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# Choice of cancer treatment as a creative problem

Roman Goot, Vladimir Goot  
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**Abstract:** The choice of a treatment method, like any other innovative process, is a two-stage process: generation and formation of an idea and its realization – implementation. Unlike most works on innovation topics, the focus here is on the first stage of the innovation process, when the methodology for the choice is only for creation, making problems, containing contradictions, arise.

## 1. Introduction

### 1.1 Innovation as a two-stage process.

The concepts creation and innovation were separated for a rather long time. It was considered, that creation is only generation and formation of new ideas, while innovation is their realization. In works on innovation, the ideas were usually described to the extent necessary for understanding, and the main attention was paid to the realization of ideas. As for creation, usually some vague general ideas were brought without any real relation to the subject matter. However, by now the quite general opinion has become that innovation activity is inseparable from creativity, since it provides the generation of new ideas, without which innovation is impossible. Thus, the innovative process turns out to be a single process consisting of two-stages. At the first stage the new idea is generated and designed; at the second stage includes its implementation. In this article, in contrast to the generally accepted, we focus precisely on the first stage, the creative part of the innovation process.

### 1.2. A Creative problem

In the works [1],[2] the definition of a creative problem was given, as a problem containing a contradiction in its conditions, so that the problem appears as unsolvable. However, as it was shown, such a problem could be resolved by introduction of an additional factor allowing to resolve this contradiction.

## 2. Cancer treatment choice

### 2.1 First stage. Creative problem

Since we are dealing with a creative problem, first, the goal should be defined, the conditions should be formed and the contradictions, that prevent us from achieving the goal, should be identified. However, the significance of the choice becomes known only at the end of the patient's life, but the choice of the methods of treatment must be made at the beginning of the treatment.

#### 2.1.1. First contradiction

At present times, clinical practice is greatly drawn to standardization since in this way it is far easier to ensure the quality and reliability of therapeutic measures. On the other hand, the natural desire to increase effectiveness and reliability of the therapy stimulates the desire to use an individual approach that potentially possesses higher effectiveness.

Thus, the first contradiction is revealed: it is necessary to pursue both: standardization and individualization.

#### Overcoming the contradiction

In order to find the necessary factor, the technique separation is used [2]: several *standard* methods of treatment are developed and an *individual* choice is made of the best method for a given case.

Let  $X = (x_n)_{n=1}^N$  be a vector that constitutes individual characteristics of the patient, and  $Y = (y_m)_{m=1}^M$  be set of the

treatment methods. To make the choice, you must first clarify how the term "best" should be interpreted in this case.

It is quite obvious that in our case the best method will be the one that provides the most effective treatment. For an oncological disease the natural indicator for effectiveness of the treatment is survival time (1), which depends on the selected treatment method

$y_m$  and the individual vector  $X$ .

$$(1) \quad T_m(X) = T(y_m, X),$$

The indicator  $T$  stands for the length of time the patient lives after the completion of the treatment. Also, it is assumed, the history of the application for each method and each treated patient (2), stored in the database of the treatment centre and accessible for use.

$$(2) \quad H_m(X) = \{Y, X, T_m\}, \quad m=1, \dots, M,$$

The problem of cancer treatment choice is discussed in detail in [3],[4]. Here we present only the method of solution and the results.

#### 2.1.2. Second contradiction

As it was stated above, the effectiveness of the treatment is represented by the indicator  $T$ . However its' value naturally could become known only at the end patient's life, but the decision over the treatment method should be made at the beginning of treatment process. Thus, a serious contradiction arises: it is necessary to make a decision and it is impossible to make it. This contradiction is resolved by using, as a required additional factor, data from the database, representing the experience of the already existing treatment.

#### 2.1.3. Overcoming the contradiction - Choice of a treatment method

Briefly, the choice procedure is as follows.

Survival time  $T$  is considered as a random value characterized by a conditional survival function.

$$(3) \quad S_m(t | X) = \Pr(T > t | X, y_m) = \Pr(T_m > t | X), \\ m=1, \dots, M.$$

Thus, the best choice comes down to the comparison of the conditional survival functions (3). To perform this, it is necessary to have a formula representation of the conditional survival function. A group of regression models is used, this group widely used in the analysis of survivality and reliability. One of the simplest models from this group is the Cox model [5].

$$(4) \quad S(t | X) = \exp \left[ - \exp(Z, X) \int_0^t \lambda_0(\tau) d\tau \right],$$

This model could be found in (4), where  $Z = (z_1, \dots, z_M)$  is the vector of regression coefficients,  $(Z, X)$  is the scalar product of vectors  $Z$  and  $X$ , and  $\lambda_0$  is a so-called base function of failure rate. The values  $Z$  and  $\lambda_0$  are parameters of function (4). The determination of  $Z$  and  $\lambda_0$  values is performed using the of data from  $H_m(X), \varphi(t) \equiv 1$ , by the methods of statistical estimation. This represents the usage of the the past experience mentioned above. The survivals comparison is described in detail in [6].

That term presume two types of problems, not coinciding in the general case. The first type is qualitative comparison by the "best-

worst” principle and is realized by the introduction of an order relation in the set of survival functions (3). The second type requires a quantitative characterization of the difference between these functions and is solved by metrization of these sets [5]. At the same time it would be useful to have a characteristic that would make the solution of both types of these problems possible. Such an object was introduced in [6] and called “directed semimetrics”. The details could be seen in [2]. In (5) could found a typical example of a linear directed semimetrics, where  $\varphi(t)$  is a bounded nonnegative function.

$$(5) \quad \rho(S_1, S_2) = \int_0^{\infty} \varphi(t) [S_1(t) - S_2(t)] dt$$

If  $\varphi(t) \equiv 1$ , that (6) is the difference in mean time lengths of patient lives after treatment.

$$(6) \quad \rho(S_1, S_2) = \bar{T}_1 - \bar{T}_2$$

Now we can formulate the decision rule for choice of the treatment method.

Method  $y_m$  is the best for patient  $X$ , if (7).

$$(7) \quad \rho(S_m(X), S_k(X)) > 0,$$

$$\forall k = m, \dots, M, k \neq m$$

## 2.2 Second stage. The innovation proces.

### 2.2.1 Testing the decision rule

Now when the decision rule is constructed, it could be accepted or rejected according to whether or not it provides a real gain in cancer efficacy treatment. This raises the necessity of testing the rule on a basis of real clinical data.

Medical practice which is followed in testing of new treatment procedure, requires clinical trials. Such trials usually last for extremely long period and are extremely labor-costy.

In addition, ethical problems may arise here if a certain group of subjects will have to be assigned to a method that is significantly different from the recommended one. Thus, we face a contradiction: we have to perform the trial, meanwhile it is impossible to do it. Once again, we face a creative problem, and in order to resolve the contradiction, we have to involve an additional external factor. Such factor might be the results of earlier made treatment decisions existing in the database and the known results of their implementation (2). Thus, the treatment results for this “alternative procedure” group consists in evaluation the potential usefulness of a particular rule retrospectively, using the data already available.

The algorithm for the testing is presented in [3]. Here we restrict ourselves to a short description.

## 3. Algorithm and results of testing [3],[4]

### 3.1 The algorithm

1. All elements  $H_m$ ,  $m = 1, \dots, M$ , belonging to the set (2), randomly divided into two non-overlapping subsets of equal numbers of elements,  $H_{m1}$  and  $H_{m2}$ , called “training” and “control”.

2. The elements from the training subset  $H_{m1}$  are used for the determination of parameters  $Z$  and  $\lambda_0$  of the survival functions  $S_m(t|X)$ , (3),(4).

3. For each element  $X$  from the control subset  $H_{m2}$ , the optimal therapy  $m0$  is obtained by the method described above.

Thus, each element obtains the labels of two methods of treatment, optimal and actually used, which are either the same or different. It

relates to each element  $X$  from  $H_{m2}$ ,  $m = 1, \dots, M$ . Consequently, for each element of the united set  $H = \bigcup_{m=1}^M H_{m2}$  it is revealed whether its

treatment was optimal or not.

We cite here shortly our articles.[3], [4].

The procedure was applied to the clinical data of a group of more than 1000 patients. The set of treatment alternatives consisted of methods **A** and **B**. By using of a random number generator, a training sample and control sample were created.

## 3.2 Results

The results are shown in Fig 1. Four survival curves are represented: the initial  $S_A(t)$  and  $S_B(t)$  for methods A, B, and for  $S_{opt}(t)$ ,  $S_{non}(t)$  after determination “optimal” and “non-optimal” methods.

Elementary conclusions can be drawn by simply observing the graphs, the “optimal” treatment method demonstrates a higher survival rate over time. For a more in-depth medical analysis, please see [3],[4]. We avoid doing it here because the purpose of the article, as the title suggests, is a bit different.

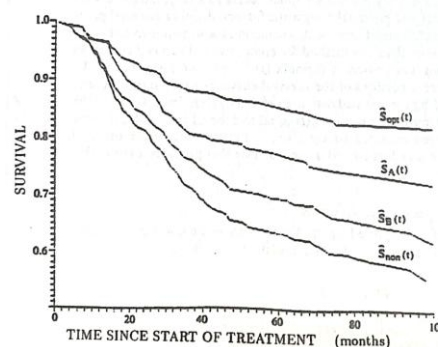


Fig 1 – Survival over time

## 4. Conclusions

In conclusion, it should be noted that the described technique and results could be interpreted as a step towards building Artificial-Intelligence based systems to be used for diagnosis and decision making in the process of determination of a treatment methods.

Additionally, the described method could have a very wide range of additional applications, in particular, the reduction healing time for patients suffering from severe diseases and body injuries.

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# Increasing the resilience of critical entities in response to the dynamic spectrum of threats

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**Abstract:** Achieving a comprehensive approach to the issue of resilience of entities that are critical to the proper functioning of the national economy requires the creation of a comprehensive framework addressing the resilience of critical entities to all hazards, whether natural or anthropogenic, accidental or intentional. For this purpose, good practice implies the use of European and international standards and technical specifications that are relevant for both security measures and resilience measures applicable to critical infrastructure.

Precisely, the presentation of updated information on a possible approach that requires innovation in the field of security and protection of critical infrastructure is the content of this publication.

**Key words:** CRITICAL INFRASTRUCTURES, PREPAREDNESS

## 1. Introduction

The most significant challenges to the functioning of vital critical infrastructure (CI) systems are natural and human-caused risk impacts, which cause an increased number of events with greater intensity, scale and impacts, leading to loss of life and a greater volume of damage. The implications for existing CI vulnerabilities are greatly exacerbated. With the predicted consequences of the changing security environment, the pressure on the readiness of CI systems will be higher, leading to loss and destruction, damage and disruption, and service interruptions.

Therefore, the change in the security environment is included as a risk to the resilience of CIs, although its impact cannot be precisely predicted, but its potential to significantly affect the resilience of states, societies and communities is identified as a common security threat. For example, in European countries, the changing security environment poses escalating risks to CI stability and security, with potentially far-reaching consequences.

Achieving a comprehensive approach to the issue of resilience of CIs, which are critical to the proper functioning of the national economy, requires a comprehensive framework creation addressing the resilience of CIs to all hazards, whether natural or anthropogenic, accidental or intentional. To this end, good practice implies the use of European and international standards and technical specifications relevant to both security and resilience measures applicable to CIs.

In this regard, leading scientists from the Institute of Metallurgical Engineering and Technologies with the Center for Hydro- and Aerodynamics “Acad. A. Balevski” at the BAS, apply modern standardized approaches to determine the goals and requirements for the development of physical protection systems, tailored to the specifics of the CI and aimed at preventing any level of potential threats both to the CI and to the population in adjacent urbanized areas [1, 2, 3, 4, 5].

That's why, the presentation of updated information on a possible approach requiring innovation in the field of security and CI protection through the application of modern standards is the content of this publication. Possible interruptions, due to technical reasons and carrying out ongoing maintenance activities, are not taken into account, as they are included in the design and technological documentation of the CI systems.

## 2. Standardization

The basic purpose of standardization is the definition of voluntary technical or quality specifications to which current or future products, production processes or services can conform. Standardization can cover various aspects, such as standardization of different classes or sizes of a product or technical specifications in the area of product or service markets where technical and interoperability with other products or systems is essential for the security and protection of CI.

Standards can contribute to supporting national policy to address significant societal challenges such as climate change, sustainable resource use, innovation, security and resilience, risk management, consumer protection and health and safety in the workplace. Targeting the development of commodity and technology standards (national, European and international) towards expanding markets could create a competitive advantage for manufacturers of CI security and protection products and systems and facilitate trade.

