top floor.

The determination of the resistance moments acting on the individual stops is as follows:

$$M_i = \frac{F_i \cdot D}{2i_g \eta_i} = \frac{1600 \times 0.58}{2 \times 27.32 \times 0.75}, Nm \quad (2)$$

where

η_i – efficiency for the respective stop.

In terms of accelerations, the two most severe cases with the largest values in elevator operation are lowering a full cabin and raising a single passenger. When starting and stopping the elevator, the accelerations must be less than the permissible value 1.5 m/s^2 . If the accelerations in the mentioned cases are greater than the permissible value, with an already selected EM, they can enter the norm by changing the flywheel moment of the system with the addition of a flywheel.

Both the torque of an EM and its speed can be in different directions. Since in mathematical formulations the direction of velocity and torque are represented by their signs, both quantities are sign-variable. The polarity of angular velocity and torque determines the direction of power transmission between the motor and the mechanism connected to it (this mechanism is considered as a mechanical load). When the shaft power of the electric motor is $P > 0$, the EM motor operates in motor mode. In this mode, the EM converts electrical energy to mechanical energy. Electrical energy is drawn from the supply power grid, converted to mechanical energy in the EM and given to the load, i.e. the mechanism. When $P < 0$ the EM is said to be operating in braking mode.

There are three types of braking modes:

✓ generator braking (with release of electrical energy into the power grid)

In this stop, the rotor is spun by an external mechanical source. The angular speed becomes greater than the synchronous speed: $\omega > \omega_0$. The slip s becomes negative, the signs of the induced voltage and current in the rotor change and the IM becomes an induction generator (IG). This method of stopping is used in micro-hydroelectric power plants and in mechanisms with a potential active moment of resistance (elevating transport mechanisms - cranes, hoists and elevators).

✓ dynamic braking

It is used for squirrel-cage IMs in flywheel mechanisms. The stator winding is disconnected from the mains and to two of the phases voltage is applied from a direct current (DC) source which creates a constant stationary field. The interaction of the rotating magnetic field of the rotor and the stationary magnetic field of the

stator produces a braking effect. In this mode IM becomes a generator, which is loaded with the resistance in the rotor circuit. Mechanical energy is converted into thermal energy, which is dissipated in the air space.

- ✓ braking by counter-locking: exclusively for IMs with a wound rotor.

As a summary – in the generator modes, the mechanical energy coming from the working machine is converted in the EM to electrical energy. In regenerative braking, electrical energy is fed back into the power grid. In practice, rotation frequencies much higher than synchronous are not allowed due to increased losses and heating and reduced efficiency. That is why, even as a generator, the asynchronous machine works with slips that are the same in absolute value as those of a motor.

3. Results obtained

In connection with the set goal, calculations were carried out for the possible recovery, i.e. returning electrical energy back to the supply power grid when the driving rotating electrical machine is switched to generator mode.

Two sets of calculations have been performed. First group of calculations have been carried out in the case that there is no previously selected EM and only the output data is used – 10-floor building (each floor with a certain height and floor slab thickness) with a lift for a maximum of 4 people. A second group of calculations have been carried out in a different way - with an already selected EM – and taking into account its nominal data (mainly rated power and rated rotational frequency).

For both sets of calculations, results have been obtained for the movement of the cabin with passengers in it in the UP and DOWN directions. The results for moving the cabin with passengers in it in the DOWN direction are assuming it moves from the top floor to the ground floor.

The obtained results are presented in tabular form below.

Table 1: Results of preliminary calculations for an electric motor for an upward direction

Number of passengers	Forces at the stops, N	Efficiency at the stops	Torques at the stops, Nm	Active power, kW	Working time, s	Active energy, $\times 10^{-3}$ kWh
4 passengers	$F_0=1600$	0.75	$M_0=22.65$	2.134	8.33	4.938
	$F_1=800$	0.72	$M_1=11.79$	1.111	8.33	2.571
	$F_2=0$		$M_2=0$	0	8.33	0
	$F_3=-800$	0.48 (load downward)	$M_3=-4.08$	-0.384	8.33	0.890
3 passengers	$F_0=800$	0.687	$M_0=800$	1.164	11.1	3.589
	$F_1=0$	0.114	$M_1=0$	0	11.1	0
	$F_2=-800$	0.596 (load downward)	$M_2=-800$	-0.477	11.1	1.471
2 passengers	$F_0=0$	0.114	$M_0=0$	0	16.65	0
	$F_1=-800$	0.596 (load downward)	$M_1=-800$	-0.477	16.65	2.206
1 passenger	$F_0=-800$	0.596 (load downward)	$M_0=-800$	-0.477	33.3	4.412

Table 2: Upward direction results with electric motor selected

Number of passengers	Active power, 6.8 kW	Working time, s	Active energy, $\times 10^{-3}$ kWh
4 passengers	Between stop 3 and stop 4	8.33	15.734
3 passengers	Between stop 2 and stop 3	11.1	20.967
2 passengers	Between stop 1 and stop 2	16.65	31.450
1 passenger	To stop 1 (we accept the last floor)	33.3	62.900

Table 3: Results of preliminary calculations for an electric motor for a downward direction

Number of passengers	Forces, N	Efficiency	Torque, Nm	Active power, kW	Working time, s	Active energy, $\times 10^{-3}$ kWh
4 passengers	$F_f=1600$	0.66	$M_f=11.21$	1.056	33.3	0.010
3 passengers	$F_f=800$	0.59	$M_f=5.01$	0.480	33.3	0.004

Table 4: Downward results with electric motor selected

Number of passengers	Active power, kW	Working time, s	Active energy, $\times 10^{-3}$ kWh
4 passengers	5.8	33.3	62.9
3 passengers	5.8	33.3	62.9

It can be seen from Table 2 and Table 4 that the greatest savings in electrical energy are achieved in the cases of raising 1 passenger from the ground floor to the top floor and when lowering 3 or 4 passengers from the top floor to the ground floor.

Other scenarios are also possible, but the ones studied so far show certain trends.

4. Conclusions

The treated topic is actual, as the results of some developments in this area have not yet been put into practice.

With the availability of smart electricity meters in recent years, the electricity generated by the elevators could be counted and deducted from the monthly bills of consumers. If this energy is not taken into account, it is immediately consumed (and recorded on another electricity meter) by the nearest consumer.

Regardless of the specific case - whether it is a new elevator or an existing one - it would be good to take into account the possible savings in electrical energy. They directly affect the monthly and annual electricity costs of administrative and domestic buildings.

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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6. References

1. Engineering Review Journal <https://www.engineering-review.bg/>.
2. Rachev S., Permissible number of switches on per hour of electric motors for horizontally moving crane mechanisms. VIII International Scientific Conference „INDUSTRY 4.0" Winter Session, 06-09 December 2023, MACHINES, TECHNOLOGIES, MATERIALS, Issue 8/2023 ISSN 1313-0226.
3. Bulgarian national daily www.telegraph.bg
4. Crowder R. Electric Drives and Electromechanical Systems, 2006, Elsevier Ltd., ISBN-13: 978-0-7506-6740-1. pp. 96, 191, 214.
5. Electrical Power Engineering Reference & Applications Handbook (ISBN 81-901642-5-2) <https://www.electricalengineering-book.com/pdf/chapter-865728.pdf>
6. Costruzioni Motori Elettrici <https://www.cmesrl.com/en/duties-motors/>
7. Hughes A. Electric Motors and Drives. Fundamentals, Types and Applications, Third edition, 2006, Elsevier Ltd., ISBN-13: 978-0-7506-4718-2. p. 376.

Appendix

INDUCTION MOTOR DATA

Type AC 200-1-6/24 – elevator two-speed induction motor

Rated power – $P_H = 6.8 / 1.4$ kW

Cyclic duration factor – CDF = 50/10 %

Number of switches on per hour – SF = 180 h⁻¹

Rated voltage – U = 380 V

Rated rotational frequency – $n_r = 897 / 193$ min⁻¹

Rated current – $I_n = 17.0 / 13.8$ A

Multiplicity of starting torque – 2.55/1.86

Multiplicity of starting current – 63.5/19.0

Rotor moment of gyration – 1.07 kgm²

Weight – 160 kg

Investigation and analysis of tested plastic films according to ASTM D6992 Standard Test Method for Accelerated Tensile Creep using the Stepped Isothermal Method

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Abstract: In the article, experimental results according to ASTM D6992 standard test method for accelerated tensile creep of plastic films were investigated and analyzed. A regression model was created based on the obtained results. Real and theoretical data were compared in order to determine deviations of the model and what is the reliability of the theoretical data.

Keywords: CREEP, PLASTIC TESTING, STEPPED ISOTHERMAL METHOD, REGRESSION ANALYZE.

1. Introduction

Materials creep is a process of slowly increasing plastic deformation at constant temperature and applied stresses below yield strength [1]. Creep deformation depends on several factors - temperature, applied load and specific characteristics of material. The process of material creep is not yet fully studied [2].

Plastics are widely used in mechanical engineering, construction, automobile manufacturing, etc [3]. Plastics are increasingly used as a structural material, as well as part of composites that are subjected to long-term loads. Studies of the creep process in plastics is very current, because it characterizes dependability of materials in long-term applications.

The test to determine creep limit has a long duration - up to 10,000 hours, therefore accelerated creep of materials is often used, as well as various mathematical models with estimated values, [4], [5]. Through these methods, duration of the test is reduced and resources are spared without compromising results.

2. Materials and methods

HDPE-mixture was chosen as test material because it is one of the most used plastics, so the obtained results and data are significant for manufacturers. Polyethylene has high mechanical-physical properties and is not affected by moisture [6]. Polyethylene is used for pipes, tanks, insulation, packaging, etc. Polyethylene is a recyclable material, which contributes to its even wider use, in addition to being a virgin material, but also as a recycled one.

The test was performed according to ASTM D6992-Accelerated tensile creep and creep-rupture of geosynthetic materials based on time-temperature superposition using the stepped-isothermal method [7]. Stepped isothermal method (SIM) consists of defined temperature steps and dwell time in order to accelerate testing process. Deformation and dead weight are presented as a function of time. The duration of the test according to the standard is a not less than 60,000 seconds.

