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”

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Properties of innovation management and innovative solutions portfolio planning

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Abstract: Innovation management is the process of making decisions in an ever-changing environment, constantly studying innovative programmes and reviewing them both in general and in parts. An innovation leader recognizes that his or her activities are surrounded by uncertainties, both internal and external. He is never immune to the emergence of unforeseen technical problems, the need to reallocate resources, new assessments of market opportunities. The system for planning and managing innovative technology in management must be sufficiently flexible. The most comprehensive and flexible innovation management systems are primarily focused on the development of prospective products as well as the transformation of innovation management functions.

Keywords: INNOVATION MANAGEMENT, PLANNING, FLEXIBLE INNOVATION MANAGEMENT, COMPANY'S ACTIVITIES

1. Introduction

Innovation management is the process of making decisions in an ever-changing environment, constantly studying innovative programmes and reviewing them both in general and in parts. An innovation leader recognizes that his or her activities are surrounded by uncertainties, both internal and external. He is never immune to the emergence of unforeseen technical problems, the need to reallocate resources, new assessments of market opportunities. The system for planning and managing innovative technology in management must be sufficiently flexible.

In the context of innovation management, a project must start with a clearly defined objective, which, like the end result, depends on the needs of the market [1, 3]. First and foremost, it is the relevant segment and its characteristics, represented by size, acceptable price, technical efficiency requirements and product take-up time. Products should be defined by their efficiency, price and date of appearance. These characteristics are interrelated and therefore some iterative process is needed to refine the purpose.

With particular care it is necessary to consider what technical level of product is required for the particular market segment likely. Too many parameters can increase research and development. (R&D) and production costs as well as development time and thus reduce profitability.

The initial definition of a project should focus on the market need and its satisfaction, not on decisions about the type of final product. The definition of the project should be short, not limiting the freedom of employees to find new solutions. At the same time, formulate clear objectives, standards for technical, cost criteria and development time. The innovation portfolio can be filled with a variety of projects: from large to small, near completion and in the early stages of development.

Limited resources will need to be allocated to each project. Some projects will be terminated during implementation, their components will vary in number and resource requirements, etc. As a consequence, the process of drawing up plans and modifying R&D plans is continuous. The number of projects included in the portfolio is determined by two factors: the size of the projects and the total R&D budget. The structure of the portfolio is determined by its manageability by management and the corporate R&D policy.

As the number of projects increases, the likelihood of at least some of them being completed effectively increases. Moreover, it is easier to 'pair' small projects with each other in the R&D process using available private resources (e.g. pilot production facilities). However, small projects usually have a moderate profit potential, resulting in products with limited market prospects. This is hardly equivalent to a company's marketing policy.

The ultimate success of any project is as much determined by technical and market strengths as it is by the quality of project management. Good governance is a critical resource for most companies and should not be scattered across many projects. Indeed, these are most often divided into phases, and the art of management lies in staggering their launches over time to ensure the effectiveness of the entire portfolio.

Innovation Portfolio Management (IPM) is an amalgamation of activities that facilitate every company to select, build, and market a

new flow of initiatives. The kind of flow that fuels business's short term and long-term goals. Innovation portfolio management is a tool to transform strategic objectives into innovation activities that are project-based. On the basis of risk profile, an innovation portfolio gives a framework to convert roughly produced ideas into real investment opportunities [7, 8].

Moreover, the innovation portfolio is a time management tool too. It helps in assessing the time required to complete to start a new initiative [2, 8]. Also, it can be used to reflect on potential opportunities that can be judiciously used as leverage in technologies, markets, and products or services. Portfolio management is also the perfect way to manage the success of innovation. The success of innovation is most of the time measured by dividing the total number of successfully implemented innovation projects BY the total amount of started projects. The main goal of portfolio management is to measure and optimize the performance of innovation projects [7].

2. Managing innovation in personnel management

Qualified staff is a major resource for any company or organisation. The constant search for innovations that will enable qualified assessment of the effectiveness of activities and personnel management is the basis for successful business development.