Also, standards are important tools for the competitiveness of enterprises and especially for small and medium-sized enterprises (SMEs), whose participation in the standardization process is important for national and European technological progress. It is therefore necessary for the standardization framework to encourage SMEs to actively participate and include their innovative technological solutions in the field of CI security in standardization efforts. This includes improving their participation at the national level, where they can be more effective due to lower costs and the absence of language barriers.

Last but not least, standards can have a wide-ranging impact on society, and in particular on the safety and well-being of citizens, network efficiency, environmental protection, accessibility and other areas of public policy. It is therefore necessary to ensure the strengthening of the role and contribution of interested organizations in the development of standards through increased support for developers and manufacturers of CI security products and system.

### 2.1 Definitions

According to the definitions in Article 2, point 1 and point 4 of Regulation (EU) No. 1025/2012 of the European Parliament and of the Council [6]:

➤ ‘standard’ means a technical specification, adopted by a recognised standardisation body, for repeated or continuous application, with which compliance is not compulsory, and which is one of the following: [6]

– ‘international standard’ means a standard adopted by an international standardisation body;

– ‘European standard’ means a standard adopted by a European standardisation organisation;

– ‘harmonised standard’ means a European standard adopted on the basis of a request made by the Commission for the application of Union harmonisation legislation;

– ‘national standard’ means a standard adopted by a national standardisation body.

➤ ‘technical specification’ means a document that prescribes technical requirements to be fulfilled by a product, process, service or system and which lays down one or more of the following: [6]

(a) the characteristics required of a product including levels of quality, performance, interoperability, environmental protection, health, safety or dimensions, and including the requirements applicable to the product as regards the name under which the product is sold, terminology, symbols, testing and test methods, packaging, marking or labelling and conformity assessment procedures;

(b) production methods and processes used in respect of agricultural products as defined in Article 38(1) TFEU, products intended for human and animal consumption, and medicinal products, as well as production methods and processes relating to other products, where these have an effect on their characteristics; EN 14.11.2012 Official Journal of the European Union L 316/19

(c) the characteristics required of a service including levels of quality, performance, interoperability, environmental protection, health or safety, and including the requirements applicable to the provider as regards the information to be made available to the recipient, as specified in Article 22(1) to (3) of Directive 2006/123/EC;

(d) the methods and the criteria for assessing the performance of construction products, as defined in point 1 of Article 2 of Regulation (EU) No 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonised conditions for the marketing of construction products ( 1 ), in relation to their essential characteristics.

## 2.2 Some basic standards of the International Organization for Standardization and the Bulgarian Institute for Standardization in support of CI security and resilience

The main international standardization structure developing standards in the field of CI security policy is the technical committee of the International Organization for Standardization (ISO) - ISO/TC 292 “Security and resilience”. At the moment, within the scope of his activity and responsibility are 67 standards and projects of standards.

The key security and resilience standards of CI are as follows:

- ISO 22300:2021- Security and resilience — Vocabulary;
- ISO 22301:2019 - Security and resilience — Business continuity management systems — Requirements;
- ISO 22313:2020 Security and resilience — Business continuity management systems — Guidance on the use of ISO 22301;
- ISO 22316:2017 - Security and resilience — Organizational resilience — Principles and attributes;

➤ ISO/TS 22317:2021 Security and resilience — Business continuity management systems — Guidelines for business impact analysis;

➤ ISO 22326:2018 Security and resilience — Emergency management — Guidelines for monitoring facilities with identified hazards.

The Bulgarian Institute for Standardization has introduced the following standards for national implementation:

➤ BDS EN ISO 22300:2021 Security and resilience. Vocabulary (ISO 22300:2021);

➤ BDS EN ISO 22301:2020 Security and resilience. Business continuity management systems. Requirements (ISO 22301:2019);

➤ BDS EN ISO 22313:2020 Security and resilience - Business continuity management systems - Guidance on the use of ISO 22301 (ISO 22313:2020);

➤ BDS ISO 22316:2021 Security and resilience — Organizational resilience — Principles and attributes (ISO 22316:2017);

➤ BDS ISO 22326:2020 Security and resilience — Emergency management — Guidelines for monitoring facilities with identified hazards (ISO 22326:2018).

It is also important to highlight the direct link between ISO/TC 292 Security and resilience and ISO/TC 262 “Risk management”, implemented by coordinating the development and reference of the following:

➤ ISO 31000:2018; Risk management — Guidelines

➤ IEC 31010:2019; Risk management — Risk assessment techniques

The Bulgarian Institute for Standardization has introduced the following standards for national implementation:

➤ BDS ISO 31000:2018 Risk management — Guidelines;

➤ BDS EN IEC 31010:2019 Risk management-Risk assessment techniques (IEC 31010:2019).

## 3. Spectrum of threats

The contemporary security environment (natural and man-made risks), characterized by an expanded range of threats (Figure 1) with greater intensity, scale and impacts, causes an increased volume of human and material losses. Hydrometeorological hazards dominate the profile of the security environment. In addition, a number of technical and technological disasters threaten the sustainability of the various national CIs and their elements.

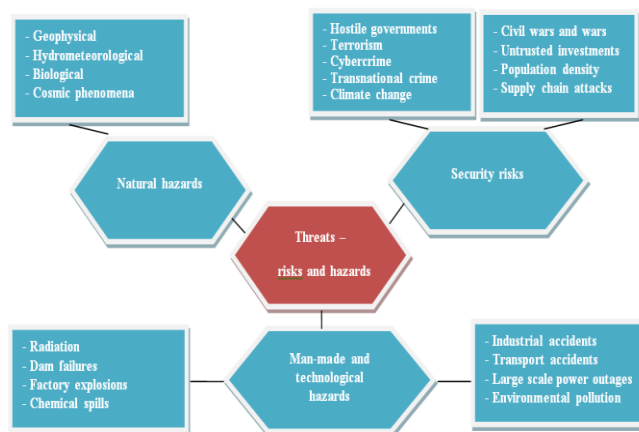


Figure 1: Threats to critical infrastructure - risks and hazards

Furthermore, an anthropogenic threat to CI resilience is emerging, arising from mismanagement, improper operation, negligence, organizational failures, and poor maintenance or insufficient investment in rehabilitation and modernization of aging CIs and assets.

We face an uncertain future with more and more pandemics, cyberattacks and high-impact events making up the “Future Risk Menu” [7]. Climate change is expected to cause local changes in average and extreme temperatures, as well as changes in rainfall patterns, disrupting roads, railways and airports nationally and internationally.

Potential cybersecurity threats, pandemics, biohazards, and other events, mostly of high consequence and low probability, are likely to affect CI resilience globally. Among these, one threat clearly stands out, located between current and future areas of risk and heavily exploiting existing vulnerabilities, with its impacts being felt across sectors. These are the cyberattacks against CI systems that are increasing in frequency, the number of targeted sectors with a lot of data being stolen or misused, and potentially outpacing the functioning and development of the entire infrastructure system.

Finally, the crisis of the COVID-19 pandemic has affected European countries in an unprecedented way. Furthermore, it is important to emphasize that the existence of pandemic-induced disruptions related to the basic and day-to-day functioning of CIs has resulted in the inability to provide services or the absence of beneficiaries for some services, due to daily mass blockades.

#### **4. Some approaches to enhancing CI readiness through resilience building**

Our country, as a member of the European Union, actively participates in the work on updating the policy to achieve a higher general level of resilience and protection of CIs, especially taking into account the changed dynamics of threats that can have an impact on CIs from several member states simultaneously.

##### **4.1. Policy and regulatory frameworks**

Resilience policy and legislative frameworks are a prerequisite for integrating CI resilience into disaster risk management and vice versa. This principle means that the member states of the European Union must have a unified approach for creating these frameworks, in order to start the process of integrating CI sustainability building across sectors in accordance with their national contexts and priorities. At present, CI legislation or its integration into other laws is insufficient for various reasons, i.e. lack of clearly defined CI policy concepts, weak integration into strategic documents and a primary focus on the *protection of assets and facilities*. It is therefore essential to rethink the approach, *shifting from CI protection to building overall resilience*.

This will lead to a set of actions enabling the following measures:

- review of existing and adoption of new strategic and policy documents or their adoption;
- amendment of existing legislation or the adoption of new CI laws and regulations;
- ensuring the integration of comprehensive CI sustainability principles into legislation relating to other sectors;
- designing and adopting new standards for building resilience and ensuring their implementation across all relevant sectors throughout the CI lifecycle.

A good example of up-to-date policies and regulatory frameworks of the European Union are the documents, namely:

➤ DIRECTIVE (EU) 2022/2557 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, of 14 December 2022, on the resilience of critical entities and repealing Council Directive 2008/114/EC;

➤ DIRECTIVE (EU) 2022/2555 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL, of 14 December 2022, on measures for a high common level of cybersecurity across the Union, amending Regulation (EU) No 910/2014 and Directive (EU) 2018/1972, and repealing Directive (EU) 2016 /1148 (NIS 2 Directive).

##### **4.2. Governance and institutional framework**

The overall governance and institutional framework are crucial to building CI sustainability both in our country and in the European Union. Across the region, diversity is found in approaches to risk reduction and CI management in a situation where there are no dedicated entities to protect CI. This is mainly due to the existing reactive approach that focuses on protection without considering the sustainability of CI as a whole and the complexity and interdependence of the sectors. A good approach requires that management be seen as an extended area of interaction and responsibilities between emergency management and civil protection services.

Following a whole-of-government and whole-of-society approach to resilience building, the prevailing view of viewing the security of each CI as an isolated process must be overcome and ensure that institution-building takes place within the framework of partnerships established between governments and the private sector. This ensures that all key stakeholders are on board this venture of building resilience.

In particular, it is essential to appoint coordination units, systematize roles, responsibilities and design, and implement adequate measures and actions to build resilience. In this regard, national disaster risk reduction platforms, such as multi-institutional and multi-sectoral mechanisms to advance disaster risk management and build resilience of societies and communities, can significantly contribute through a range of supporting activities and services.

In addition, building cross-border resilience should be included in the promotion of regional or sub-regional partnerships, cooperation and coordination of CIs. Therefore, the building of CI resilience should be provided as a complete, integrated package, thereby ensuring the sustainable development of EU member states.

##### **4.3. Coverage of all CI systems**

Building resilience is the responsibility of both CI owners and operators as well as other important actors at national and local levels. The traditional CI security approach only addresses physical parameters such as assets and facilities, operation/maintenance, without considering the full range of functions and services provided, including resources, limited cooperation and coordination, or fragmented resilience. In most countries, apart from public authorities, actors from traditional CI sectors are most active in mitigation and protection activities (eg energy, water, food, transport, telecommunications, health care and banking and finance). Modern disaster risk management is guided by the principle that disaster risk reduction is not the exclusive competence of a national organization, such as a government, but the responsibility of all stakeholders, including society as a whole.

In this way, building resilience is the result of their interactions and the underlying risk management will be achieved by integrating all critical sectors, by involving all relevant key stakeholders and by providing CI-related services. Different key stakeholders have different roles and responsibilities during the phases of the CI resilience building cycle.

#### 4.4. Availability of resources

For the functioning and viability of CIs, adequate resources must be planned and established that are imperative to support their needs before, during and after disasters. The term "resources" must be understood in its complexity, uniting various aspects, ranging from financial resources, through material and technical means, to human and professional. During the COVID-19 pandemic, the importance of human resources for CIs has proven to be significant and vital to their operations and the services they provide. This principle of building CI resilience should be considered in conjunction with private sector involvement, both in the roles of system owners and operators, or the expertise of external actors.

Here's why, CI investments should be proactive and anticipatory, enabling building resilience and transforming CIs into responsive systems rather than reactive structures. After disasters, funding must be provided for efforts to sustainably rebuild affected infrastructure. These investments should be scaled up by both the public and private sectors after assessing critical needs and priorities. Capacity building is one of the key pillars for having a sustainable CI.

The capacity of all stakeholders in CI sectors, along with disaster risk management systems, must be developed to address all risks, hazards and threats, as well as complex disasters that have low probability and high impact. A complex task must be carried out continuously, addressing different roles and responsibilities of actors in the CI security and resilience process – from sensitizing resilience building among policy-makers and decision-makers to providing professional training and specialized training professionals and emergency responders by disseminating knowledge to other key stakeholders and increasing general public awareness.