The test was carried out on a calibrated universal creep testing machine, which has an appropriate range of values - temperature, dead weight and linear deformation according the standard and the selected material. The results are generated automatically, and the error of the measured values is less than 0.5% according the calibration data atmospheric conditions are controlled according to the standard requirements.

Suitable gripping jaws were chosen, which, on one hand, do not allow sample slipping, and on the other hand, do not apply excessive load on sample, which would rupture it. Mechanical system of the lab stand is stable and minimizes errors of the sample's alignment. The insulation of the stand does not permit fluctuations in temperature. The stand, including the dead weight system and gripping is shown in fig. 1.

The selected test program is shown in Fig.2 and Table. 1. Six temperature steps, each of 10 000 seconds are selected in order to meet the requirement for a minimum duration of 60,000 seconds.



Fig.1 Universal creep testing stand

Table 1: Temperature steps and dwell times

Steps	1	2	3	4	5	6
Dwell Time (min.)	170	170	170	170	170	170
Temperature (C°)	23	30	37	44	51	58

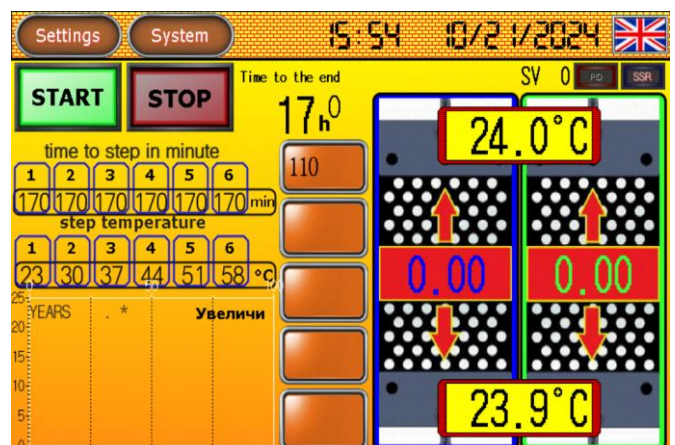


Fig. 2 Test program

The calibrated dead weights used for tensile creep stresses are 4(3 discs of 10 kg and 2 discs of 5kg) The samples have dimensions - length 120 mm, thickness 1.3 mm, width 100 mm. The sample is textured and contains six holes-diameter of which is 20 mm. Accelerated creep testing of the materials means using equivalent times [8]. Each minute of testing at a certain temperature determines equivalent time according to the standard shown in

Temperature Co	Equivalent times (min.)
23	1
30	10
37	100
44	1000
51	10000
58	100000

- Regression equation
- Result variable
- Stochastic residuals.

3. Results and discussion

[illegible]

Mathematical and statistical processing was performed with the program product MINITAB. For the purposes of the study, the data of only one sample were selected. The equivalent years were selected as the independent variable, and the dependent linear deformation in percentages[11]. The data from the study were processed and the following regression model was obtained:

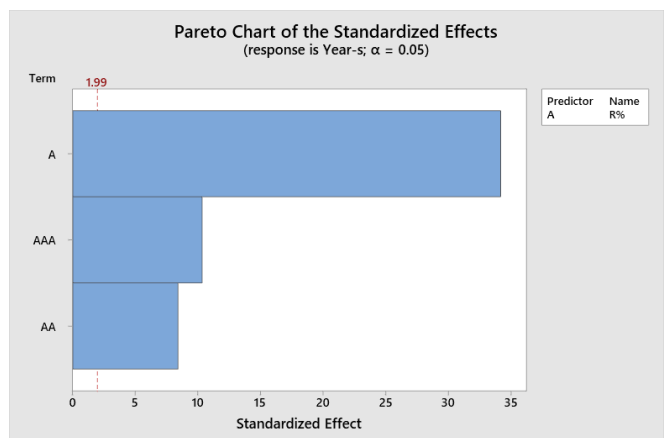
Table 3 presents the coefficients of the variables and standard errors.

			95% Upper			
Term	Coef	SE Coef	Bound	T-Value	P-Value	VIF
Constant	0.000143	0.000578	0.001107	0.25	0.805	
R%	-0.00251	0.001111	-0.00066	-2.26	0.027	15.19
R%*R%	0.009659	0.000806	0.011003	11.98	0.000	1.55
R%*R%*R%	0.01379	0.00133	0.01601	10.33	0.000	13.36

S	R-sq	R-sq(adj)	PRESS	R-sq(pred)	AICc	BIC
0.0017454	95.12%	94.91%	0.0002429	94.36%	-713.27	-702.71

Source	DF	Seq SS	Contribution	Adj SS	Seq MS	F-Value	P-Value
Regression	3	0.004099	95.12%	0.004099	0.001366	448.49	0.000
R	1	0.003558	82.57%	0.000016	0.003558	1167.97	0.000
R%*R%	1	0.000215	5.00%	0.000437	0.000215	70.70	0.000
R%*R%*R%	1	0.000325	7.55%	0.000325	0.000325	106.81	0.000
Error	69	0.000210	4.88%	0.000210	0.000003		
Lack-of-Fit	13	0.000097	2.26%	0.000097	0.000007	3.72	0.000
Pure Error	56	0.000113	2.62%	0.000113	0.000002		
Total	72	0.004309	100.00%				

The Pareto diagram, shows the absolute values of the standardized effects from the largest to the smallest effect fig 5 [12]. The chart also draws a reference line to show which effects are statistically significant. The components are after the significance line, therefore all the coefficients are significant.



A Normal Probability Plot for the response variable 'Year-s'. The x-axis is labeled 'Standardized Residual' and ranges from -4 to 4. The y-axis is labeled 'Percent' and is on a probability scale from 0.1 to 99.9. A solid red diagonal line represents the expected normal distribution. Blue dots representing the standardized residuals are plotted along this line. The points follow the line closely, indicating that the residuals are approximately normally distributed.

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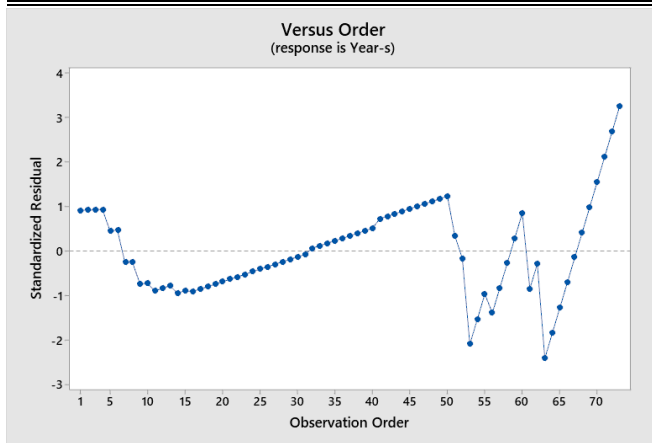


Fig. 7 The standardized residuals in order of obtains

Analysis of residuals is performed using plots in Fig. 6,7. The values of the standardized residuals should be within ± 2 [13].

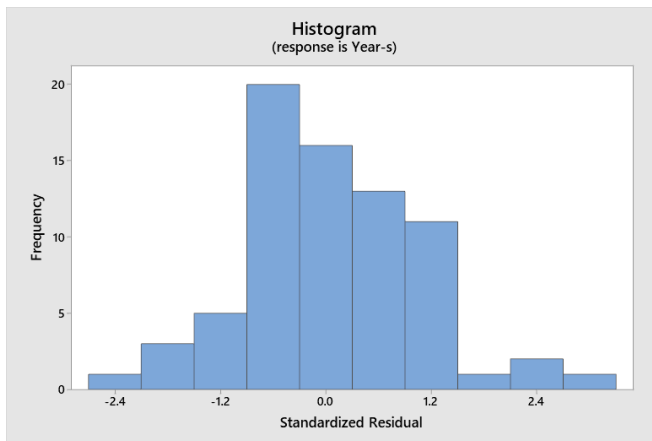


Fig. 8 Histogram of standardized residuals

Figure 8 shows a diagram of the standardized residuals, which shows that the normal distribution is right-skewed.

4. Conclusions

From the obtained regression model, the relative elongation according to equivalent years can be predicted with an accuracy of 98.4%.

The verification of the results obtained from the model show that they are statistically significant, which proves the mathematical dependence between the variables. The use of a regression model leads to obtaining adequate results and eliminating random errors caused by various factors. The model can also be used for creep tensile testing of other materials in order to reduce duration of the test. It is possible to use other mathematical models in order to optimize test duration and used resources.