A personnel management system is created at the moment when any company starts to operate, if it plans to become successful and has the necessary qualities that are inherent in any innovation. Personnel management is an administrative function within an organization that oversees the hiring, organization and support of employee positions. A branch of human resources, personnel management focuses on recruiting the right individuals to fit a position and supporting those already working for the company. This area also functions as a tool for evaluating the hiring process and gaining insight into employee satisfaction. Personnel management professionals work to provide the resources and tools staff members need to thrive in their work environment every day [7, 8]. Types of personnel management:

- Strategic.
- Tactical.
- Operational.

Personnel management can be broken down into several elements as listed below:

1. Job analysis: This function of personnel management determines how a position fits into the overall company framework. It's a measure of the role and not the employee.
2. Strategic personnel planning: Also called strategic workforce planning, this element involves hiring the most qualified individual to fit a necessary role in an organization. It ensures that hiring processes are consistent, fair and effective.
3. Performance appraisals: Identifying how employees are evaluated is the function of this element of personnel management. Using this element, professionals in personnel management decide how often employees are

assessed and the methods used to rate employee performance.

4. Benefit coordination: Determining the type of benefits employees receive and planning for their distribution is an essential part of personnel management. This element also involves choosing plans such as personal health care benefits.
5. Continuing education: To keep staff involved in growing their career and investing in their workplace, personnel management oversees employee development through continuing education. This may include offering seminars, learning lunches or arranging for staff to attend professional conferences.
6. Pay and salary distribution: Another part of the operational activities of personnel management staff is to ensure employee payroll functions correctly. It may also involve setting pay scales or job levels.
7. Attendance and leave: Managing personnel also means overseeing time off for sick and personal days. This function also involves leaves of absence or short-term disability.

The emergence and development of a system goes through all phases of the innovation process, which corresponds to key economic laws. All transformations are aimed at increasing the efficiency of employees and thus the success of the company as a whole.

A study of the HRM system itself as an innovation should be conducted with a focus on these criteria [1, 4]:

1. Personnel development and career management: curricula are designed in conditions of mismatch between qualification requirements and actual competencies of employees, therefore individualization of the learning process is necessary in order to obtain the most effective result at the minimum cost.
2. Building an incentive system: traditional incentive factor- It is the employee's salary which is determined by the value of a particular job. In addition to this, a rewards system is also prevalent, which involves a variable wage component that is determined by each employee's monthly contribution to the work of the department and the organization as a whole.
3. Shaping corporate culture: if every employee is aware of the core values and mission of the company, it has a positive impact on the effectiveness of his work and the process of transferring these values is the corporate culture.
4. Developing a competency model: This innovation is intended to regulate the multifunctionality of a multitude of workplaces and competently build a technological chain that avoids conflicts and focuses on quality and efficiency of work.
5. Computer technology in management: software products not only allow to keep records of personnel according to various parameters, but also to generate the necessary reporting documents, which can be easily transferred in electronic form.

At the heart of innovative approaches to personnel management is the consideration of the characteristics of human resources:

- Humans are intelligent beings who respond to external influences emotionally and meaningfully rather than automatically, so the interaction between the organisation and the employee is reciprocal.
- People strive for continuous improvement and development, thus improving the quality of each enterprise.
- On average, a person's work activity lasts from 30 to 50 years, which means that the relationship between

employees and the company can be characterized as long-term.

- People choose their work intelligently, they are guided by certain goals and in return they expect their ideas to be realised. The further course of cooperation depends on how satisfied the employee is with the interaction with the organization and vice versa.

Innovation or innovation is the result of creative activity aimed at the development, creation, distribution and profitable use of new types of competitive products, modern technologies, the introduction of new organizational forms and management methods. Innovation is characterised by the efficiency of investment in the development of the economy, providing cost savings or creating the conditions for such savings.

The role of innovation continues to grow. In most industrialised countries, the number of people involved in scientific development, research and experimental processes doubles approximately every ten years. A decisive factor in scientific and technological progress is the high rate of technical renewal of production, the introduction of high-efficiency products and technologies. The most important feature of innovation is therefore the novelty of consumer characteristics, with technical novelty playing a secondary role.