Consequently, the capacity building portfolio should be based on the life cycle of all potential hazards, an inclusive and systematically organized approach. This capacity building process should be systemic, involving all relevant stakeholders and placed at the heart of CI resilience building.

#### 4.5. Technology and innovation

Technologies and innovations are among the main features of the modern approach to building CI sustainability. Although they are often used to reduce risk, they are not yet fully incorporated into practices, given the financial costs and the need for specialized resources and knowledge. Therefore, their application should be the starting point for designing sustainable policies, norms, codes and standards while using new and emerging technologies and smart solutions.

In addition, CI resilience building should include measuring/determining the reliability of future infrastructure systems, addressing anticipatory resilience as a future-oriented knowledge system that addresses new extreme risk events, such as changing climate conditions and emerging risks for security. Accordingly, CI design must be more innovative, intuitive and secure, ensuring sustainability beyond existing frameworks. In this regard, partnerships should be established to advance the research and development agenda with relevant partners, such as academia and the private sector. In addition, innovative solutions are sometimes linked to the implementation of effective solutions, such as nature-based solutions, which are approaches that weave natural features or processes into the CI built environment to promote adaptation and resilience.

### 5. Conclusion

As complex, interconnected and interdependent systems and networks, CIs provide vital support for daily life and activities, providing services and making a crucial contribution to the sustainable development of society in the face of current and

emerging future risks and threats. To achieve resilience, the paradigm needs to shift from risk to resilience, adopt and implement a standardized approach for all hazards, for all society and for the life cycle of CIs, and ensure policies that are future-oriented. Thus, CI resilience can be understood as the ability to anticipate, withstand or absorb shocks and stresses while CI adapts to new conditions, which would lead to rapid recovery and transformation to better cope with stresses and shocks in the future.

#### ACKNOWLEDGMENTS

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# Intelligent Energy Guardian for Polygeneration Devices: Design, Implementation, and Experimental Evaluation

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**Abstract:** The article presents an intelligent energy guardian for a polygeneration device. The proposed solution aims to optimize energy usage and minimize wastage by incorporating smart control algorithms that continuously monitor and adjust the energy flow between different subsystems of the device. The energy guardian utilizes machine learning techniques to learn the device's energy usage patterns and adapt to changing conditions, such as varying energy demands and supply constraints. The article outlines the design and implementation of the energy guardian, and presents experimental results that demonstrate its effectiveness in improving energy efficiency and reducing operational costs. Overall, the intelligent energy guardian offers a promising solution for enhancing the performance of polygeneration devices and promoting sustainable energy use.

**Keywords:** ENERGY MANAGEMENT, RENEWABLE ENERGY SOURCES, POLYGENERATION, LOSS REDUCTION, DATA ANALYSIS

## 1. Introduction

In recent years, there has been a growing interest in polygeneration devices that can efficiently produce multiple forms of energy simultaneously. These devices offer a promising solution to meet the increasing energy demands while minimizing environmental impacts. However, the complexity and variability of energy generation and consumption patterns in polygeneration systems pose significant challenges in terms of maintaining optimal performance and ensuring the safety and reliability of the entire system.

To address these challenges, intelligent energy guardians have emerged as a crucial component in polygeneration devices [1-4]. An intelligent energy guardian acts as an advanced control system, constantly monitoring, analyzing, and optimizing the operation of the polygeneration system. It provides real-time decision-making capabilities, ensuring optimal energy generation, distribution, and consumption, while taking into account various factors such as load demands, energy storage, and renewable energy availability.

The article aims to provide a detailed overview of the design considerations involved in developing an intelligent energy guardian. It will discuss the selection and integration of sensors, data acquisition systems, and communication protocols to gather real-time information from different components of the polygeneration device. Furthermore, the article will delve into the implementation of intelligent algorithms and decision-making models that enable the energy guardian to optimize energy generation and consumption patterns [1-2].

To evaluate the effectiveness of the proposed intelligent energy guardian, a series of experiments will be conducted. These experiments will simulate various scenarios, taking into account different load demands, renewable energy availability, and storage capacities. The performance metrics such as energy efficiency, reliability, and system stability will be analyzed to assess the impact of the energy guardian on the overall operation of the polygeneration device.

The findings of this research have significant implications for the field of polygeneration and smart energy systems. The intelligent energy guardian has the leading to improved energy efficiency, reduced operational costs, and a more sustainable energy infrastructure. Moreover, the insights gained from this study can contribute to the development of intelligent control systems for a wide range of energy applications, paving the way for implement in Industry 4.0.

## 2. Description of the proposed solution

Energy (power) guard, in the classical sense, allows limiting the excess of contractual power that an industrial consumer orders from the distributor. It is a fixed fee paid by the consumer, and if it is not utilized, no compensation is provided. However, exceeding the

contracted power leads to penalties and additional charges. Rising energy prices and the requirements imposed by the European Union on businesses necessitate changes, such as conducting audits of facilities to reduce costs, including determining energy demand during specific time intervals.

Furthermore, increasingly, companies are implementing solutions that enable partial coverage of their electricity demand through the installation of renewable energy systems. The most common example of such installations is photovoltaic panels, whose capacity is tailored to match the facility's peak demand. However, this popular solution has certain issues, with the most significant one being its dependence on weather conditions. Without the utilization of energy storage systems, this solution lacks the ability to buffer energy, even for short periods of time.

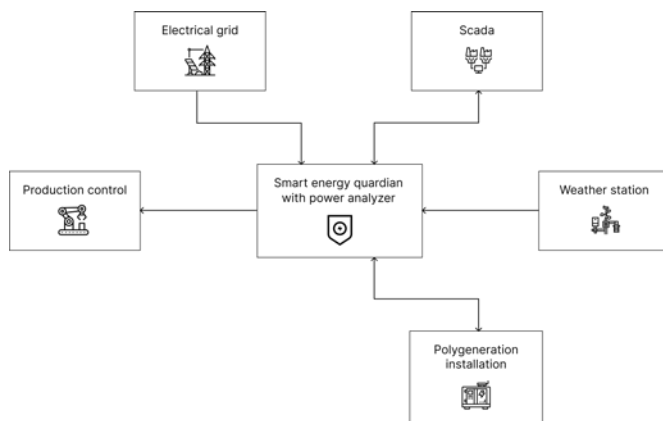


**Fig. 1** Fragment of a sample polygeneration installation

The system analyzed in the article is based on generating electrical energy using solar radiation but incorporates a modernized Rankine cycle. In this case, heat is collected from solar collectors through an intermediate medium, such as thermal oil, which then heats a buffer tank. Subsequently, the thermal oil heats a heat exchanger acting as a low-boiling-point refrigerant evaporator in the steam turbine cycle. The low-boiling-point refrigerant, while

expanding through a turbogenerator, converts mechanical energy into electrical energy, and then, upon condensation in another heat exchanger, provides useful heat [3,4]. Before returning to the evaporator, the low-boiling-point refrigerant is preheated by a heat exchanger powered by geothermal energy (Fig.1). The system is modeled for the purpose of analyzing the operation of such an energy system in conjunction with an intelligent energy guard [5].

The described control algorithm, in addition to known solutions such as an alarming system for high power consumption and managing the shutdown of non-critical processes in the event of exceeding the contracted power, also analyzes all facility processes [1]. It comprises data from the facility, the polygeneration system, and weather information (Fig. 2). Analyzing this data allows for reducing the energy drawn from the power grid and predicting the settings for the polygeneration system based on weather data and the predicted facility demand.

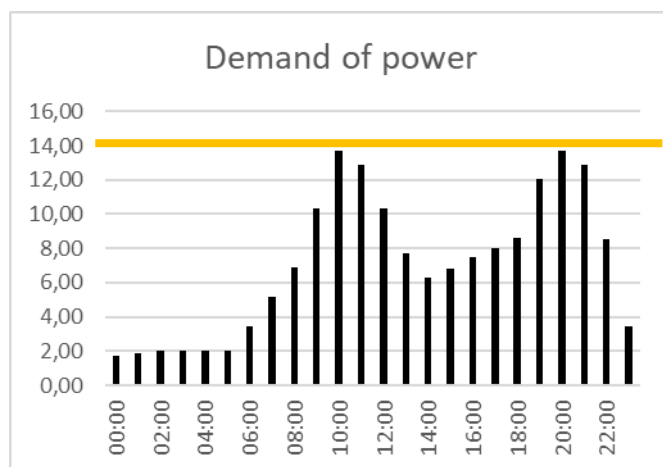


**Fig. 2** Schematic diagram of the sample system.

The next part of the article will verify the possibility of adapting the energy guard to increase the total power generated by the polygeneration system, extend its operation, and adjust to the facility's demand based on data for a sample enterprise.

### 3. Data analysis

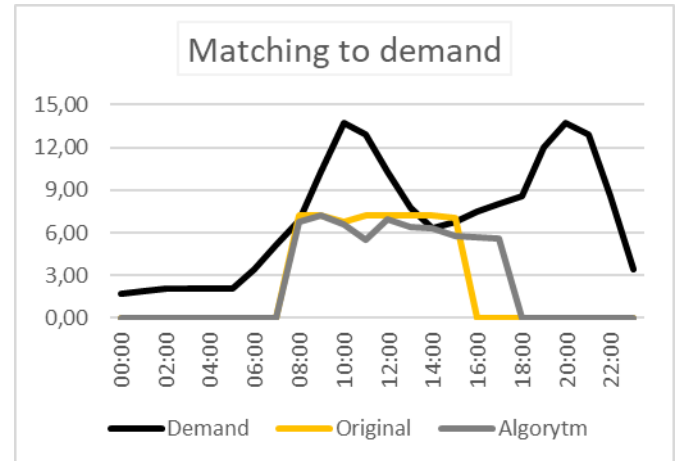
To conduct the analysis, a facility operating in a two-shift system, five days a week, from 6 am to 10 pm, was selected. For the purpose of the article, a representative working day of the facility has been chosen. The energy consumption profile is shown in Fig. 3 and covers a 24-hour period, including the operational period of the facility and the resting time, which as observed, also involves energy consumption.



**Fig. 3** Chart of daily power demand for a sample industrial facility and the minimum achievable contracted power.

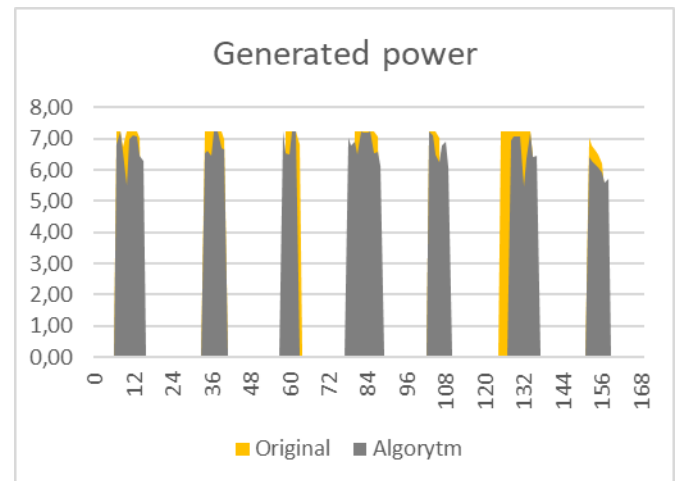
To examine the impact of employing the intelligent energy guardian, a numerical model was used in the MATLAB environment, along with a built-in tool for conducting neural network training [6,7]. For this purpose, learning was performed using the Twin-Delayed Deep Deterministic Policy Gradient (TD3PG) algorithm. A detailed description of the actor-critic method employed was provided in the publication [8].

Below are the results of simulation experiments comparing the original control approach with the implementation of the intelligent energy guardian. The original approach aimed at maximizing instantaneous power, while the intelligent algorithm, based on demand and weather data, sought to adapt to the facility's needs and maximize operational uptime without shutdowns.



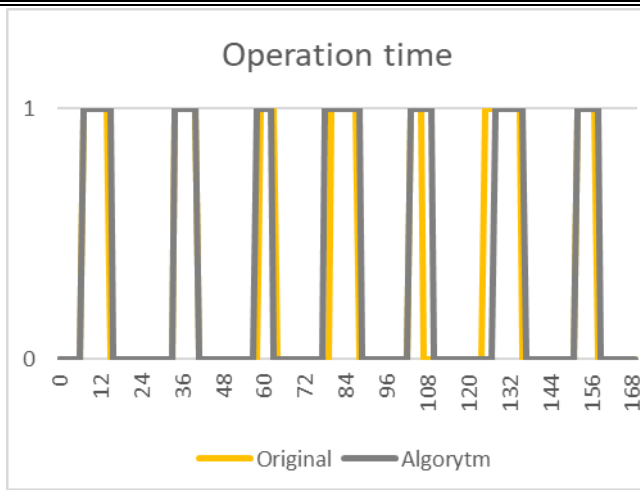
**Fig. 4** Schematic diagram of the sample system.