5. References

1. Xu, Zhen & Zhu, Qiang. (2024). A Novel Approach to Estimate Creep Rupture Life of the Co-Ni-Cr-W-Fe-Mn Superalloy by Multi-Station Compressive Creep Tests. 10.3233/ATDE240520.
2. Li, Yuan & Keegan, Kaitlin & Baker, Ian. (2024). Observations of creep of polar firm at different temperatures. 10.5194/egusphere-2024-2337.
3. Treaty, Scientists & Courtene-Jones, Winnie. (2023). Policy Brief: Role of chemicals and polymers of concern in the global plastics treaty. 10.5281/zenodo.7941525.
4. Iskakbayev, Alibay & Teltayev, Bagdat & Aitbayev, Yerbol & Zhaisanbayev, Azamat. (2024). Accelerated Creep of Asphalt Concrete at Medium Temperatures. Applied Sciences. 14. 9393. 10.3390/app14209393.
5. Lu, Joan & Xu, Qiang. (2024). Modelling Long Term Creep Deformation and Creep Damage and the Extrapolation Methods. 10.3233/ATDE240658.
6. Fisis, Sifat & Komposite, Kayu & Terbuat, Plastik & Polietilen, Bahan & Tinggi, Kerapatan & Hdpe, & Rahayu, Yuyu & , Rahayu & Setiawan, Wahyu & Amban, Gunung & Manokwari, Papua & Barat, & Pelaksana, Balai & Rumah, Penyediaan & Ii, Papua & Hijau, Lembah & Korespondensi, Penulis & Asosiasi, & Biodiversitas, Peneliti & Kehutanan, Papuaasia. (2024). PHYSICAL BEHAVIOUR OF WOOD PLASTICE COMPOSITE MADE OF RECYCLED HIGH-DENSITY POLYETHYLENE (HDPE). 9. 229-237. 10.46703/jurnalpapuasiasia.Vol9.Iss2.313.
7. Liu, Wenbo & Zhang, Shuguang. (2023). Accelerated creep model based on the law of energy conservation and analysis of creep parameters. Mechanics of Time-Dependent Materials. 28. 10.1007/s11043-023-09628-6.
8. Liu, Yanyan & Huang, Dongsheng & Sheng, Baolu & Wang, Wendao. (2023). Prediction of the long-term flexural behavior of glued laminated bamboo using accelerated creep test. Wood Science and Technology. 57. 10.1007/s00226-023-01491-5.
9. Masi, Filippo. (2024). Introduction to Regression Methods. 10.1002/9781394325634.ch2.
10. Araripe, Patrícia & Lara, Idemauro & Palma, Gabriel & Cahill, Niamh & Moral, Rafael. (2024). Diagnostics for categorical response models based on quantile residuals and distance measures. Journal of Applied Statistics. 51. 1-23. 10.1080/02664763.2024.2367150.
11. Lu, Min & Ishwaran, Hemant. (2024). Model-independent variable selection via the rule-based variable priorit. 10.48550/arXiv.2409.09003..
12. Sari, Ceni & Supardi,. (2022). PARETO DIAGRAMS STUDY OF GROSS REGIONAL DOMESTIC PRODUCT EXPOSURE IN CERTAIN SECTORS IN A REGION. JURUTERA - Jurnal Umum Teknik Terapan. 9. 23-27. 10.55377/jurutera.v9i02.6643.
13. Ospina, Raydonal & Espinheira, Patrícia & Arias, Leilo & Xavier, Cleber & Leiva, Víctor & Castro, Cecilia. (2024). New Statistical Residuals for Regression Models in the Exponential Family: Characterization, Simulation, Computation, and Applications. Mathematics. 12. 3196. 10.3390/math12203196.

Frost resistance of hollow ceramic structural elements for ceramic beehives

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Abstract: In laboratory conditions, the frost resistance of hollow ceramic samples (constructive elements of ceramic beehives) was examined by applying a standardized methodology for assessing the reliability of ceramic products. For both sample types that were investigated (each with different phase compositions), the result for the frost resistance coefficient K_{fr} is above 84%. The products retain their structural integrity and high resistance in an extreme temperature environment. It was not observed any significant damage that could disrupt their functionality. The obtained results prove the assumptions that the ceramic beehives are appropriate for use in vast geographical regions characterized by critical temperatures and high diurnal and seasonal temperature amplitudes. At the same time, the experimental data can serve for further optimization of the recipe compositions, the technological regime, and for improvements of the construction characteristics of the ceramic elements that build the ceramic beehive.

Keywords: CERAMIC BEEHIVE, FROST RESISTANCE, MARL, KAOLIN, MOISTURE ABSORPTION

1. Introduction

There are various natural, anthropogenic, and complex factors causing moderately negative to fatal effects on the normal development and survival of bee families [1-3]: diseases typical for the brood and the adult bees; impact of natural enemies of the honey bee (mainly various insects, birds and others); environmental pollution from growing industrial activity; increasing use of toxic insecticides for plant protection in the agricultural sector; intensive noise pollution (transport traffic, industrial production, construction, and others); annual fires with extensive localization, global climate changes and many other.

Bee farms nowadays are widely using several basic systems of beehives [4] made of different materials (wood, polystyrene, and others).

Due to its suitable workability, wide availability, natural origin and environmental friendliness, wood is a predominant and relatively cost-effective raw material for the production of beehives [2]. The use of wood as the main construction material allows the use of various technological methods of processing, accurate implementation of the designed construction options, and preparation of a wide assortment of products [4]. Spruce, pine, fir, pine, linden and others are used in the production of various beehive systems [2, 4]. The existing experience in the practice shaped the opinion that coniferous resinous trees are better raw materials for beehives as they can provide higher resistance to the impact of destructive cyclic weather factors (mainly during the winter season).

At the same time, in the course of active exploitation of the widely spread standard wooden beehives, it is observed a critical disadvantage [4] - the relatively low resistance under dynamic extreme climate conditions.

To effectively overcome some of the existing main problems in the beekeeping sector, an innovative beehive was created. Its construction consists of hollow ceramic elements that form air chambers providing thermal insulation of the hive. [5].

For materials with a porous structure (such as many types of ceramics), frost resistance is a key factor in their durability. The moisture that has penetrated the material's pores freezes at low temperatures, which leads to the expansion of water and, accordingly, to an increase in the internal tension in the pores. Repeated freezing and thawing causes: microcracks, widening of existing cracks, reduction of mechanical strength, damage to the surface layer, and other damages.

The frost resistance of the material depends on its porosity, capillary structure, absorption properties, and strength. Various tests and analyses determine how well a material can retain its properties and structure under continuous exposure to freeze-thaw cycles.

The study of frost resistance of hollow ceramic structural elements composed of anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$) - marl clay and washed kaolin ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$) is of key importance for creating resistant and long-lasting materials suitable for use in

beehives. Ceramic elements created on the basis of these minerals combine good mechanical strength and a specific microstructure with porosity that supports their thermal insulation properties. Despite these advantages, the porous structure is still vulnerable to climate influences, such as freezing and thawing, which can lead to the accumulation of water deposits in the hollow of the material. Over time, this process causes micro-level expansion and contraction, leading to microcracks and structural deterioration of the material.

The present work aims to study the degree of resistance of ceramic structural elements (for the production of ceramic hives) to freezing and thawing cycles and to analyze their impact on the microstructure and the strength of the elements. The obtained results are intended to be used for improvements of the material so that it provides reliable protection and comfort for bee colonies and their owners.

2. Experimental procedures

For the purpose of the study and the examination of the frost resistance of hollow ceramic elements were used the following methods:

2.1. Preparation of the samples:

- There were prepared two types of samples and from each type were prepared 5 elements. The types are respectively: from a mixture of marl clays - anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$), with dimensions of 162 mm x 75 mm x 25 mm with a cavity of 66%; and from a mixture of washed kaolin ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$) with dimensions of 310 mm x 156 mm x 25 mm with a cavity of 66%.
- The samples were produced according to a previously established technology for the production of elements for hives by slip casting.

2.2. Initial measurement and analysis:

- Marl clay samples - anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$), size 162mm x 75mm x 25mm with a cavity of 17mm or 66% cavity;
- Washed kaolin samples ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$) measuring 310 mm x 156 mm x 25 mm with a cavity of 17 mm or 66 % cavity;

To register results for changes in the pores and possible microcracks, we performed an initial microstructural analysis of the samples (fig. 1,2, and 3). For this, we used a scanning electrical digital microscope, Wireless Microscope HiView, version 1.4, 2000 c USB 1600x, Windows 2000/2003/XP/Vista/7, Linux.

The main physical properties of the samples were determined at the beginning of the study, as follows:

- Compressive strength - 2550 kg/cm² washed kaolin; compressive strength of marl clay (anorthite) - 2250 kg/cm²;
- Moisture absorption - of the washed kaolin sample - 2,65%; moisture absorption of the marl clay (anorthite) sample - 3,4%.

2.3. Exposure to freeze-thaw cycles [6]:

The samples are exposed to frost-thaw cycles according to the following procedure:

- The samples are dried in a dryer at $105 \pm 5^\circ\text{C}$ to a constant mass and after that their weight is measured. They are cooled to an ambient temperature of 25°C and the mass is measured again. [Md]
- After that, the samples are immersed in a tank of tap water at room temperature and the water is heated in the vessel to $80^\circ\text{C} \pm 3^\circ\text{C}$ for 2 hours. At cool saturation, water enters only the fully open pores, while at 80°C water temperature, it is assumed that it enters the semi-closed pores.
- The water-saturated samples are weighed with an electronic scale with accuracy ± 1 gram and the results are recorded [Mw]. Then the samples are left to air for 20 minutes and weighed again [Ms]
- They are placed in a freezer chamber at temperature of $-18^\circ\text{C} \pm 3^\circ\text{C}$. Each freezing cycle is at least 5 hours, counted from the moment of reaching the set temperature - 15°C .
- Follows a rapid thawing by blowing warm air at temperature of $105^\circ\text{C} \pm 5^\circ\text{C}$ for 20 minutes and subsequently leaving at room temperature 25°C for 20 minutes.
- Each subsequent cycle starts by pouring over with tap water for minimum 2 minutes, weighing them immediately and after resting for 20 minutes. After that they are placed in the freezing chamber for the next freezing.

The first freezing period lasts 6 hours, each subsequent freezing period must last minimum 5 hours in the chamber after reaching the set temperature. A cycle of defrosting and subsequent humidification follows. This freeze-thaw cycle is repeated 51 times.

3. Results and Discussion

3.1. Monitoring of the microstructural changes:

- We are monitoring for cracks on the sample surface.
- Using a scanning microscope, we scan the surface of the samples for cracks and capillaries after cycles 35 and 50.
- After cycle 35 and cycle 50 for all the anorthite samples ($\text{CaAl}_2\text{Si}_2\text{O}_8$), there is no change in dimensions, nor capillary cracks (fig.1). For the samples of washed kaolin ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$) there is no change in dimensions. After cycle 50, on one of the parts of a kaolin sample is identified a crack of 1 mm – 2 mm (fig.3) with a length of about 50 mm. The crack is observed in the funnel area. After cycle 50 capillaries are noticed on the surface layer of the same sample (fig.3). For the rest of the samples are not observed any defects or cracks (fig. 2).



Fig. 1 A marl clay sample from left to right: at the beginning; after cycle 35; after cycle 50



Fig. 2 The surface of a washed kaolin sample at the beginning; after cycles 35; and after 50 cycles (from left to right)

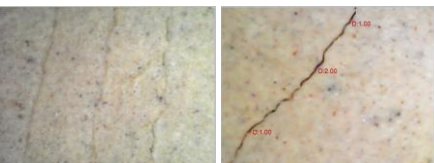


Figure 3 Surface capillaries and a crack on one of the washed kaolin samples

3.2. Measurement of physico-mechanical properties after freezing and thawing cycles:

After the 35th and the 50th cycles, the key physico-mechanical parameters are measured again: sample sizes, and compressive strength. The results of these measurements are presented in tables 1 and 2 respectively for marl clay and washed kaolin.