The methodology for systematically describing innovation in a market economy is based on international standards. A group of national experts on science and technology indicators has been set up to coordinate the collection, processing and analysis of information on science and innovation within the Organisation for Economic Co-operation and Development (OECD). Innovation management is a system for managing innovation, the innovation process and the economic relationships that arise from this management.

Innovation management is based on the following basic points: the purposeful search for an idea that serves as the basis of this innovation; the organization of the innovation process to create this innovation; this involves carrying out an organizational and technical complex of work to turn the idea into an innovation; the process of promoting and introducing the innovation to the market, which requires a creative approach and active action of salespeople. The foresight function in innovation management covers the long-term development of changes in the technical, technological and economic state of the management object as a whole and its individual parts. The result of forecasting is a prognosis, i.e. an assumption about the possible direction of the respective changes. The hallmark of innovation forecasting is the alternative nature of the technical and economic indicators included in the process of innovation creation. Alternativeness implies the need to choose one solution among mutually exclusive options.

3. The use of innovation management in the company's activities

The need for innovative enterprise development places new demands on the organisation, content and methods of management activities. The organisation of innovation management in an enterprise is a system of measures aimed at rational integration of all its elements into one innovation management process. The innovation management organisation combines the above elements of the innovation management process into a single system.

Table 1. The process of innovation management organisation in the enterprise

Stage 1	Defining the goal of innovation management.
Stage 2	Choosing an innovation management strategy.
Stage 3	Definition of innovation management techniques.

Stage 4	Developing an innovation management programme.
Stage 5	Organisation of work on the implementation of the programme.
Stage 6	Control over the implementation of the planned programme.
Stage 7	Analysis and evaluation of the effectiveness of innovation management techniques.

The organisation of innovation management is already laid in the creation and implementation of the innovation, i.e. in the innovation process itself. The innovation process serves as the basis of the force on which the effectiveness of the use of innovation management techniques will depend. The important stages in the organization of innovation management are the development of an innovation management program and the organization of the work to carry out the planned work. An innovation management programme is a set of measures agreed in terms of timing, outcomes and financial support to achieve a set objective.

An integral part of innovation management is the organisation of work on the implementation of the planned action programme, i.e. the determination of certain types of activities, the volume and sources of funding for this work, specific implementers, deadlines, etc.

Innovative economy is the economy of a society based on knowledge, innovation, on benevolent perception of new ideas, new machines, systems and technologies, on readiness for their practical implementation in various spheres of human activity. In the innovation economy, under the influence of scientific and technological knowledge, the traditional spheres of material production are transformed and radically change their technological base, because production that does not rely on new knowledge and innovation proves unviable in the innovation economy. The most significant features of the innovation economy include [52]:

- Any individual, group of persons, enterprise anywhere in the country and at any time can obtain any necessary information about new or known knowledge, innovations on the basis of automated access and telecommunication systems.
- Modern information technology and computer systems are produced, shaped and made available to every individual, group of persons and organizations, thus ensuring the implementation of the previous paragraph.
- Infrastructures are in place to ensure the creation of national information resources in the quantities needed to support the ever-accelerating pace of scientific and technological progress and innovative development;
- A process of accelerated automation and computerisation of all spheres and sectors of production and management is underway; radical changes in social structures are taking place, resulting in the expansion and activation of innovative activity in various fields of human activity.

Given that innovations are currently a necessary factor for increasing the competitiveness of a company, it is necessary to focus on measuring and evaluating their performance. Measuring innovation performance covers a wide range of entities, from simple innovation projects to the entire economy. Different existing levels and categories of innovation activities to be measured must be defined and partially extended to all significant levels of performance measurement.

4. Conclusion

Each proposal for an innovation plan should be based on a selected variant of a comprehensive business strategy, respecting the strategy of cost-effectiveness, based on scientific, technical and economic information. Innovation is crucial to a company's business strategy. They make it possible to win new markets and market segments, to reduce production costs, which creates the prerequisite for lowering prices and increasing market share.

Innovations in the company are largely based on developmental changes in production and on the market, they lead to the expansion of the production process. The term innovation can be understood as the introduction of "something new" into the current activities of the company. These are new knowledge, technologies, products, but also their various improvements and combinations.