Fig. 4 illustrates the relationship between the demand of the analyzed facility and the power generated by the polygeneration system using both the original control approach and the discussed algorithm. It is evident that both the operational uptime has been extended and the power demand has not been exceeded. The algorithm aimed to adapt to the demand as much as allowed by the weather conditions and the nominal power of the polygenerator.



**Fig. 5** Schematic diagram of the sample system.

Based on the daily analysis, it was decided to verify the difference in system performance over the course of a week. The charts shown in Fig. 5 and 6 illustrate the difference, respectively, for the generated power and the operational time of the polygeneration system. In both cases, there is a noticeable improvement in the performance of the polygeneration system when the intelligent energy guardian is applied. It can also be observed that there are stages of the polygenerator's operation where the original control temporarily prolongs the system's operation. However, these are isolated occurrences.



**Fig. 6** Schematic diagram of the sample system.

Table 1 presents a comparison of the performance of the polygeneration system in different periods. In all cases, both in terms of power and operational time, using the intelligent energy guardian control proved to be more favorable. This is particularly evident in the daily example presented, which can be attributed to the atypical weather conditions of that day, better handled by the neural algorithm. However, a more reliable comparison is provided by the weekly and yearly periods, which average out the long-term operation of the system, taking into account various weather conditions. The last column of the table presents the percentage by which the implementation of the control algorithm increased the efficiency of the power installation.

**Table 1:** Summary of control results

|                    | Original    | Algorytm | Percentage of improvement |
|--------------------|-------------|----------|---------------------------|
| Daily power [kW]   | 57,15       | 62,92    | 10,09                     |
| Week power [kW]    | 346,78      | 392,27   | 6,58                      |
| Year power [kW]    | 14090,09283 | 14903,27 | 5,77                      |
| Daily duration [h] | 8           | 10       | 25,00                     |
| Week duration [h]  | 49          | 55       | 12,24                     |
| Year duration [h]  | 2098        | 2402     | 14,48                     |

#### 4. Results

The results confirmed the validity of working on advanced energy guardians for industrial facilities. This article focused solely on one component of such a system, namely the management of the polygeneration installation. The advanced algorithm based on neural control allowed for a significant increase in energy generation on a daily, weekly, and yearly scale. Furthermore, it extended the operational time of the polygeneration system in each of these periods. However, it is evident that the system is unable to ensure energy self-sufficiency for the facility and only provides full energy demand coverage to a limited extent. This is particularly noticeable when the Normal Irradiance (DNI) decreases. The lack of solar radiation prevents the system from operating, which is why systems based on the Rankine cycle would be most suitable when utilizing waste heat from the facility, which would be available throughout its operation. It would also be reasonable to expand the

polygeneration installation with other renewable energy sources to reduce carbon footprint and increase energy independence. The system could also allow for energy surplus storage in the form of compressed air, for example. This would enable the use of a higher-capacity installation that would not waste excess generated energy.

It is justifiable to analyze this solution for other components of industrial facility operation as well, such as adjusting the sequence of tasks based on momentary energy consumption. By combining data on orders, weather conditions, instantaneous and projected energy consumption, as well as generated and stored energy, it would be possible to successfully reduce the contracted power. Through a multi-level management system, it would be possible to increase energy generation during peak demand or predictively distribute multiple production processes over time to avoid such peaks. For these reasons, intelligent control algorithms, which form the basis of modern energy guardians, seem to fit perfectly into the direction of development outlined by Industry 4.0.

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# Major operational characteristics of an innovative ceramic beehive

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**Abstract:** Prototypes of an innovative collapsible beehive, built of long-lasting, structural elements of quartz ceramics with high atmospheric resistance and the presence of air cavities with thermal insulation properties, were prepared. Prescription compositions, an original set of molds, and an adequate heat treatment regime applicable to obtain the structural details were developed. The role of the various technological factors in the formation of the performance indicators of the end products was analyzed. The main characteristics of the prepared experimental prototypes and their major functional advantages in comparison with the existing standard and traditional hives were observed. The presented innovative beehive provides a favorable natural habitat for the normal and safe development of bee families and allows the full application of modern approaches for the efficient and ecological production of high-quality natural apian products.

**Keywords:** INNOVATIVE BEEHIVE, GLASS CERAMICS, CERAMIC BEEHIVE

## 1. Introduction

The essential contemporary importance of beekeeping [1-5] is based on its economic contribution due to the traditional application of apian products in the food and culinary industry, the production of therapeutic and cosmetic products, and the specific role of bee families as part of the global ecosystem [3, 4].

During different periods, a considerable number of various collapsible hives of diverse sizes have been developed, which refer to two main groups: vertical and horizontal. At present, several basic types of beehives are gained significant popularity in the country, such as Dadant Blatt, Langstroth-Ruth, Roger Delon, Farrar, Lounger, etc. According to their volume, hives are divided into single-hull, double-hull, and multi-hull (for example, pavilion type and others). Currently, in beekeeping, various types of wooden, plastic, polystyrene, polyurethane, and traditional wicker beehives are used [2]. Considerable economic experience is obtained in the operation of large bee farms made primarily of wood hives [1]. In the exploitation of different types of standard hives (for example, plastic, etc.), a significant drawback is their low fire resistance and the inevitable aging of the materials, accompanied by a decrease in the mechanical properties of the products and some cases by the release of harmful products with an unfavorable and potentially toxic impact for bee families [5]. Additional destructive factors accelerating this process are cyclical daily and seasonal climatic atmospheric impacts of a different nature [1,2].

According to further beekeeping development, the implementation of long-term and complex solutions needs to be required to increase productivity and efficiency in bee farms as well as the possibilities for producers to operate in dynamic conditions and a competitive market environment. Increasing the functional characteristics of the material base of bee farms is an adequate approach in this case. In terms of designing and producing new models of beehives, the application of non-traditional materials is considered an expedient and promising means [6-12]. At the same time, in the existing possibilities observation, the conducted research work from other thematic areas is considered [13-25].

The current report aims to present the technological conditions for the preparation of experimental prototypes of an innovative (frame) beehive consisting of quartz ceramic structural elements with air thermal insulation cavities and their characteristics. A summary comparison [11] of the performance indicators of the developed innovative beehive and the prevailing types of standard and traditional beehives applicable in practice is performed.

## 2. Experimental procedures

During the initial experiments, it was found that using the commercially available standard slurries was not suitable for fulfilling the main development objectives. After additional laboratory investigation, modified poly-component [11] compositions (comparable to classical ceramics) were developed that are applicable for the preparation of slip masses as well as

molding of structural details (in the form of blanks), and preparation of experimental products after applying a suitable drying regime and high-temperature treatment. Based on the acquired experimental experience, as an adequate alternative possibility, the prototypes of an innovative collapsible beehive from structural elements obtained from quartz ceramics were prepared [12]. During the implementation of the development, a set of original gypsum molds was used, similar to those used for the preparation of previous experimental samples.

The technological conditions for the preparation of structural quartz ceramic hollow elements with the necessary characteristics were investigated. The required properties of items are the purity of the quartz glass used, processing of the raw material in the mill units, the fractional composition of the ground vitreous mass, suspension preparation methodology, main characteristics of the obtained suspension, optimal pH values, the role of introduced modifiers, conditions of forming the blanks, the density of semi-finished products, drying process, mode of high-temperature processing (corresponding to the crystallization ability of the material in a certain temperature interval), etc.

A standard approach for ceramic production (slip casting) was applied that allows the preparation of items with a complex shape and high density, both within limited batches and large production series. Using the technological capabilities of ceramic production enables the production of non-flammable, non-combustible, long-lasting, waterproof, and heat-resistant structural elements contrived from technical ceramics, many times superior to the complex indicators of all materials used for the production of standard collapsible hives offered on the market (wood, plastic, etc.) and the parameters of the existing traditional wicker hives of the non-separable type.

## 3. Results and Discussion

The limit saturation method was applied to prepare a suspension with low moisture content. During wet grinding, two to three times a short-term stop of the mill unit was made, and an introduction to the composition of 1/10 (of the amount of glass in the slurry) of ground vitreous mass with a fractional composition of 50÷100 microns was added. Equilibrium viscosity was reached after about 2-3 hours of additional grinding. The method allows obtaining the extremely saturated suspension with up to 4 times lower water content. During the molding process of the samples, the ceramic slurry is rapidly absorbed from the walls of the mold, providing the preparation of products with low drying shrinkage. The formed layer is determined by the technological time for the slurry to be absorbed from the mold, and it is according to the required thickness of the technical products. The applied method of slip casting provides technological possibilities for the production of various hollow structural elements with complex shapes and high density (fig. 1 and 2).

The rate of absorption of the prepared slurry from the walls of the mold and the density of the products are largely determined by the pH of the suspension. Silicic acid reveals maximum stability at

pH  $5\pm0.3$ , while in a neutral environment, it intensively polymerizes, which is accompanied by the release of water and decreasing the concentration of  $H^+$ . The presence of pH values within the range of 4.5 to 6 is considered an essential technological factor. To reduce the pH of the used suspension, HCl was used, and to increase the pH values  $NH_4OH$ . After preparing a stable slurry based on powdered amorphous quartz glass, preliminary experimental samples were prepared from the obtained slip mass, and a drying regime and high-temperature sintering were performed. The firing shrinkage coefficient of the obtained experimental samples was determined. As a consequence, models and a set of gypsum molds were designed and produced applicable for slip casting molding of hollow structural elements to build ceramic beehives.

After conducting a series of experiments, both the optimal technological absorption time (about 25 to 45 minutes) of the slip from the mold and removal of the residual liquid phase by pouring were determined. Three-layer structural elements (solid wall/air chamber/solid wall) with a wall thickness of 6 mm and an air cavity width of 18 mm were obtained (fig. 3). Either the low thermal conductivity and lower transport and operating mass of the prototypes are due to the presence of a high percentage of cavities (over 60%) in the prepared structural details. Thus, produced innovative ceramic structural items (panels and profiles) with a high volume of air cavities (with the correct shape) should not consider or classify as products of standard porous ceramics.

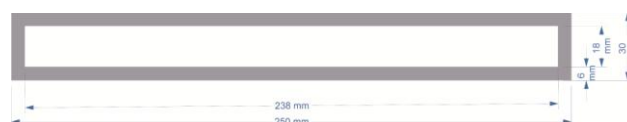
A significant role in the characteristics of the end products is observed by the applied increasing rate in temperature values, especially in the range from 1000°C to the final temperature from 1200 to 1300°C (in this particular case 1250°C). With a gradual increase in the temperature (50–100 K/h) of heat treatment, an increase in the crystallization tendency is observed, accompanied by a change in the phase composition and the formation of high-temperature cristobalite. This effect significantly contributes to the reduction of strength indicators and other operational properties of the obtained products. It is expedient to apply the established optimal speed of increasing the temperature values (from 400 K/h), which significantly avoids the risk of forming separate centers of crystallization. To prevent crystallization in the present development, a sintering intensifier (1.2%  $B_2O_3$ ) is additionally introduced.



**Fig. 1.** Prototype of an innovative collapsible beehive made of quartz ceramic items with assembly profiles.



**Fig. 2.** Prototype of an innovative collapsible beehive made of quartz ceramic items with assembly profiles.



**Fig. 3.** Sectional scheme of quartz ceramic constructional elements, with high dense thick walls and the hollow area in the casting item.

Throughout preparing the samples within the entire technological cycle, the formation of a partially porous structure decreases the mechanical characteristics of the products. For samples of quartz ceramics with a porosity of 3%, a hardness of about 5.5 on the Mohs scale is characteristic [12], while with an increase in porosity up to 20%, the hardness values decrease drastically to about 2 on the Mohs scale. For different products, the strength of pressure varies from 50 to 600 MPa, and the bending strength from 3 to 80 MPa, according to the specifics of the specific compositions, the structure of the obtained materials, and the technological conditions of synthesis [12].

The developed innovative collapsible ceramic hive provides a favorable microclimate and an ecological, hygienic environment for the life cycle of bee colonies and minimizes the risk of the development of mites, fungal cultures (molds, etc.), a variety of potentially dangerous microbiological agents, the impact of rodents and others.