Table 1. Marl clay samples.

No of cycle	Marl rock sample dimensions anorthite ($\text{CaAl}_2\text{Si}_2\text{O}_8$),	Moisture absorption coefficient [%]	Compressive strength [kg/cm^2]	Defects/ presence of capillaries and cracks
1	162 mm x 75 mm x 17mm	3,40	2250	No
35	162 mm x 75 mm x 17mm	3,35	2200	No
51	162 mm x 75mm x 17 mm	2,22	2150	No

Table 2. Washed kaolin samples.

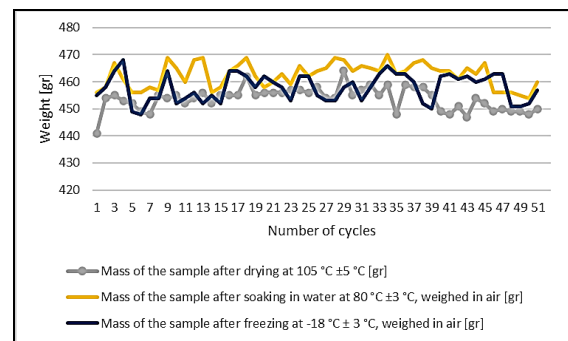
No of cycle	Dimensions of the washed kaolin sample ($\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$)	Moisture absorption coefficient [%]	Compressive strength [kg/cm^2]	Defects/ presence of capillaries and cracks
1	310 mm x 156 mm x 25 mm	2,65	2550	ne
35	310 mm x 156 mm x 25 mm	2,00	2450	ne
51	310 mm x 156 mm x 25 mm	0,68	2400	ne

The results we obtained show that after 50 frost-thaw cycles of the samples, a crack with the size of 1 mm is observed on the surface of only one of them. This defect is located in the area of the technological holes, which are the result of the casting process. This is probably one of the weakest areas of the element, where the tension concentration is higher and the structural resistance is lower.

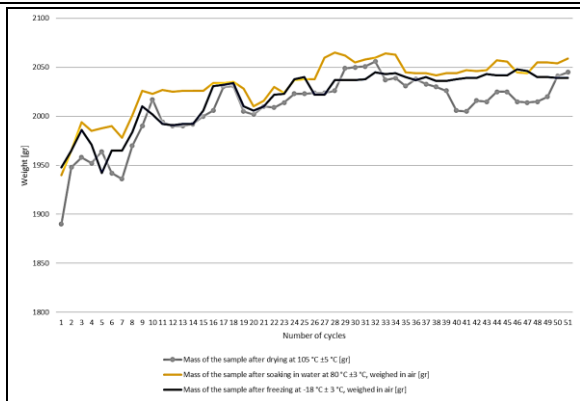
We observe that the compressive strength decreases both for the samples from kaolin (5,88%) and marl clay (4,44%).

The experimental method we have applied allows us to get a holistic and comprehensive view of the effect of freezing and thawing cycles on the structural and mechanical resistance of hollow ceramic elements composed of marl clay and glass ceramics.

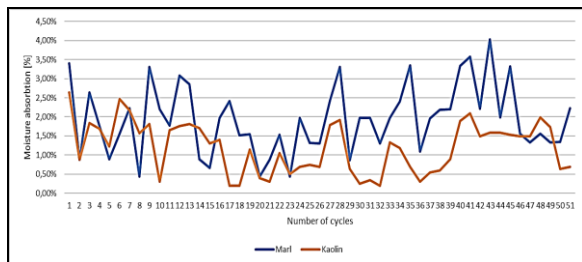
The focus of the analysis is the change of the weight of the samples when they are watered, dried, frozen, and defrost. All measurements are included in a table. Based on the obtained results we present the following graphs: Graph 1 Shows the mass of the marl clay samples after drying, after soaking in water, and after freezing. Graph 2 contains the same information but for the kaolin samples. Graph 3 displays the information about the water absorption of the two types of samples over the 50 cycles.



Graph 1. Mass change of marl clay samples



Graph 2. Mass change of washed kaolin samples



Graph. 3. Moisture absorption of marl clay and washed kaolin samples

3.3. Evaluation of frost resistance and analysis of results:

The frost resistance coefficient was calculated for the samples of marl clay anorthite: $K_{mr}=84.45\%$ and washed kaolin $K_{mr}=84.30\%$. According to the standard, the coefficient should be smaller than 85% for a product to be considered frost-resistant. In the case of our experiment, both sample types can be considered frost-resistant.

For the samples of washed kaolin we found that the material shows stability under existing conditions (drying, soaking in water, and after freezing). Weight changes are minimal, indicating high resistance to freeze/thaw cycles. The location of the crack is around the technological openings related to the casting process: The crack is concentrated around the technological opening, indicating that this area is more susceptible to microstructural defects in cold due to the different density of the material in this area. Another reason may be the accumulation of internal pressure during the casting and baking of the element. Such pressure becomes a reason for a higher degree of water absorption by the pores leading to freeze expansion. Lower water absorption of the kaolin samples is connected to less pores. During the cycles of watering, water can not be spread evenly on the surface and while freezing uneven tensions are created. This is the reason why for these samples we observe capillary structural changes on the surface.

For the samples of marl clay, we observe relatively higher water absorption and weight change, especially after soaking in water and freezing. We connect this observation to the higher porosity of the material which would generally mean it shall be more prone to defects. We observe that for the course of 50 frost-thaw cycles, there are no changes of the structure on the surface of the samples, no cracks, nor capillaries which means that the higher porosity contributes to an even distribution of inner tensions.

4. Conclusion

Our analysis shows that for both types of examined samples, a sufficient level of frost resistance is reached. They passed successfully through 50 frost-thaw cycles without significant changes which can damage their functionality. This leads us to the conclusion that the selected casting mixtures (marl clay (anorthite) and kaolin) have physicomaterial properties that make them appropriate for use in places with variable or extreme temperature conditions.

5. References

1. M. L. Winston, "The Biology of the Honey Bee", Book, Revised Edition, Publisher Harvard University Press, 1991.
2. D. M. Caron, L. J. Connor, "Honey Bee Biology and Beekeeping", Book, Publisher Wicwas Press, Revised Edition, Eds R. G. Muir, A. Harman, 2013.
3. R. M. Johnson, "Honey Bee Toxicology", Annual Review of Entomology, 60(1), 2015, pp. 415–434.
4. P. Nenchev, I. Zhelyazkova, "Beekeeping". Academic Publishing House, Trakia University, Stara Zagora, Bulgaria, 2010.
5. T. Lepkova, I. Martinova, M. G. I. Marinova, B. Pincheva, "Ceramic beehive – conceptual paper," Science. Business. Society., vol. 4, No. 2, 2019, pp. 52–54.
6. БДЦ EN 1344:2014

Investigation properties of part – holder of breaking shoe beam made of SG60/SE300 steel cast

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Abstract: The main reason to perform this research investigation was to find a reason for appearing failures in exploratory condition of a part holder of breaking shoe beam. This part is incorporated in an assembly in railway wagon. This part together with few others was damaged in exploratory condition. It means that cracks were noticed on these parts. Some parts were completely broken. Because of that purchaser of parts complained of received parts to the producer. One of these parts was delivered to Prof Cvetkovski to find a reason and to give opinion about the reason for failure. The damaged parts are made of cast steel SG60/SE300. Many types of investigation was performed in order to solve this problem. As first visual control was done. After that, radiographic control was made. Investigations continued with determination of chemical composition and macro and micro metallography and determination of non-metallic inclusions. Finally mechanical testing like tensile testing, hardness measurement and impact toughness were performed too. Performed research confirmed that typical casting defects in the investigated part like the hot tears, slag inclusions, shrinkage porosity and segregation are the main reasons for failure of the delivered parts, holder of breaking shoes i.e. appearing of cracks or their completely fracture.

KEYWORD: HOLDER OF BREAKING SHOE BEAM, SG60/SE300, STEEL CAST, HOT TEARS, SLAG INCLUSIONS, FRACTURE, MICROSTRUCTURE,

Introduction

This technical report was prepared on the request of company for production of parts for railways vehicles. Subject of investigation is holder of breaking shoe beam as a part of assembly mounted in railway wagons. Because of accident, which happened to some of these parts in exploitation conditions, the purchaser of parts submit complaint to the producer in order to explain the reason for the failure. According obtained information's, about sixty parts were delivered to the purchaser. Six of them were failed. More concretely in few parts was noticed cracks and few parts were completely fractured.

One of the rejected parts was returned to the supplier in order to be performed investigations and to find a reason for appearing of defects – cracks. Producer of assembly asked Prof Cvetkovski to make investigations and find a reason for occurred accident.

It has to be point out that casting parts were produced by subcontractor i.e. casting company. Damage of parts happened in exploitation conditions. During routine control was detected that some parts have cracks but some of them were completely broken. Investigated part is one of the few parts in which cracks appeared in exploitation period. It was clearly confirmed that casting technology is base reason for failure of parts [1, 2].

1 Material for investigation

Investigated part was produced by steel casting GS60 (GE300) with material number 1.0558. It is defined as steel cast for general engineering purposes. Designation C60 of this of steel cast is according DIN EN 1681 while designation CE300 is according EN 10293. After casting heat treatment i.e. normalization was performed [3]. Once cast, steel alloys will often have a non-homogeneous microstructure, which includes large grains as well as other unwanted structural components normalizing the casting will deliver a uniform, fine-grained structure with greater mechanical predictability and improved machining qualities [4, 5].

This cast has a fairly low ductility and a moderately high tensile strength among cast carbon, non-alloyed steels. Delivered steel holder for investigation is presented in the figure 1. This part is obtain by send casting process.



Figure 1 Received holder for investigation

2 Performed investigations

2.1 Visual inspection

Visual inspection of the holder (figure 2) was done by necked eye and magnifying lens. Inspection confirmed that one macro crack was formed in the holder. On the top of the part the crack is much wider. Propagating into interior crack become thinner and stop to propagate in the material. It is quite normal to expect that crack will continue to grow if part continue to work. Other cracks or some other defects was not detected in the holder by visual inspection. It can be seen too that part is painted after production.



Figure 2 Crack on the specimen

2.2 Radiographic testing (RT)

Radiographic testing was performed using x-ray tube XXG-2005 and Kodak T500 films with Pb foils. The seven expositions of the investigated specimen was made. Besides macro crack, noted during visual inspection, no other significant casting defects were detected Figure 3 (a-c).

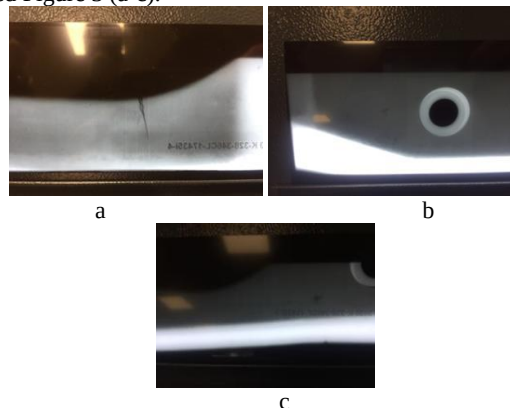


Figure 3 Radiographic films

2.3 Determination of the chemical composition of the holder

For determination of the chemical composition of the investigated holder, piece with dimension 30x30 was cut. The emission spectrometer type SPECTRO was used for chemical analysis. Obtained concentration of chemical elements were compared with the values prescribed in previously mentioned standards (tables 1 and 2).

Table 1 Chemical composition of the analyzed steel casting compared compared with DIN 1681prescribed values

Element %	C	Si	Mn	P	S	Cu
Measured (SPECTRO)	0.44	0.32	0.724	0.019	0.05	0.15
Standard DIN 1681)	0.27-0.32	0.456	0.75-0.90	0.04	0.04	0.3

Table 2 Maximum concentration of unspecified elements in analyzed specimen is given in DIN EN 10293 standard

Element %	Cr	Ni	Mo
Measured values (SPECTRO)	0.349	0.182	0.08
Standard EN 10293)	0.3	0.4	0.12

2.4 Metallography

For the metallographic investigations was prepared specimen cut from the holder containing the macro crack (figure 4). Standard metallographic preparation of the specimen was performed. After grinding and polishing with diamond powder, Nital (3%) etching of the specimens was done. Macro and microanalysis were made on the specimen. Polished specimen was used for the analysis of the material cleanliness (non-metallic inclusions) or any others type casting defects. Optical microscope Meiji Techno was used for metallographic investigation.

2.4.1 Macro metallography

Figure 5 presents prepared specimen for macro metallographic investigation. Macro inspection confirmed that one macro crack was formed in the holder. On the top (origin, Point A) the crack is much wider. Propagating into interior crack become thinner and stop to propagate in the material point B. Other cracks was not detected in the holder by macro metallography.

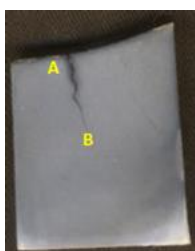


Figure 5 Metallographic specimen with crack cut from the holder

2.4.2 Analysis of the non-metallic inclusions

Non-metallic inclusions were analyzed on polished metallographic specimens using optical microscope Meiji Techno. Magnification of x100 was used for this analysis. As can be seen from the metallographic pictures, material is pretty clean concerning non-metallic inclusions. The presented inclusions are small mainly rounded, randomly distributed (figure 6 (a-c)).

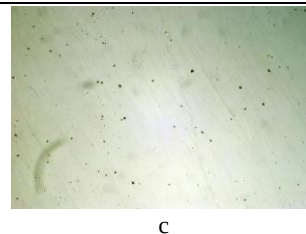
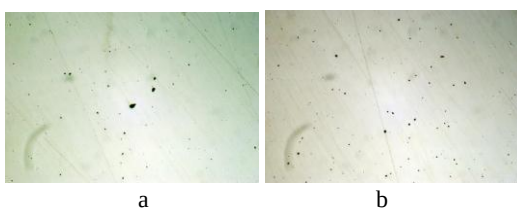


Figure 6 (a-c) Nonmetallic inclusions in casting x100

2.3.3 Analysis of defects on the polished surface

Figure 7 (a and b) present beginning and end of the macro crack. It can be seen from the figure 7a that crack origin is pretty wide, but it must be point out that very big defect so call slag inclusion is detected on the left side of the crack. End of the crack is shown on the figure 7b. It is important to say that propagation of crack is forced by presence of the of the defects in the material like shrinkage cavities.

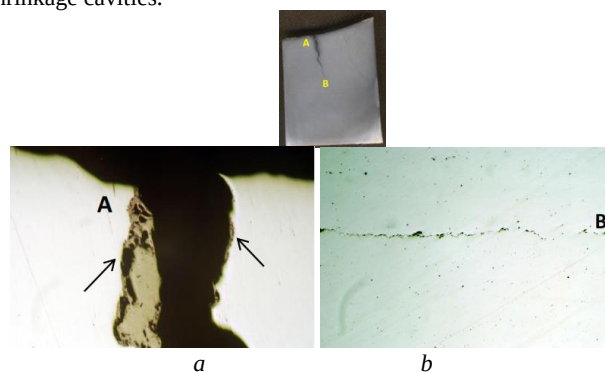


Figure 7 (a and b) a. beginning b. end of crack

Figure 8 presents end of this central crack magnified x500. Shrinkage cavities are clearly noticed during this magnification.

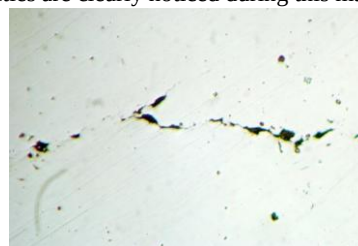


Figure 8 End of the crack x500 - shrinkage cavity

Figure 9 shows polished surface of the specimen. It is clearly seen crack formed beneath the surface, which start from the some impurity, and it's propagate almost parallel with the surface of the specimen.



Figure 9 Crack beneath the surface x100 (on the left side of the macro crack)

Figure 10 presents cracks, which are, formed on the surface of the specimen. Their orientation is different.

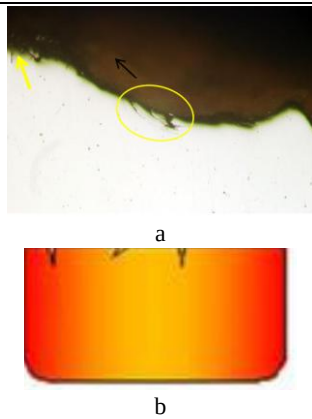


Figure 10 a. Formed cracks on the surface of the specimen with different orientation, x100 b. hot tears schematic presentation (right side from macro crack)

2.4.3 Micro metallography

Figure 11(a and b) presents microstructure of the investigated, casted part (holder) after normalization. It is clearly seen that microstructure consists of ferrite and pearlite. It can be concluded that ferrite delineate former austenite grains. Segregation in the part can be seen too.

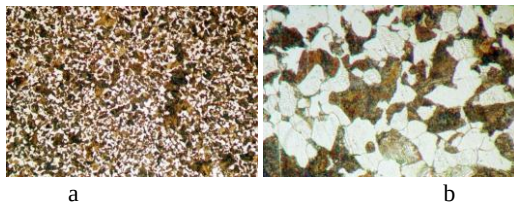


Figure 11 Microstructure of the normalized specimen etched with Nital
a. x100 b. x500

Figure 12 (a-d) shows microstructure of the specimen in the neighbourhood of the crack. With black arrows are shown slag inclusions.

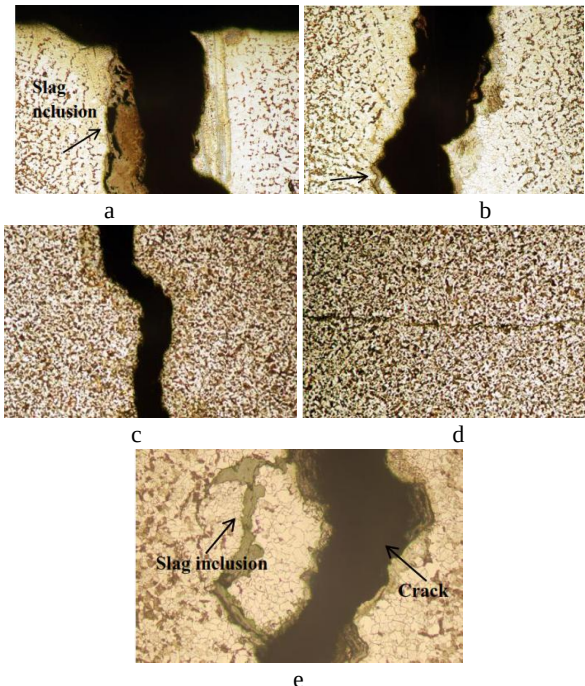


Figure 12 Present defects in the specimen i.e. slag inclusions near the crack

2.5 Tensile testing

For determining tensile properties of casted part, one round specimen was machined. Obtained results from testing probe are

given in the table 3. Diagram stress-deformation is given in the figure 13, and fractured surfaces of the specimen are shown in figure 14.

Table 3 Tensile properties of the material – holder

Tensile properties	RP _{0.2}	Rm, MPa	A
Measured values	660	750	17
Standard EN 1293	300	600-750	15

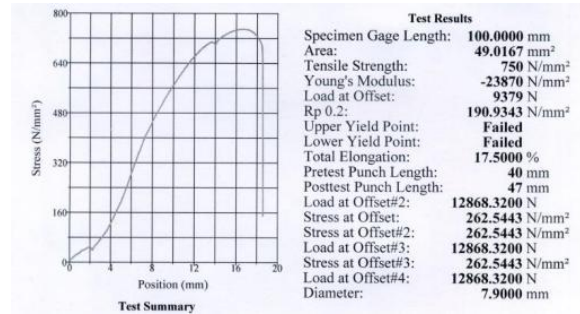


Figure 13 stress-strain diagram



Figure 14 Fractured surface of tensile specimen

2.6 Impact toughness

Impact toughness testing was performed at ambient temperature i.e. 20 °C as is standard requirement for this material. Three specimens with V notch were prepared. Because of lower thickness of the part nonstandard specimens with dimension is 10x8x55. According standard for material with thickness beneath 13 mm the value of impact toughness should be 27J. It is clear that specimens with proper dimensions should fulfill requirements. Fractured surfaces of Charpy specimen is given in figure 15, and obtained toughness value is given in the table 4.