The functional structure and distribution of the internal volume of the hive are by the existing modern concepts for the efficient production of bee products of high quality and allow the exercise of active control of the individual stages of the development of bee families, the use of a standard set of honeycombs and tools (centrifuges, etc.), the application of highly efficient modern farming methods to obtain high yields without risking the integrity and condition of bee colonies.

The relatively lightweight hollow structural details and the installed stationary supports of the hive body allow active application of the so-called possibilities of mobile beekeeping. It is enabled through transportation and temporary (seasonal) positioning of bee farms in suitable agricultural or forest areas with the presence of honey-bearing plant species.

At the same time, if there is a need to carry out decontamination and settlement of new bee families, it is possible to apply a variety of sanitary treatments, including highly effective thermal treatment,

which is practically inapplicable and destructive for all other types of hives (wooden, plastic, etc.).

The various types of standard collapsible frame hives (wooden, plastic, polystyrene, polyurethane) that are gained significant popularity are characterized by relatively limited shelf life, aging of the material with the release of potentially toxic products, an increased risk of the emergence and development of fungal, and other biologically active cultures with a negative impact, limited ability to carry out the full sanitary treatment if it is necessary and practically complete unreliability in fire conditions.

The archaic non-separable hives that existed for a long historical period are primitive composite products made of artisanal methods from untreated thermally natural plastic clays and reinforcing organic materials mainly of plant origin. According to the availability of raw materials, the specificity of different regions, and the capabilities of individual producers, there are several variations of "wicker hives" characterized mainly by a conical shape, different volume, and height, a typical woven structure contrived from the plant origin materials (willow, hazel, vine, papur, etc.) and applied surface screeds from plastic masses obtained from directly mined clay, wood ash, and animal manure. An additional structural element is the so-called "hat" made of straw or fern. The main advantages of this type of beehive are their ease of creation from common, natural materials by applying basic skills without the need for highly qualified personnel, specialized equipment, energy costs, etc. The fixed honeycombs and limited structural functionality restrict the full development of the bee family and do not allow effective control of the individual stages of the bee life habitat. When extracting the bee product, due to the immovably fixed frames, it is impossible to apply centrifugation, and there is a significant risk of partial destruction of the bee colony. Due to its non-separable structure formed by flammable and combustible components and natural clays subjected only to air drying, this type of hives is characterized by relatively low yields and limited purity of the final products, insufficient resistance in prolonged contact with the water environment, and unreliability in fire conditions.

#### 4. Conclusions

An innovative collapsible (frame) beehive is developed, consisting of long-lasting structural elements of quartz ceramics with high atmospheric resistance and the presence of air cavities with heat-insulating characteristics.

The role of various technical indicators for the preparation of the designed structural details is examined: purity of the quartz glass used, duration of the processing of the raw material in the mill facility, fractional composition of the ground vitreous mass, suspension preparation methodology, characteristics of the obtained slurry, optimal values of pH, introduced modifiers, conditions of molding samples by the slip casting method, the density of the slug, drying process, specificity of the high-temperature treatment regime (corresponding to the crystallization ability of the material in a specific temperature interval), etc.

The contrived ceramic hive provides a favorable microclimate and a suitable natural habitat for the normal development of highly productive bee families with minimal risk of the development of mites, fungal cultures, and other potentially harmful microbiological agents.

In terms of relevance and significance, the development is connected to the original innovative product with superior functional characteristics (in comparison with competitive products presented on the market), which has commercial potential for positioning in an independent product niche.

The specific characteristics of the presented ceramic hive ensure a long operational period with negligible depreciation, the possibility of applying modern highly efficient economic approaches, high yields of bee products, and significant resistance to cyclical climate changes such as contact with the water environment and fires.

The developed innovative hive is a full-fledged alternative to the existing traditional non-separable and standard collapsible hives (made of other materials), and in the long-term aspect can be considered as a possible main long-lasting material asset in beekeeping that provides a long operational period with minimal depreciation (with proper use) and reduced risk of losses in case of disaster occurrences.

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# Determining the quality of renovation layers using laser technology

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**Abstract:** The paper presents the results of research aimed at determining the quality of renovation layers using laser technology. In order to repair and renovate shaped parts of molds for casting aluminum alloys under high pressure, samples of experimental welds were prepared on the base material quality 1.2343 (Dievar). The renovation layers were created using additional materials Dievar, UTP A 7002 and NIFIL NiCu7 res. NiCu7 with Dievar combination. The microstructures on the cross-sections of the deposits were checked using the light microscopy technique. The technique of scanning electron microscopy and semi-quantitative EDX microanalyses were analyzed distribution of alloys in deposits. The microhardness of the deposits was determined.

**Keywords:** RENOVATION LAYERS, LASER TECHNOLOGY, MICROSTRUCTURE, QUALITY

## 1. Introduction

Renovation of functional parts of unheated aluminum alloy injection molds is a subject of many researches [1]–[4]. Possibilities of extending the lifetime of forms, as well as saving financial resources reaching several hundred thousands of Euros is their primary goal [5]–[8]. Aluminum alloy injection technology is most widely used in the automotive industry. It is a serial or mass production of components that are subject to high quality requirements. Any damage to the functional surface of the mold is reflected in the final product, the quality of which is constantly monitored. High Pressure Die Casting (HPDC) is a technological process widely used for casting complex of aluminum castings, mainly associated with the automotive industry. In this process, molten metal with a temperature of 670 – 710 °C is forced into the cavities of the molds at filling speeds of 30 – 100 m.s<sup>-1</sup>, under pressures ranging from 40 – 80 MPa [9]. This loading, in combination with the corrosive properties of liquid aluminum, leads to aluminization or oxidation of the mold surface, which results in thermal fatigue of the surfaces followed by cracking, soldering and erosive wear. The service life of die matrices made of steel alloys is approximately 100000 cycles and can be increased either by heat treatment, thin coating or cladding [10]–[12]. The paper presents the results of research into the possibility of applying additional materials based on the base material or high-alloy maraging steel. The cladding layers were made using laser welding.

## 2. Materials and Methods

Medium alloy tool steel marked Dievar (W. Nr. 1.2344; 48 HRC) from Uddeholm Boehlers was used as the base material to produce test hardfacing layers. It is characterized by high heat strength and resistance to tempering, as well as very good toughness and plastic properties at both normal and elevated temperatures. Furthermore, the steel shows very good resistance to thermal fatigue cracking and low sensitivity to sudden thermal shocks. It is well malleable when hot and well machinable in the soft annealed condition. The chemical composition of the base tool steel and its mechanical properties are presented in Table 1.

**Table 1:** Chemical composition of the base material Dievar (wt. %).

| C    | Mn   | Si   | Cr   | Mo   | V    | P     | S     | Fe   |
|------|------|------|------|------|------|-------|-------|------|
| 0,36 | 0,42 | 0,16 | 5,09 | 2,31 | 0,64 | 0,001 | 0,009 | Bal. |

As part of the experiments, 3 types of additional materials were used and 4 test coatings were made. Their chemical composition is in Table 2. Wire Uddeholm Dievar 1.2344 was used as additive material with a diameter of  $\varnothing$  1.0 mm, hardness of 46–48 HRC. The coating for the test sample was made in two layers. Cladding wire UTP A 702 is used for repair, preventive maintenance and production of highly stressed cold and hot working tools, such as punching dies, cold and hot cutting knives, Al-die cast moulds, cold forging dies, drawing-, stamping- and chamfering tools. UTP A 702 was with a diameter of  $\varnothing$  1,0 mm and hardness of 32–35 HRC. . The

coating for the test sample was made in two layers. Cladding wire Nifil NiCu7 is a solid wire with Good bead appearance with excellent corrosion resistance in saline solutions. Suitable for desalination plant construction applications and joining MONEL type. Used was wire a diameter of  $\varnothing$  1,0 mm and hardness of 150 – 170 HV. The test sample was made as a single layer. As the fourth layer, a two-layer test sample was made from a combination of additional materials. The base layer was made with additional material Dievar and the cover layer using NiCu7.

**Table 2:** Chemical composition of the used filler material (wt. %).

| Filler mat. | C    | Mn  | Si  | Cr  | Mo  | Co   | Ni   | Ti  | V   | Cu   | Fe   |
|-------------|------|-----|-----|-----|-----|------|------|-----|-----|------|------|
| Dievar      | 0,35 | 0,5 | 0,2 | 5,0 | 2,3 | -    | -    | -   | 0,6 | -    | Bal. |
| UTP A 702   | 0,02 | -   | -   | -   | 4,0 | 12,0 | 18,0 | 1,6 | -   | -    | Bal. |
| NiCu7       | 0,10 | 3,0 | 1,0 |     |     |      | Bal. |     |     | 30,0 | 1,0  |

The welding of the test samples was carried out using a disc laser TruDisk 4002. Cladding parameters used in the experiment are listed in Table 3.

**Table 3:** Used cladding parameters

| Cladding parameters                | Dievar | UTP A 702 | DRATEC DT-SG 6356 | NiCu7 + Dievar |
|------------------------------------|--------|-----------|-------------------|----------------|
| Laser power P [W]                  | 1500   | 1500      | 1600              | 1500           |
| Wire feed speed v [mm/s]           | 6      | 6         | 6                 | 6              |
| Cladding speed v [mm/s]            | 10     | 10        | 10                | 5              |
| Focusing [mm]                      | 0      | 0         | 0                 | 0              |
| Shielding gas flow rate Ar 4.6 [l] | 7      | 7         | 10                | 12             |

The quality of the coating layers was evaluated using macrostructural and microstructural analysis using an Olympus XX microscope. Transverse metallographic sections were etched using aqua regia for samples with a coating made with Ni 18% and more. An etchant (1g picric acid+5ml HCl, 97 ml ethylalcohol; HNO<sub>3</sub>:HCl (3:1)) was used to make the structure of the base and additional material visible.

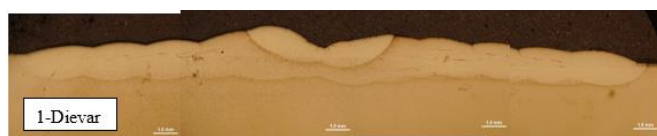
Vickers hardness was evaluated on metallographic grindings according to EN ISO 9015-1. The measurement was carried out in lines, from the surface of the coating layer towards the base material. Shimadzu HMV2 hardness tester, Vickers indenters and 2940N load were used.

## 3. Results

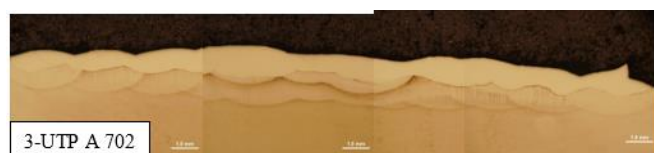
The quality of the clad layers was assessed using non-destructive and destructive methods. A visual inspection confirmed the significant fragmentation of the surface of the deposits. The segmentation corresponded to the used diameter of additional

materials and their mutual mixing. On the surface of the weld (the presence of cracks was noted in the covering layer made with NiCu7 additional material). In practice, when renovating functional surfaces, several cladded layers are applied in order to eliminate the mixing of the weld with the base material and also because of the allowance for chip machining to the required final dimensions and tolerances.

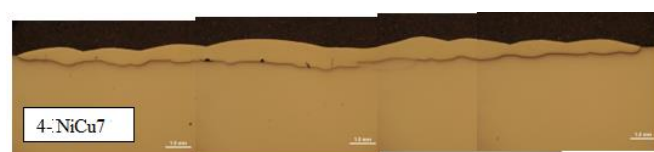
The results of the evaluation of the macrostructures are recorded in Fig. 1 to 4. Fig.1 shows the macrostructure of the coating made with the additional material Diavar. The coating was made as two-layered. A relatively substantial fragmentation of the surface is recorded. The presence of pores in the base cladded layer was observed on the metallographic cuttings. Figure 2 shows a coating made with the additional material UTP A 702. The coating was two-layered. On the macrostructure, the powering of the base and second so-called cover layer of the coating is clearly notable. The presence of internal defects on the cuttings was not recorded. The macrostructure of the weld made with Nifil NiCu7 additional material is shown in Fig. 3. The coating was made as a single layer. The presence of pores was noted at the interface between the base material and the coating. On Fig.4 there is a two-layer coating made by a combination of two additional materials. On the base layer of the coating made with the additional material Diavar, the covering layer was welded using additional material NiCu7. This cover layer contained cracks extending from the surface to the underlying layer. In the base layer the cracks did not reach the base material. Cracks were classified as hot. Their likely cause was an inappropriately chosen heat mode during welding. The heat-affected area of the base material was narrow, similar to the previously welded samples. The parameters of the area correspond to the welding technology used and heat input.



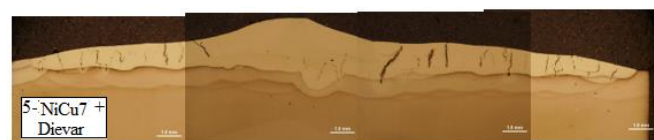
**Fig. 1** Cladd made of Diavar



**Fig. 2** Cladd made of UTP A 702



**Fig. 3** Cladd made of Nifil NiCu7



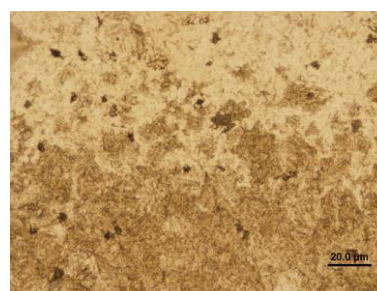
**Fig. 4** Cladd made of Nifil + Diavar

The microstructures of the evaluated samples are documented in Fig. 5 to 10. Figure 5 shows the microstructure of the base material Dievar. It is a structure of tempered martensite. The transitional heat-affected area of the base material is also documented in Fig. 6. The structure is formed by loosened coarse-grained martensite. Figure 7 shows a structure of tempered martensite without significant grain boundaries, which was located in the base weld layer made with the additional material Dievar. A similar structure was also found in the second coating layer. The structure of the cladding metal of sample No.2 made using additional material UTP

A 702 is shown in Fig. 8. This is a characteristic martensitic low-carbon structure with a columnar arrangement of grains. The structure of the cladding metal made using NiCu7 additional material is shown in Fig. 9. This is a casting structure characteristic for Monel.



**Fig. 5** Microstructure of base material (BM) Dievar



**Fig. 6** Microstructure of HAZ in BM Dievar



**Fig. 7** Microstructure of fist cladded layer with Dievar



**Fig. 8** Microstructure of cover layer cladded with UTP A 702



**Fig. 9** Microstructure of cover layer cladded with wire NiCu7

The microstructure in the area of mixing of the cladding metal made with additional material Dievar and NiCu7 on the fourth sample is shown in Fig.10. Based on the macroscopic analysis, numerous cracks were identified in the test sample. This is an unacceptable

error. Their likely cause was an incorrectly selected thermal mode when welding individual layers. Cracks were classified as hot. They were initiated on the surface of the deposit and spread towards the underlying deposit layer. This base layer made with additional material Dievar stopped their spread. Pores not exceeding 0,2 mm were only rarely found in the undercoat layer made with the additional material Dievar.



**Fig. 10** Microstructure in the area of mixing the cladding metal Dievar and NiCu7

In addition to metallographic analyses, the hardness values in individual areas were determined on the transverse cuttings. The measured results of average hardness from 5 measurements in each area are shown in Table 4.

**Table 4.** Average hardness values HV<sub>0,3</sub> measured in individual areas of test samples

| Area of measurement | Cover layer | First layer | HAZ | Base material |
|---------------------|-------------|-------------|-----|---------------|
| Dievar              | 605         | 620         | 530 | 483           |
| UTP A 702           | 350         | 360         | 511 | 476           |
| NiCu7               | -           | 165         | 630 | 482           |
| Nifil + Diavar      | 182         | 530         | 460 | 475           |

The measured hardness values correspond to the chemical composition of the additional materials and changes in the structures due to the heat introduced during welding. The maximum hardness values were manifested by heat-unprocessed welds made with the additional material Dievar, with a hardness in the range of 605-620 HV<sub>0,3</sub>. In practice, the heat treatment by tempering must follow the welding for the purpose of removing residual stresses after welding and reducing the hardness due to improving the toughness of functional surfaces. The lowest average value of 165 HV<sub>0,3</sub> was recorded in a single-layered weld made with NiCu7 additional material. This is a nickel alloy which, as it turned out in later experiments, is not a suitable material concept even for short-term interaction with the molten metal of the Al alloy.

#### 4. Conclusions

The paper presents the results of research focused on the area of restoration of functional surfaces of components. The possibilities of applying progressive high-alloy types of additional materials in the form of wires during laser welding were analyzed. The quality of newly created layers was evaluated by means of non-destructive inspection of the surfaces and also by means of destructive tests. The quality of the proposed welding parameters was evaluated primarily on metallographic cuttings. These revealed several imperfections and the need for further and more thorough optimization of the welding parameters. The aim of the comprehensive research was to recommend a suitable type of additional material for renovating the functional surfaces of injection molds to manufacturers of aluminum components. From the types of additional materials presented, it is possible to recommend the additional material Dievar for renovation of functional surfaces. The quality criteria is also met by the additional material based on the progressive maraging steel UTP A 702. This one however requires heat treatment by annealing in order to remove internal stresses, but especially to achieve the required hardness of the

functional parts of the molds, which is 44-48HRC. Similarly, heat treatment by tempering is also required for coatings made with Dievar additional material. Additional material based on Monel can be marked as unsuitable for renovation. In addition to the high sensitivity to the amount of the heat introduced into the deposit, its solubility in interaction with the Al alloy is also problematic, as further research has shown. With the appropriate chemical composition of additional materials using progressive methods of production of functional layers, it is possible to restore damaged surfaces to a significant extent, extend the service life of components and thus save considerable financial resources.

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## Processing and properties of polymer - mineral compositions

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**Abstract:** Recycled plastics find more and more applications. In addition to recycled bulky products, the number and type of products also being used in polymer - mineral composites based on recycled PE and PP. One of the paving products sought by investors are traditional concrete blocks. However, they have their drawbacks, they are heavy, so their transport, logistics must meet stricter requirements, are products that are not very resistant to cracking as a result of impact, are fragile. Mineral-polymer products are the solution to such problems. Innovative compositions for their processing are a polymer - mineral mixture, containing mainly recycled material and mineral fillers (sand, ceramic waste dust). They are therefore products made of waste materials from recycling, recyclates and flakes of polymer materials.

The technology for producing the polymer - mineral composition is based on the extrusion and compression molding technology of the compositions obtained. Polymer compositions are secondary materials, after recycling in the form of recyclates, flakes, and waste plastics, mineral fillers, that is waste ceramic dust, sand as well as activating substances (dyes, plasticizers, adhesion compatibilizers, polymer-mineral wetting agents). As a result, plastic waste and ceramic waste that cannot be recycled will be effectively processed. The sprinklers were made of various polymer materials (PP, HDPE) as well as characterized by different shape of working elements and a variable degree of contamination with mineral sludge. The research on the structure of manufactured materials and melt flow rate are presented. The influence of the type of material and mineral deposits on the process ability of the tested polymer-mineral compositions was determined.

**Keywords:** RECYCLED PLASTICS, POLYMER SANDS COMPOSITES, POLYMER PROCESSING, PROPERTIES OF COMPOSITES

### 1. Introduction

Material recycling of polymeric plastics makes it possible to achieve measurable savings, as well as their management, this applies to more and more plastic waste that otherwise must be landfilled. There is a need to produce compositions and products that have the performance characteristics of porous polymeric materials and the performance characteristics of mineral material products [1-5], which will be characterized by the visual effect of a porous structure, high mechanical strength, impact strength and hardness, low abrasiveness, high weather resistance and low manufacturing cost [1, 4-6]. In addition, for environmental reasons, there is a need to use post-production and post-consumer waste of polymer plastics, mineral post-production waste such as fly ash and ceramic waste, which occurs in large quantities [5, 6-12]. The mineral filler in the produced composition is, for example, silica fly ash which is a by-product of coal combustion, shredded ceramic waste which is post-production waste, construction quartz sand.



**Fig. 1** Main components of polymer - mineral composition; recycled polymer plastic and mineral waste, example

A product that can be made from plastic waste with a few tens of % addition of mineral compounds are polymer-mineral compositions, which, when processed by extrusion, can be used to produce garden architectural elements (bench slats, balcony panels, outdoor floor profiles), replacing concrete, ceramic, cast and vibro-pressed products [13-20]. Polymer compositions can be made from recycled plastic, after recycling in the form of recyclates, flakes, and waste plastics, mineral fillers, that is, waste industrial dust, ceramic waste or sand. As a result, plastic waste and mineral, ceramic waste, which so far cannot be reused, will be efficiently processed to create new products [14, 20, 21-25].

The expected performance characteristics of the polymer-mineral composition products are as follows:

- manufactured from recycled waste plastics,
- shape, dimensions do not differ from concrete products,
- have a smooth or textured surface,
- are not subject to mechanical damage, do not break, do not crack,
- are as much as about 30% lighter than traditional products,
- are characterized by very low hygroscopicity, ease of cleaning,
- are resistant to oils, greases, acid compounds,
- are characterized by complete frost resistance, up to -70°C,
- have a variety of colors, uniform color throughout the mass of the product [4, 6, 10, 13, 22].

The essence of the material produced is a polymer-mineral composition for the manufacture of building and garden architecture products by extrusion and pressing, mainly sections such as bench slats, balcony panels, outdoor floor panels, paving blocks, paving slabs and others [23-31].

The purpose of the work is to determine the possibility of recycling and reuse of plastic waste containing several tens of percent mineral waste. The scope of work includes the study of the recyclability of polymer recyclate, using the Melt Flow Rate (MFR) method and the processing of polymer-mineral recyclate in the extrusion process. The scope of work also includes structural studies of the morphology of the produced polymer-mineral composites [30-37].

### 2. Materials and methods

Recycled plastics find more and more applications. In addition to recycled bulky products, the number and type of products also being used in polymer sands composites based on recycled PE and PP. One of the paving products sought by investors are traditional concrete blocks. However, they have their drawbacks, they are heavy, so their transport, logistics must meet stricter requirements, are products that are not very resistant to cracking as a result of impact, are fragile. Polymer - mineral products are the solution to such problems. Innovative compositions for their processing are a mineral-polymer mixture, containing mainly recycled material and mineral fillers (sand, ceramic waste dust). They are therefore products made of waste materials from recycling, recyclates and flakes of polymer materials.

The process water cooling sprinklers found in this type of cooling equipment have very large dimensions of 300x300x2400 mm. They are mainly made of PP, HDPE and PVC, and so far have not undergone any recovery and recycling processes leading to the manufacture of products from these materials. The waste panels are composed of about 5-20% plastics, and strongly associated sludge, primarily mineral, in amounts ranging from about 80 to 95% by weight. So far, in practice, used sprinkler parts are a huge amount of about 50 thousand tons per year, and in Poland alone, are not subjected to any recovery and recycling processes. This means that every year thousands of tons of plastic waste from the overhaul of cooling towers and fan coolers end up in landfills or are deposited in disused mines and will decompose emitting CO<sub>2</sub> and other toxic substances into the atmosphere for the next 100 years.



**Fig. 2** View of used cooling tower sprinklers used in processability studies of polymer - mineral composites.

Four types of cooling tower sprinklers were used in the conducted research immediately after disassembly from cooling towers. These are sprinklers made of HDPE and PP. The sprinkler samples used differ primarily in the degree of mineral contamination, resulting from the use of the sprinkler in question. This includes the way it is used, the cooling conditions, the type and quality of the cooling medium. This translates, in effect, into the amount and type of organic contamination in the tested sprinklers.

### 3. Results and Discussion

The technology for producing the polymer - mineral composition is based on the extrusion and compression molding technology of the compositions obtained. Polymer compositions are secondary materials, after recycling in the form of recyclates, flakes, and waste plastics, mineral fillers, that is waste ceramic dust, sand as well as activating substances (dyes, plasticizers, adhesion compatibilizers, polymer-mineral wetting agents). As a result, plastic waste and ceramic waste that cannot be recycled will be effectively processed.



**Fig. 3** The appearance of the shredder blades and the made polymer-mineral recyclate.

The samples were subjected to a knife grinding process in a single shaft XC-GP 230 from Xiencheng, with a drive power of 4.0 kW. A sieve with a hole size of 5.95 mm was used.

Fig. 3 shows an example of the samples to be subjected to grinding. The sprinklers were made of various polymer materials (PP, HDPE) as well as characterized by different shape of working elements and a variable degree of contamination with mineral sludge.



**Fig. 4** Appearance of particulate refresher plates and mineral sludge for the production of polymer - mineral composites.