Figure 15 Fractured surface of impact specimen

Table 4 Impact toughness value for tested Charpy specimens

Specimen no	1	2	3
Impact value	25	24	20

2.6 Hardness measurement

Hardness measurement was made using HRB method. According with standard requirement for normalized steel cast (SG60) DIN 1681 hardness values should be in range 165/215 HB. Hardness was measured from the top of the specimen toward its interior. As can be seen from the figure 16, the highest hardness value is measured at the top of the specimen i.e.185HB. But the hardness in the interior is 163HB. It means that difference of 20HRB units. Because of that additional measurement's was made on the top of the specimen, and the same values were obtained. In order the explain such situation metallographic analyze was made figure 16b. It can be seen that at the top of the specimen microstructure is deformed and consist of fine grains Microstructure in the interior consists of ferrite and pearlite. Microstructure have to be normalized ferrite pearlite like in the lower part of the figure 16b. Anyhow, hardness values in the range of standard requirement.

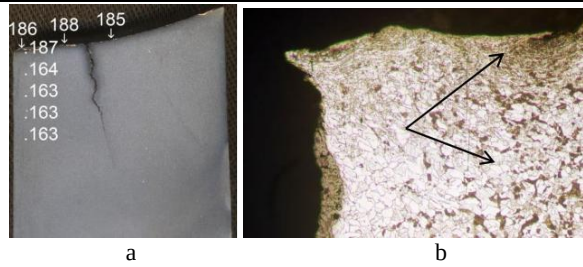


Figure 16 (a and b)

a. Measured hardness values

b. microstructure near the top of the specimen and in the interior

Discussion

Chemical composition of the holder is in accordance with standard requirement, only carbon content is over upper limit prescribed with standard 0.44 %C, and required values should be 0.27-0.32%C. In order to determine mechanical properties of the casting, specimens were prepared from the investigated holder near the crack. Hardness values were measured on the metallographic specimen. It was decided for this option because we did not have testing coupons. Generally, it can be concluded that mechanical properties fulfil requirement. More concretely mechanical properties of the investigated specimens correspond with values prescribed by standard.

It was found from metallographic analysis that few types of casting defects directly influence the quality of the casting holder i.e. formation of macro crack [6-8]. One of them are hot tears and another slag inclusions, besides shrinkage cavity and segregation contribute for defects formation in the investigated part too [9]. It can be concluded from the metallographic analysis that besides main crack and another crack were detected; some of them starts from surface and some appear and propagate beneath the surface these type of cracks are known as a hot tears or hot cracks [10]. Another detected defects are slag inclusions. Slag inclusions located immediately near to the macro crack. Both types of defects belong to the metallurgical casting defects [11,12]

Description and reasons for the appearing of hot tears in casting:

- hot tears are intercrystalline discontinuity (cracks),
- cracks run along the grain boundaries,
- the risk of cracks at alloys with a high freezing range is higher than with a small freezing range,
- the reason are stresses during solidification because of hindered a small freezing range contraction (residual stress)
- the main reason for formation of hot tears are the geometry of casting.

Prevention:

- design appropriate to casting, prevention of residual stresses, wide difference in the wall thickness and hot spots)
- prevention of hot sand effects .

The main reasons for appearing of slag inclusions are the following:

Slag inclusions are divided in two main groups - endogenous and exogenous inclusions

Endogenous inclusions are caused by the reaction products during the melting process (especially during deoxidation). Exogenous inclusion are caused by other materials in the melt e.g. refractory lining.

Prevention of slag inclusion appearing in casting are the following: use of clean charge,

optimization of gating and feeding system (lamellar flow), decrease of the dissolved oxygen, decrease of the overheating temperature Shrinkage cavities were detected on the metallographic specimen too. Nevertheless, they are pretty small and propagate along the imagine line, figure 8.

Metallographic specimen with macro crack was broken after performed investigation. Our idea was to perform visual inspection on the fractured surface (figure 17). It is clear that fractured surface is coarser in the upper half. With arrows and circles are denoted locations with impurities. Besides crack and impurities were detected on the fractured surfaces.

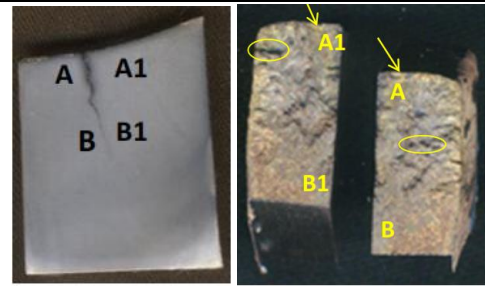


Figure 17 Fractured surface of metallographic specimen

Additionally pictures from other damaged holders were required from purchaser in order to compare the location and types of defects. It was concluded that macro cracks were detected in all cases, and its location is almost at the same for all specimens. It is another confirmation that casting technology is the main reason for the accident.



Conclusion

From the performed investigation was concluded that formation of macro cracks in the investigated holder is influenced by few types of casting defects i.e. hot tears and slag inclusion. Besides shrinkage cavities, (porosity) and segregation were detected on the metallographic pictures too. It is well known what are the reason for their appearing. So our opinion is that these defects are results of unappropriated casting technogy like mold design, too high or too low casting temperature, deformation during cooling and many other. If producer did not undertake necessary precautionary these crack should not appear. As most important for appearing of this metallurgical reason could be slag in the molten metal, very high temperature of molten metal, stress of the casting during cooling, improper design of casted part and similar.

Although mechanical properties of the part are in accordance with standard requirement, casting technology is the main reason for cracks appearing.

Literature

- [1] DIN EN 10293, Steel castings for general engineering uses English version of DIN EN 10293
- [2] EN1559-1:2011, Founding Technical conditions of delivery – Part 1: General
- [3] EN1559-2:2011, Founding Technical conditions of delivery – Part 2: Additional requirement for steel casting
- [4] DIN 1681:1967-06 Steel Castings for General Use; Quality Specifications
- [5] 1681: GS-60 Cast Steel
- [6] SCRATA, Steel casting research and trade association, Comparators for the definitions of surface quality of steel castings
- [7] MSS SP-55-2001, Quality standard for Valves, Flanges, Fittings and other piping components,
- [8] Avinash Juriani, Casting Defects Analysis in Foundry and Their Remedial Measures with Industrial Case Studies, IOSR Journal of Mechanical and Civil Engineering, Volume 12, Issue 6 Ver. I (Nov. - Dec. 2015)
- [9] Sparrow Xiang, 22 Types of Casting Defects: Tips for Prevention, Lasted Update: August 27, 2024
- [10] Dr. D.N. Shivappa1, Mr. Rohit2, Mr. Abhijit Bhattacharya3 “Analysis of Casting Defects and Identification of Remedial Measures – A Diagnostic
- [11] Akash A. Gaware, Dr. A. K. Mahalle, A Review on Investigation of Casting Defects with Simulation, International Journal of Innovations in Engineering and Science, Vol. 2, No.5, 2017
- [12] Vaibhav Ingle1 Madhukar So, Defects, Root Causes in Casting Process and Their Remedies: Review, Int. Journal of Engineering Research and Application www.ijera.com ISSN : 2248-9622, Vol. 7, Issue 3, (Part -3) March 2017, pp.47-54

Laser ablation in liquid as innovative method for preparation of ZnO-zeolite nanocomposites

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Abstract: Laser ablation in liquid is an eco-friendly and efficient method to produce nanomaterials with interesting properties in a laboratory scale. Previously reported ZnO nanoparticles, obtained by nanosecond and millisecond pulsed laser under various laser parameters, demonstrated photocatalytic, gas-sensing, and antibacterial activity. Here we explore the possibility for laser ablation of Zn metal plate in natural zeolite suspension and isolation of a composite ZnO-Zeo. It was characterized by UV-vis, XPS and SEM methods. The characteristic UV-vis peak for ZnO nanoparticles was observed at 340 nm, which is associated with small particles size, proven by SEM images to be 30-50 nm. The spherical ZnO particles are located on the zeolite surface. It was found that the attraction forces between both phases cause a shift in Zn 2p XPS peak positions which were determined at 1022.0 eV and 1045.1 eV for 2p_{3/2} and 2p_{1/2} levels, respectively. The approach for laser ablation in suspension could open avenue for simultaneous formation and incorporation of various nanoparticles into different supports.

Keywords: LASER ABLATION IN LIQUID, ZnO NANOPARTICLES, ZEOLITES, NANOCOMPOSITES.

1. Introduction

Laser ablation in liquid (LAL) is a versatile method for preparation of various types of colloidal nanoparticles such as monometallic and bimetallic nanoparticles, metal oxides, metal sulfides and carbides. Laser irradiation of inert metals leads to break down of large pieces of material into smaller ones giving diverse metallic nanostructures, while reactive metals undergo laser-induced chemical reactions that take place in a limited zone near the laser beam, producing metal oxides by oxidation of metals in aqueous solution or causing formation of metal sulfides, carbides, chlorides in organic solvents [1-5]. The changes in laser parameters permit to tune the morphology and structure of the material, size and size-distribution of the nanoparticles and thus to alter the properties of laser-assisted nanomaterials. It is worth mentioning that this technique is convenient, easy-to-do and cost-effective approach to fabricate from nanoparticles to functionalized nanocomposites, which are needed for development of recent nanotechnology. Another advantage of this method comes from the environmental point of view, as it is an environmentally friendly approach. It uses small amounts of solvents and reagents to produce neat nanoparticles without formation of side products and chemical waste. The above-mentioned characteristics render the method among innovative and efficient methodologies for fabrication of materials with unique properties [6-7].