The polymer processing was carried out with the use of a single-screw extruder, type W-25 with the screw diameter of D=25 mm. The plasticizing unit was equipped with four heating zones. The process line was composed of the extrusion coating head, vacuum calibrator, the cooling bath and the remaining process line components.

The extrusion head used in the conducted research, is used for extruding a section in the form of a strip has a width - 15.5 mm, while the height of the nozzle is 2.0 mm. The extrusion head has two heating zones and corresponding two ring heaters mounted on the head body. The laboratory extrusion line for poring sections also includes a cooling bath, with a length of 1740 mm, a width of 220 mm and a depth of 200 mm. A belt extraction system was also used in the study, designed to transport the extrudate using a 100 mm wide, 2000 mm long belt.



**Fig. 5** Experimental investigations of the possibilities of effective production, by plasticizing with extrusion, of new polymer - mineral compositions.

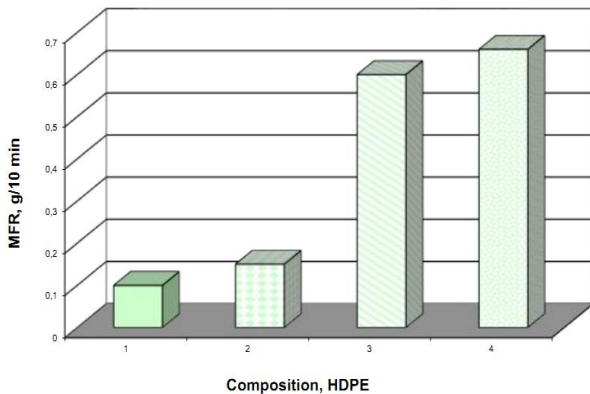
The process of extrusion of HDPE and PP recyclates was realized with the developed and set conditions, set in the extrusion process line. They are as follows: the temperature of the heating zones of the plasticizing system, respectively: 160, 170, 180 and 190 °C; head temperature in the heating zones 190 °C. The set screw speed was changed in the range of 0.83÷1.66 s-1 (50÷100 rpm). The temperature of the coolant in the cooling bath, determined by a temperature sensor, was in the range of 16÷19 °C.

The Melt Flow Rate (MFR) is a measure of the ease of flow of the melt of a thermoplastic polymer. It is defined as the mass of polymer, in grams, flowing in ten minutes through a capillary of a specific diameter and length by a pressure applied via prescribed alternative gravimetric weights for alternative prescribed temperatures. The method is described in the similar standards ASTM D1238 and ISO 1133. MFI tests were carried out on the test stand equipped with a Ceast weight plastometer type 6542.00 with additional equipment and a laboratory balance.

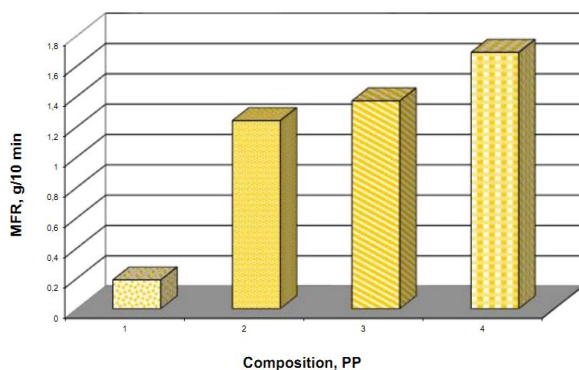


**Fig. 6** View of MFI instrument, Ceast 6542.0 and selected measurement samples.

The results of tests of the melt flow rate of recyclates, produced from cooling tower sprinklers, are characterized by MFR values ranging from 0.10 to 1.69 g/10 min. Such a wide range of MFR is mainly due to the content of mineral deposits deposited on the plastic.



**Fig. 7** Block diagrams illustrating the dependence of MFI on contents of polymer compositions with HDPE.

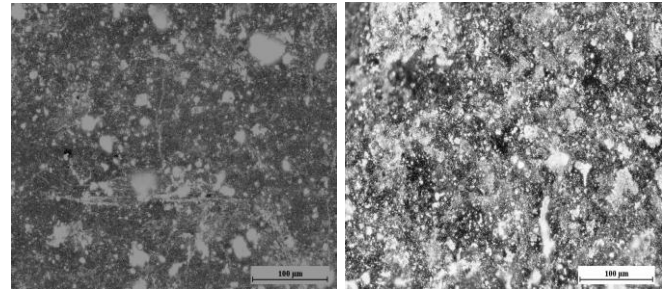


**Fig. 8** Block diagrams illustrating the dependence of MFI on contents of polymer compositions with PP.

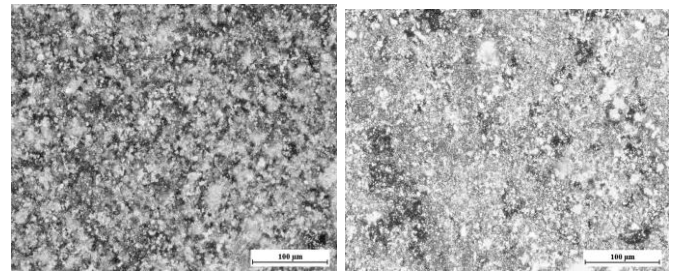
Samples of untreated recyclate, had in their composition a significant amount of crushed sludge, bound to flakes and in loose form, which affected their lower processability. The determined values of the melt flow rate indicate the possibility of their further processing by extrusion and injection molding.

The investigation and analysis of the porous structure of the produced parts were conducted using an confocal microscope, type

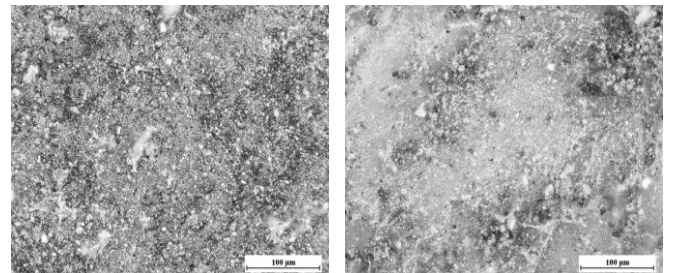
Nikon Eclipse LV100ND and copyright position of image analysis of structure. The morphology shows that the plastic-mineral structure is present throughout the cross-section. No solid outer layer is visible, with no mineral filler content. The resulting structure is characterized by the variable position of the mineral filler in the polymeric material. This is due to the type and amount of mineral waste in the shredded sprinklers.



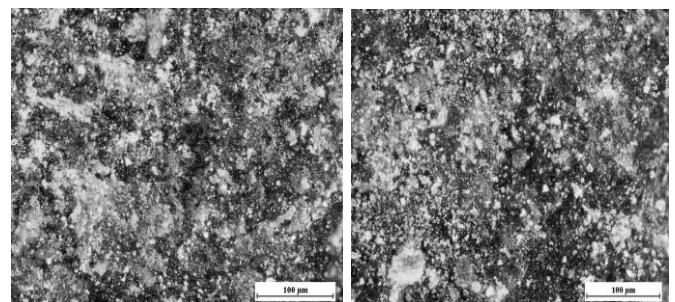
**Fig. 9** Fragment of the cross section of the polymer compositions with HDPE, test samples 1 and 2.



**Fig. 10** Fragment of the cross section of the polymer compositions with HDPE, test samples 3 and 4.



**Fig. 11** Fragment of the cross section of the polymer compositions with PP, test samples 1 and 2.



**Fig. 12** Fragment of the cross section of the polymer compositions with PP, test samples 3 and 4.

Microscopic examination of the morphology showed a significant difference in the structure of the different compositions. The precipitate visible on the surface of the sprinklers has a significantly lighter hue. Compositions 3-4 have a visible yellow glow, which is the residue of the precipitate. All compositions were characterized by heterogeneity in the distribution of sediments and irregularity in their dimensions. In addition, in the studied compositions, mineral sediments form agglomerative clusters distributed irregularly on the surface.

#### 4. Conclusions

The packaged design of shredders, in which thin-walled, interconnected plastic elements are separated by voids containing air or varying amounts of solidified mineral sludge, causes difficulties in the shredding process and requires the development of both the appropriate geometry of the working elements of the shredding system and the selection of tool materials and their surface treatment. The heterogeneity of the shredded waste and the variable content of impurities can adversely affect the stability of the shredding and purification processes and result in difficulties in selecting appropriate process parameters.

The trials and tests carried out will enable the preparation of a prototype sample batch of recyclates purified and with different contents of mineral fraction derived from sprinkler sludge, bound to plastic and obtained during separation of shredding and waste treatment products, to be scheduled for subsequent stages of testing.

The results of tests of the melt flow rate of recyclates, produced from cooling tower sprinklers, are characterized by MFR values ranging from 0.10 to 1.69 g/10 min. Such a wide range of MFR is mainly due to the content of mineral deposits deposited on the plastic.

Microscopic examination of the morphology showed a significant difference in the structure of the polymer compositions. The precipitate visible on the surface of the sprinklers has a significantly lighter hue. Above that, the amount of type and amount of mineral precipitate is different in each case. All compositions were characterized by inhomogeneity of distributed precipitates and irregularity of their dimensions, especially visible in composition 1. In addition, in the case of composition 4, the precipitates form agglomerative clusters distributed irregularly on the surface of the produced test samples.

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# Statistical Analysis of the Mechanical Properties of Aluminum Alloys EN AW-6060 (AlMgSi0,5)

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**Abstract:** Aluminum belongs to the group of light metals, which as pure aluminum does not have good enough mechanical properties for most engineering requirements. Therefore, in order to improve the exploitation properties of aluminum, it undergoes an alloying process, where different chemical elements are added to it, each of which has its own different role. Alloying is carried out mostly to increase hardness and tensile strength, then to increase machinability and stiffness, and sometimes toughness and castability. The most important chemical elements used for alloying aluminum are magnesium, copper, silicon, zinc and manganese, while chromium, titanium and iron are used as impurities. This paper presents the parameters of descriptive statistic mechanical properties of aluminum alloys EN AW-6060 (AlMgSi0,5).

**KEYWORDS:** ALUMINUM ALLOY, CHEMICAL COMPOSITION, TENSILE STRENGTH, HARDNESS.

## 1. Introduction

Aluminum belongs to the group of light metals, and its mechanical properties in the form of pure aluminum are not satisfactory for the vast majority of requirements. Therefore, alloying elements (silicon, iron, copper, manganese, zinc, chromium, etc.) are added to aluminum in its production. Each alloy element has its own specific purpose, which is primarily related to the improvement of mechanical and chemical properties. Aluminum alloy is a compound with about 97% aluminum, while the rest is made up of alloy elements [2-3, 16, 18-19]. There are many aluminum alloys and they are divided into families of aluminum alloys, with regard to the main alloying element of that family. Aluminum alloys of the 6xxx series are characterized by excellent deformability, the possibility of thermal hardening, good corrosion resistance and relatively good mechanical properties. Therefore, in the form of semi-finished products (in the form of bars and pipes), it is often used as a construction material where relatively low mass, medium mechanical properties and good resistance to external influences are required. The aim of the paper is to conduct laboratory tests of the most important mechanical properties of aluminum alloy EN AW-6060 (AlMgSi0,5), based on which the obtained test results will be compared through tables and diagrams.

## 2. EN AW-6060 (AlMgSi0,5)

Alloy EN AW-6060 (AlMgSi0,5) is a heat-hardening, corrosion-resistant alloy, especially in atmospheric conditions. It is excellent for processing by kneading and extruding, with the possibility of making very complex shapes [5-6, 10, 18-19]. The alloy itself is available in several variants, with different proportions of silicon and magnesium, thus optimizing different groups of properties, such as mechanical properties, surface appearance, suitability for anodizing, etc. The declared mechanical properties of the investigated alloy are in accordance with the 6xxx series (table 1) [16, 18-19].

Average hardness and strength can be further improved by adding silicon and copper to the aluminum base. Heat treatment, either artificial or natural aging, results in an additional improvement in hardness and strength.

**Table 1.** Declared mechanical properties of aluminum alloys EN AW-6060 [16, 18-19]

| Property         | Value     |
|------------------|-----------|
| HB               | 65 ÷ 70   |
| $R_m$ , MPa      | 195 ÷ 215 |
| $R_{p0,2}$ , MPa | 150 ÷ 160 |
| $A_{50}$ , %     | ≥ 6       |

Good weldability and solderability and good deformability in the cold state make it excellent for constructions of transport applications. However, as with other aluminum alloys, they are sensitive to pitting in an aggressive medium. The mentioned phenomenon occurs due to the heterogeneities present in the metal, which lead to the formation of local galvanic microcells between the intermetallic particles and the aluminum matrix. Pitting corrosion is a complex process that can be affected by various factors such as pH value, temperature, medium or structural characteristics of the oxide passive film [18-19]. The presence of intermetallic phases improves the mechanical properties of the alloy, but leads to additional sensitivity to corrosion, which, for example, comes to the fore when welding this alloy with the recommended additional material (EN AW 4043). During the process itself, melting and mixing with the base material occurs, which results in additional complexity in the distribution of intermetallic compounds in the microstructure. The declared chemical composition of the tested alloy EN AW-6060 (AlMgSi0,5) is shown in table 2 [2, 16, 18-19], based on which it can be concluded that silicon and magnesium are the most abundant alloying elements.

**Table 2.** Declared chemical composition of EN AW-6060 alloy [2, 16, 18-19]

| Si          | Fe          | Cu   | Mn   | Mg          | Cr   | Zn   | Ti   | Al   |
|-------------|-------------|------|------|-------------|------|------|------|------|
| 0,30 ÷ 0,60 | 0,10 ÷ 0,30 | 0,10 | 0,10 | 0,35 ÷ 0,60 | 0,05 | 0,15 | 0,10 | rest |

Research of mechanical properties of different of aluminum alloy are presented in papers [1, 3-4, 7-8, 11, 17, 20, 23-24].

Research of mechanical properties and different methods of processing technology of aluminum alloy EN AW-6060 (AlMgSi0,5) are presented in papers [9, 15].

The mechanical characteristics and application of aluminum alloys in the automotive industry are presented in papers [5-6, 10].

The processing of aluminum alloy products using different methods of additive technologies is shown in works [4, 8, 14].

### 3. Materials and methods

When designing and developing a new product, one of the most important items is a good knowledge of the material from which the product will be made. The material is selected according to many criteria such as its mechanical properties, price, availability, workability, storage possibility, etc. Figure 1 shows the test samples that were used for the purposes of laboratory tests.



Figure 1. Test sample

Tests were performed on aluminum alloy: EN AW-6060 (AlMgSi0.5), in the laboratory of the Faculty of Mechanical Engineering in Slavonski Brod (Croatia). In order for the results to be as authoritative as possible, the tests were performed on 10 test samples of aluminum alloy EN AW-6060.

Tests were performed on aluminum alloy: EN AW-6060 (AlMgSi0.5). In order for the results to be as authoritative as possible, the tests were performed on 10 test samples of aluminum alloy EN AW-6060.

For the calculation of descriptive statistics parameters of data about mehaničkim svojstvima legure aluminija EN AW-6060 we used software package MS-Excel, which is described in the papers [12-13, 21-22].

### 4. Research results and discussion

Aluminum alloy EN AW-6060 is the most commonly used alloy due to its good mechanical properties. This alloy is extremely suitable for extruding, which is confirmed by the value of the tensile strength, which is the lowest of the 10 tested alloys. Lower tensile strength results in easier workability and therefore easier extruding.

Table 3 shows the mechanical properties for 10 test samples of aluminum alloy EN AW-6060.

Table 3. Mechanical properties of aluminum alloy EN AW-6060

| Sample no. | HB | $R_m$ | $R_{p0.2}$ | $A_{50} (min)$ |
|------------|----|-------|------------|----------------|
| 1.         | 68 | 211   | 169        | 8              |
| 2.         | 69 | 208   | 165        | 8              |
| 3.         | 71 | 207   | 165        | 6              |
| 4.         | 70 | 210   | 166        | 7              |
| 5.         | 68 | 204   | 163        | 8              |
| 6.         | 71 | 203   | 165        | 7              |
| 7.         | 71 | 204   | 161        | 8              |
| 8.         | 70 | 202   | 160        | 6              |
| 9.         | 71 | 204   | 165        | 8              |
| 10.        | 69 | 209   | 166        | 6              |

In Table 4 is given descriptive statistic of mechanical properties of aluminum alloys EN AW-6060.

Table 4. Descriptive statistic of mechanical properties of aluminum alloys EN AW-6060

| Parameters         | Sign     | HB       | $R_m$    | $R_{p0.2}$ | $A_{50} (min)$ |
|--------------------|----------|----------|----------|------------|----------------|
| Minimum            | Min      | 68.000   | 202.000  | 160.000    | 6.000          |
| Maximum            | Max      | 71.000   | 211.000  | 169.000    | 8.000          |
| Range              | R        | 3.000    | 9.000    | 9.000      | 2.000          |
| Total (Sum)        | $\Sigma$ | 698.000  | 2062.000 | 1645.000   | 72.000         |
| Arithmetic mean    | AM       | 69.800   | 206.200  | 164.500    | 7.200          |
| Geometric mean     | GM       | 69.790   | 206.178  | 164.482    | 7.145          |
| Harmonic mean      | HM       | 69.780   | 206.156  | 164.463    | 7.089          |
| Median             | Med      | 70.000   | 205.500  | 165.000    | 7.500          |
| Std. deviation     | STD      | 1.229273 | 3.190263 | 2.592725   | 0.918937       |
| Coef. of variation | CV       | 1.761136 | 1.547169 | 1.576125   | 12.76301       |
| Variance           | Var      | 1.51111  | 8.67778  | 5.82222    | 0.888889       |
| Skewness           | Skew     | -0.43067 | 0.23509  | -0.31079   | -0.47251       |
| Kurtosis           | Kurt     | -1.46117 | -1.60439 | 0.42117    | -1.80748       |

The hardness of this alloy ranges from 68-71 HB. The tensile strength ( $R_m$ ) of this alloy ranges from 202-211. The  $R_{p0.2}$  of this alloy ranges from 160-169 and  $A_{50}$  of this alloy ranges from 6-8 (min).

Arithmetic mean (AM), geometric mean (GM) and harmonic mean (HM) for all mechanical properties of aluminum alloys EN AW-6060 are approximately the same.

The median for hardness (HB),  $R_{p0.2}$  and  $A_{50}$  is higher than arithmetic mean (AM), geometric mean (GM) and harmonic mean (HM), while for tensile strength ( $R_m$ ) it is lower than AM, GM and HM.

On the Figure 2 are given values for frequency of hardness (HB) of aluminum alloys EN AW-6060. For hardness values (HB) of 68, 69 and 70 the frequency is 0.20%, while for HB=71 the frequency is 0.40%.

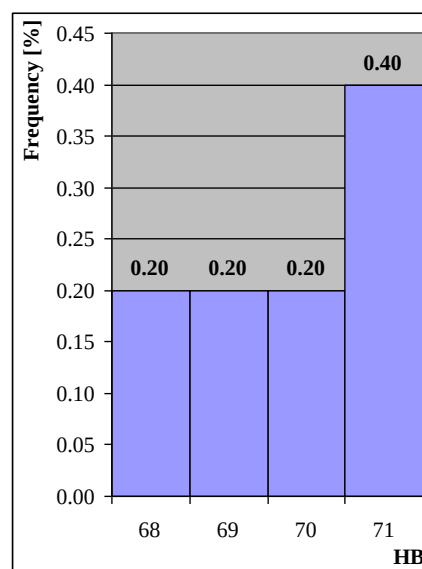
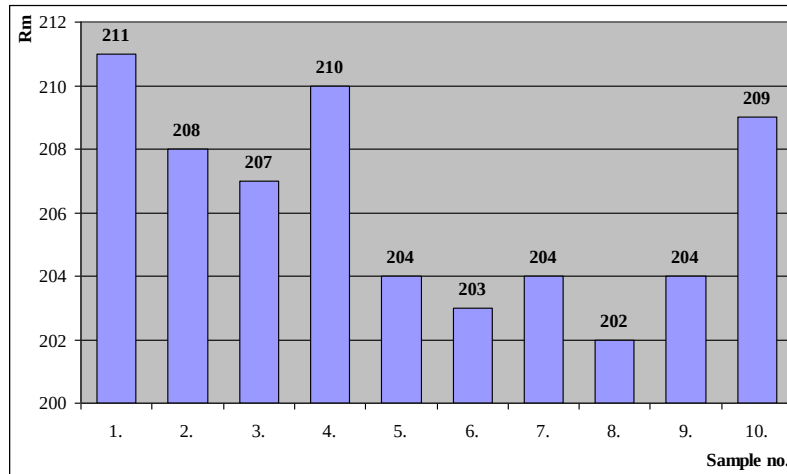


Figure 2. Values for frequency of hardness (HB) of aluminum alloys EN AW-6060

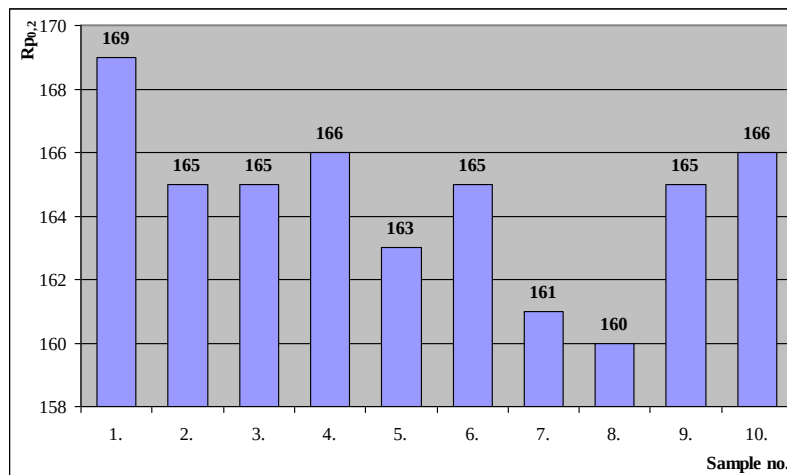
On the Figure 3 are given values for tensile strength ( $R_m$ ) of aluminum alloys EN AW-6060 for all ten experimental points. The lowest value of  $R_m$ =202 is in the 8th experimental point, and the highest  $R_m$ =211 is in the 1st experimental point.



**Figure 3.** Values for tensile strength ( $R_m$ ) of aluminum alloys EN AW-6060 for all ten experimental points

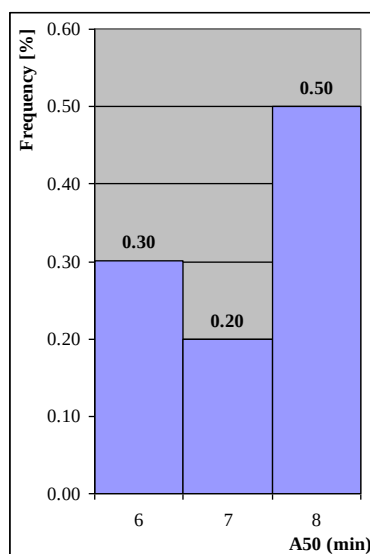
On the Figure 4 are given values for  $R_{p0,2}$  of aluminum alloys EN AW-6060 for all ten experimental points. The

lowest value of  $R_{p0,2}=160$  is in the 8th experimental point, and the highest  $R_{p0,2}=169$  is in the 1st experimental point.



**Figure 4.** Values for  $R_{p0,2}$  of aluminum alloys EN AW-6060 for all ten experimental points

On the Figure 5 are given values for frequency of  $A_{50}$  (min) of aluminum alloys EN AW-6060. For  $A_{50}=6$  (min) the frequency is 0.30%, while for  $A_{50}=7$  the frequency is 0.20% and for  $A_{50}=8$  the frequency is 0.50%.



**Figure 5.** Values for frequency of  $A_{50}$  (min) of aluminum alloys EN AW-6060

## 5. Conclusion

Aluminum has justified its expensive production by the fact that in today's world, hardly anything can be produced or built without aluminum products. Its exceptional mechanical and technological properties have made it a highly positioned technical material in the world.

Due to the large number of aluminum alloys and due to numerous different combinations, aluminum has found its application in almost all branches of production. The reasons for the use of aluminum derive from the properties that aluminum alloys possess, namely high specific strength, easy processing, toughness, low maintenance costs, durability and recyclability. Alloys of the 6xxx family are mostly used for extruding purposes, and various profiles with exceptional technological properties are made from them. Their properties are justified by the fact that such profiles are used on the facades of buildings and in the production of windows that are exposed to external, changing atmospheric conditions.

For all mechanical properties of aluminum alloy EN AW-6060, the range of all measured values is small, so the scattering of experimental points is also small.

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