ZnO is well-known for its antibacterial, photocatalytic, photovoltaic and sensing properties that strongly depend on its morphology, crystallinity, surface area, size and dimensions of nanoparticles. According to the synthetic method and reaction conditions, these parameters may vary in wide ranges and thus allowing to produce ZnO for various applications. Among many methods such as precipitation [8], sol-gel [9], hydrothermal [10], ZnO can be produced by LAL applying femtosecond, nanosecond or millisecond pulsed lasers with specific wavelengths [11-23]. For example, infrared femtosecond laser ablation was applied to tune ZnO band gap by doping with Mg²⁺ ions and formation of structure defects within the nanoparticles [18]. In another case, laser ablation of Zn in NH₄NO₃ solution provided N-doping of ZnO [19]. Dorrani et al. demonstrated that the size of ZnO NPs produced by 532-nm-wavelength nanosecond laser is smaller than that of nanoparticles formed by 1064-nm laser, which also affected the photoluminescence properties of the studied particles [15]. Abbas et al. used LAL-synthesized ZnO NPs for further hydrothermal treatment to improve surface area and defects density that enhance the photocatalytic activity of ZnO [17]. ZnO nanospheres and ZnO nanorods were prepared via the laser ablation of a Zn plate in water using nanosecond- and millisecond-pulsed lasers, respectively. The ZnO nanorods showed better photocatalytic performance towards dye degradation than their spherically shaped counterparts [23].

When ZnO nanoparticles are used as photocatalyst, their separation from the reaction mixture could be a problematic, especially in large-scale systems. To avoid such difficulties, ZnO can be immobilized onto a support which would allow easier recovery of the nanocomposite. At the same time, often synergetic effect of photocatalytic action of nanocomposite is observed, resulting from adsorption of target molecules on the support and getting it in close contact with photocatalyst's surface. Zeolites are suitable candidates, as they have chemically and thermally stable and porous structure which is an ideal template for formation, growth and immobilization of nanoparticles on it. Zeolites are microporous crystalline aluminosilicates, consisting of SiO₄ and AlO₄ tetrahedrons connected in a network via oxygen bridges. The presence of Al³⁺ ions make the framework with a negative charge that is compensated by exchangeable ions, such as Na⁺, K⁺, Ca²⁺, Mg²⁺, etc. This structure determines the exceptional ion-exchange properties of zeolites and their specific application in water treatment, catalysis and many other areas [24]. Shaw et al. alter the adsorption capacity of a zeolite by growth of porous layer of ZnO nanoflakes on the zeolite surface and ensure effective and rapid removal of heavy metal ions and organics [25]. Impregnation of ZnO in three types of zeolites was proposed as heterogeneous photocatalysis in [26].

This paper describes the preparation of nanocomposite ZnO-zeolite through laser ablation of zinc metal plate in suspension of zeolite by using second-harmonic laser with nanosecond pulse width and pulse energy of 51 mJ/pulse. The obtained colloid was characterized by SEM, XPS and UV-vis spectroscopy. Thus, the work demonstrates the application of LAL for nanocomposites fabrication, while keeping the structure of zeolite support unchanged.

2. Experimental

2.1. Materials

A natural zeolite from East Rhodopes mountain in Bulgaria was used. The raw material was milled and fractioned, washed several times, dried and analyzed. The XRD analysis showed that it mainly consists of clinoptilolite (76%) [27]. The Na-modified form of zeolite was prepared by ion-exchange with Na⁺ ions from 2M solution of NaCl, then the solid was separated, washed, dried and used further for preparation of nanocomposites. A Zinc plate with 2-mm thickness and 99.5% purity of the metal, was degreased in organic solvents and washed twice with deionized water via sonication, and then used for ablation.

2.2. Method

The ablation procedure was carried out by using Nd:YAG laser with a wavelength of 532 nm, in a quartz cuvette with dimensions of 30 mm × 30 mm × 50 mm, and a wall thickness of 2 mm. The

liquid medium was prepared from 50 mg Na-modified zeolite and 20 cm³ deionized water, dispersed in an ultrasonic bath for 360 s. Then, Zn metal plate was immersed in the suspension in vertical position and fixed on the quartz wall of the cuvette. The reaction mixture was agitated by a magnetic stirrer during the experiment, the laser beam was focused on the target and the ablation lasted for 45 min. The laser parameters used were as follows: a pulse energy of 51 mJ/pulse, a pulse width of 7 ns, and a repetition rate of 10 Hz. The obtained colloid was centrifuged, nanocomposite was separated from supernatant and prepared for characterization by UV-vis spectroscopy, Scanning Electron Microscopy (SEM) and X-ray Photoelectron Spectroscopy (XPS). The sample is denoted as ZnO-Zeo. For comparison, the same procedure was applied for preparation of ZnO NPs by laser ablation of Zn plate in neat, deionized water.

3. Results and discussion

The nanocomposite ZnO-Zeo was prepared by laser ablation of zinc metal plate in the presence of zeolite dispersed in deionized water. During laser irradiation tiny zinc droplets and zinc ions react with water at extremely high temperatures, attained from the second-harmonic laser, to give ZnO nanoparticles. Their formation was proven by UV-vis spectrum of supernatant isolated from the freshly prepared colloid, shown in Fig. 1. The peak at 340 nm is typical for absorption of ZnO nanoparticles that originated from an electron transition from the valence band to the conduction band of the semiconductor [11, 23]. The absorption band of nanosecond-laser-produced ZnO NPs was detected at 365 nm in [23] which is associated with bigger size nanoparticles than that in this composite. Kim et al. found size- and shape-dependance to wavelengths of the laser, when ablated Zn plate in neat water [16]. The absorbance below 300 nm arises from the zeolite framework.

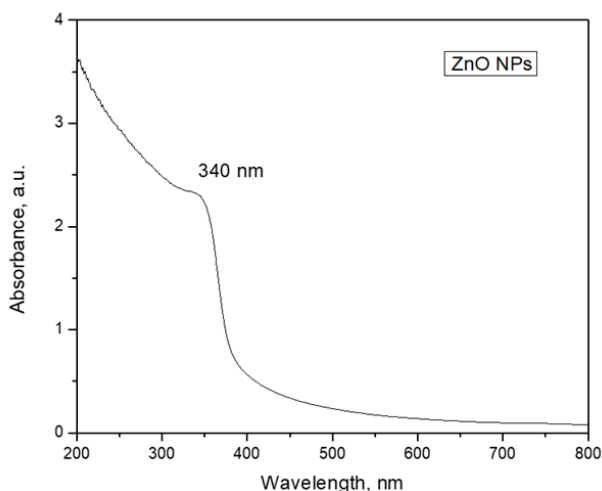


Fig. 1. UV-vis spectrum of as-prepared suspension.

The morphology of the nanocomposite was observed by SEM and displayed in Fig. 2. It can be seen that ZnO NPs with an average size of 30-50 nm are located on the zeolite surface. Like neat ZnO NPs, produced for purpose of comparison, the shape of particles is spherical, which was also observed for other ZnO NPs produced by nanosecond laser [12-16]. The size of ZnO NPs prepared in water (without zeolite) varies in the range 50 – 200 nm, which is bigger than that of nanoparticles obtained in zeolite suspension. It could be explained by the presence of zeolite in ablation medium. Most probably zeolite, that occurs in the aqueous suspension during the zinc-metal ablation, gains part of the irradiation energy and thus affects nucleation and growth of ZnO NPs in the sample ZnO-Zeo. Kulinich et al. ablated Zn plate with a second harmonic pulse laser with fluence of 30 mJ/pulse at ambient

pressure and prepared NPs with broad particle size distribution up to 100 nm. They found that the pressurized water medium resulted in smaller particles (< 20 nm) and narrow size distribution [13]. Change of laser wavelength to 1064 nm and increasing of pulse energy to 120 mJ/pulse gave ZnO NPs in the range 10 – 90 nm [23]. Therefore, the size, dispersity, band gap, defects of ZnO strongly depend on the laser parameters, time and medium used.

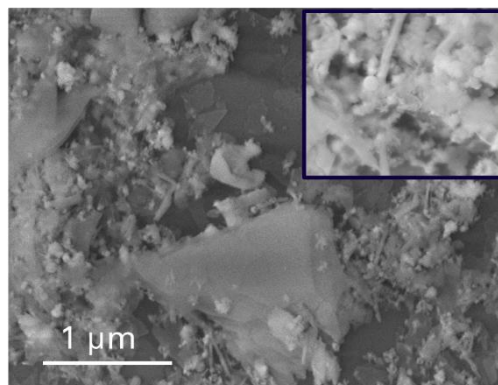


Fig. 2. SEM images in the sample ZnO-Zeo at different magnifications.

The surface chemistry of nanocomposite was studied by XPS analysis. Figure 3 shows Zn 2p XPS spectrum of ZnO-Zeo sample, that consists of doublet at 1022.0 eV and 1045.1 eV for 2p_{3/2} and 2p_{1/2} levels, respectively. For comparison, the XPS spectrum of ZnO NPs, synthesized herein at the same laser conditions, was also measured. The 2p_{3/2} and 2p_{1/2} peak positions are observed at 1021.4 eV and 1044.5 eV, respectively. Similar positions (1021.5 ± 0.1 eV and 1044.6 ± 0.1 eV) were reported for other ZnO NPs prepared by laser ablation in neat water [23]. The slight shift of the signals for ZnO-Zeo can be attributed to the interactions between ZnO NPs and zeolite framework in the sample ZnO-Zeo.

O1s XPS peak for ZnO-Zeo sample was detected at 532.3 eV (Fig. 4) and assigned to oxygen atom from zeolite network, while a signal for oxide ion from ZnO was not observed due to low abundance of ZnO-nanoparticles onto zeolite surface. As a matter of fact, the O1s signal for ZnO NPs, prepared in neat water, was registered at 530.2 eV with a shoulder at 532.0 eV raised from O²⁻ in ZnO lattice and hydroxyl groups on the oxide surface, respectively. Other authors also reported similar peak positions for pure ZnO [23, 28, 29].

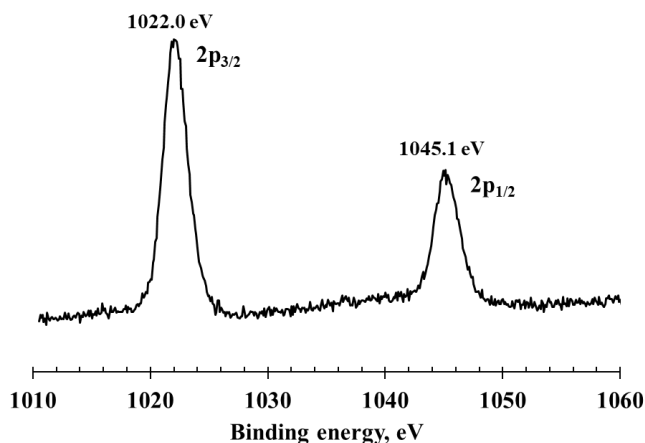


Fig. 3. Zn 2p XPS spectrum of the sample ZnO-Zeo.

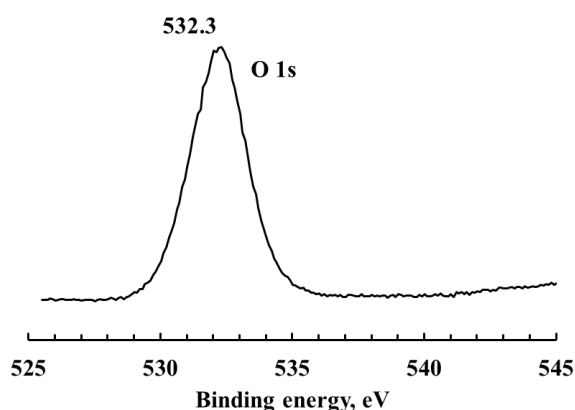


Fig. 4. O1s XPS spectrum of the sample ZnO-Zeo.

4. Conclusions

We applied the method of laser ablation in liquid and prepared nanocomposite ZnO-Zeo. Although part of the laser energy was absorbed by the zeolite in the reaction mixture, the ablation of Zn plate by focused laser beam led to formation of ZnO nanoparticles that were deposited on the zeolite surface. The SEM images of ZnO-Zeo and ZnO samples revealed that the size of the ZnO NPs on zeolite is smaller than that of neat ZnO nanoparticles. The adsorption and photocatalytic properties of the nanocomposite will be analyzed in our future work.

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6. References

1. Zeng, H.B.; Du, X.W.; Singh, S.C.; Kulinich, S.A.; Yang, S.K.; He, J.P.; Cai, W.P. Nanomaterials via laser ablation/irradiation in liquid: A review. *Adv. Funct. Mater.* **2012**, *22*, 1333–1353.
2. Niu, K.Y.; Yang, J.; Kulinich, S.A.; Sun, J.; Du, X.W. Hollow nanoparticles of metal oxides and sulfides: Fast preparation via laser ablation in liquid. *Langmuir* **2010**, *26*, 16652–16657.
3. Niu, K.Y.; Yang, J.; Kulinich, S.A.; Sun, J.; Li, H.; Du, X.W. Morphology control of nanostructures via surface reaction of metal nanodroplets. *J. Am. Chem. Soc.* **2010**, *132*, 9814–9819.
4. Qin, W.J.; Kulinich, S.A.; Yang, X.B.; Sun, J.; Du, X.W. Preparation of semiconductor nanospheres by laser-induced phase separation. *J. Appl. Phys.* **2009**, *106*, 114308.
5. Zhang, J.; Chaker, M.; Ma, D. Pulsed laser ablation based synthesis of colloidal metal nanoparticles for catalytic applications. *J. Colloid Interface Sci.* **2017**, *489*, 138–149.
6. Zhang, D.; Liu, J.; Li, P.; Tian, Z.; Liang, C. Recent advances in surfactant-free, surface charged and defect-rich catalysts developed by laser ablation and processing in liquids. *ChemNanoMat* **2017**, *3*, 512–533.
7. Xiao, J.; Liu, P.; Wang, C.X.; Yang, G.W. External field-assisted laser ablation in liquid: An efficient strategy for nanocrystal synthesis and nanostructure assembly. *Prog. Mater. Sci.* **2017**, *87*, 140–220.
8. Mukhopadhyaya, S.; Pratim Das, P.; Maity, S.; Ghosh, P.; Devi, P.S. Solution grown ZnO rods: Synthesis, characterization and defect mediated photocatalytic activity. *Appl. Catal. B* **2015**, *165*, 128–138.
9. Hasnidawani, J.N.; Azlina, H.N.; Norita, H.; Bonnia, N.N.; Ratim, S.; Ali, E.S. Synthesis of ZnO Nanostructures Using Sol-Gel Method. *Procedia Chem.* **2016**, *19*, 211–216.
10. Han, X.G.; He, H.Z.; Kuang, Q.; Zhou, X.; Zhang, X.H.; Xu, T.; Xie, Z.X.; Zheng, L.S. Controlling morphologies and tuning

the related properties of nano/microstructured ZnO crystallites. *J. Phys. Chem. C* **2009**, *113*, 584–589.

11. Honda, M.; Goto, T.; Owashi, T.; Rozhin, A.G.; Yamaguchi, S.; Ito, T.; Kulinich, S.A. ZnO nanorods prepared via ablation of Zn with millisecond laser in liquid media. *Phys. Chem. Chem. Phys.* **2016**, *18*, 23628–23637.
12. Ishikawa, Y.; Shimizu, Y.; Sasaki, T.; Koshizaki, N. Preparation of zinc oxide nanorods using pulsed laser ablation in water media at high temperature. *J. Colloid Interface Sci.* **2006**, *300*, 612–615.
13. Kulinich, S.A.; Kondo, T.; Shimizu, Y.; Ito, T. Pressure effect on ZnO nanoparticles prepared via laser ablation in water. *J. Appl. Phys.* **2013**, *113*, 033509.
14. Kondo, T.; Sato, Y.; Kinoshita, M.; Shankar, P.; Mintcheva, N.; Honda, M.; Iwamori, S.; Kulinich, S.A. Room temperature ethanol sensor based on ZnO prepared via laser ablation in water. *Jpn. J. Appl. Phys.* **2017**, *56*, 080304.
15. Dorrnanian, D.; Solati, E.; Dejam, L. Photoluminescence of ZnO nanoparticles generated by laser ablation in deionized water. *Appl. Phys. A* **2012**, *109*, 307–314.
16. Kim, K.K.; Kim, D.; Kim, S.K.; Park, S.M.; Song, J.K. Formation of ZnO nanoparticles by laser ablation in neat water. *Chem. Phys. Lett.* **2011**, *511*(1–3), 116–120.
17. Abbas, K.N.; Bidin, N. Morphological driven photocatalytic activity of ZnO nanostructures. *Appl. Surf. Sci.* **2017**, *394*, 498–508.
18. Chelnokov, E.; Rivoal, M.; Colignon, Y.; Gachet, D.; Bekere, L.; Thibaudau, F. Band gap tuning of ZnO nanoparticles via Mg doping by femtosecond laser ablation in liquid environment. *Appl. Surf. Sci.* **2012**, *258*, 9408–9411.
19. Tarasenko, N.; Butsen, A.; Pankov, V.; Velusamy, T.; Mariotti, D.; Tarasenko, N. Laser assisted preparation of doped ZnO nanocrystals. *Nano-Struct. Nano-Objects* **2017**, *12*, 210–219.
20. Goto, T.; Honda, M.; Kulinich, S.A.; Shimizu, Y.; Ito, T. Defects in ZnO nanoparticles laser-ablated in water-ethanol mixture at different pressures. *Jpn. J. Appl. Phys.* **2015**, *54*, 070305.
21. Sett, D.; Basak, D. Tuning the luminescence and UV photosensing properties of ZnO nanorods by strategic aqueous chemical growth. *Mater. Res. Express* **2015**, *2*, 105008.
22. Gavrilenko, E.A.; Goncharova, D.A.; Lapin, I.N.; Nemoykina, A.L.; Svetlichnyi, V.A.; Aljulaih, A.A.; Mintcheva, N.; Kulinich, S.A. Comparative study of physicochemical and antibacterial properties of ZnO nanoparticles prepared by laser ablation of Zn target in water and air. *Materials* **2019**, *12*, 186.
23. Mintcheva, N.; Aljulaih, A.A.; Wunderlich, W.; Kulinich, S.A.; Iwamori, S. Laser-ablated ZnO nanoparticles and their photocatalytic activity towards organic pollutants. *Materials* **2018**, *11*, 1127.
24. Rodriguez-Iznaga, I.; Shelyapina, M.G.; Petranovskii, V. Ion Exchange in Natural Clinoptilolite: Aspects Related to Its Structure and Applications. *Minerals* **2022**, *12*, 1628.
25. Shaw, R.; Mittal, T.; Tiwari, S.; Tiwari, S. K. Enhanced adsorption at ZnO nanoflakes@zeolite core shell interface: A study of changing adsorption dynamics. *J. Environ. Chem. Eng.* **2018**, *6*, 1424–1433.
26. Batistela, V. R.; Fogaca, L. Z.; Fávoro, S. L.; Caetano, W.; Fernandes-Machado, N. R. C.; Hioka, N. ZnO supported on zeolites: Photocatalyst design, microporosity and properties. *Colloids Surf. A: Physicochem. Eng. Asp.* **2017**, *513*, 20–27.
27. Panayotova, M.; Mintcheva, N.; Gicheva, G.; Djerahov, L.; Mirdzveli, N. Proceedings of 20th International Multidisciplinary Scientific GeoConference SGEM 2020, Albena, Bulgaria, 18 - 24 August 2020; p. 77–84.
28. Yang, L.; Zhao, Q.; Willander, M.; Liu, X.; Fahlman, M.; Yang, J.H. Origin of the surface recombination centers in ZnO nanorods arrays by X-ray photoelectron spectroscopy. *Appl. Sur. Sci.* **2010**, *256*, 3592–3597.
29. Sett, D.; Basak, D. Tuning the luminescence and UV photosensing properties of ZnO nanorods by strategic aqueous chemical growth. *Mater. Res. Express* **2015**, *2*, 105008.