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Концептуален модел за гласуване с биометрична идентификация

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Резюме: Електронната идентификация постепенно се превръща в предпочитана услуга, която е налична и интегрирана в редица бизнес процеси. Адресирането на риска от субективни грешки и пропуски при идентифицирането на гласуващите граждани би довело до значително смекчаване на възможните последици от контролиран вот и същевременно до значително оптимизиране в работата на изборните комисии. В тази статия предлагаме цялостен подход, базиран на биометрична идентификация за технологично подпомогнат процес по идентифициране на гласуващи граждани. Констатациите от това изследване допринасят за управлението на риска от грешки и пропуски при идентификацията на гласоподавателите и предоставят ценни възможности за включването на биометрична идентификация при формулирането на проактивни стратегии за гарантиране на честен вот.

Ключови думи: система за гласуване, биометрична идентификация, избори, изборни списъци, идентификация на избиратели

Conceptual model for voting with biometric identification

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Abstract: Electronic identification is gradually becoming a preferred service available and integrated into a number of business processes. Addressing the risk of subjective errors and omissions in the identification of voting citizens would lead to a significant mitigation of the possible consequences of a controlled vote and at the same time lead to a significant optimization in the work of election commissions. In this paper, we propose a comprehensive biometric-based identification approach for a technology-assisted citizen voter identification process. The findings of this research contribute to the management of the risk of errors and omissions in voter identification and provide valuable opportunities for the inclusion of biometric identification in the formulation of proactive strategies to ensure a fair vote.

Keywords: voting system, biometric identification, elections, electoral lists, voter identification

1. Въведение

През последните три години в Република България се провеждат поредица от предсрочни парламентарни избори, както и редовни избори за местна власт и европейски парламент. В някои случаи на една и съща дата се провеждат повече от един избор. Закупени са машини за електронно гласуване и в изборното законодателство са направени промени, които позволяват на гражданите да гласуват както електронно с машините, така и с хартиени бюлетини. В резултат на негативна кампания и политически натиск машините за електронно гласуване са превърнати в принтери за отпечатване на бюлетини в изборната секция. Поради това проблемите и съмненията за манипулиране на изборния резултат при ръчно броене на бюлетините, отпечатани централизирано, и на място в изборната секция, остават, а и резултатите от видео наблюдението в изборните секции потвърждават извършването на манипулации.

Един от методите за манипулиране на вота е събирането (под някакъв предлог или срещу заплащане) на лични карти и гласуване от името на притежателите на картите за определена партия или кандидат.

Еднозначната идентификация на гласуващото лице е една възможност за минимизиране на манипулирането на вота на гражданите. В момента идентификацията и сверката с избирателния списък се извършват въз основа на лична карта [1], която може да бъде представена и от друго лице. Квалифицираният електронен подпис [2], [3] е единственият сигурен законово установен електронен идентификатор, но липсва политическа воля за масовото му приложение.

Биометричната идентификация [4], [5] се основава на биологични данни, които са характерни за всеки един гражданин, и практически е невъзможно двама граждани да имат едни и същи биометрични данни.

Пръстовият отпечатък е специфичен за всеки един пръст на всеки отделен гражданин. При издаването на лични документи съгласно чл. 17 от Закона за българските лични документи всеки гражданин предоставя пръстови отпечатъци [7], които се съхраняват в базата данни на МВР. През последните години

пръстовите отпечатъци се снемат с електронни устройства и се съхраняват в цифров вид [8]. Съществува добре дефинирана релация между пръстовите отпечатъци, ЕГН и номер на лична карта за всяко лице над 14 години, гражданин на Република България. Право на глас имат лицата над 18 години, т.е. всеки с право на глас е регистриран с пръстовите си отпечатъци в МВР.

Освен с пръстови отпечатъци МВР разполага и със снимки на всички граждани, които имат лична карта или паспорт (чл. 22 от Закона за българските лични документи). Цифровизирането на снимките може да се използва за лицево разпознаване, което е друг вид биометрична идентификация.

На по-късен етап е възможно да се приложи и идентификация на базата на данни за ириса на очите [6] – в сегашния вариант на Закона за българските лични документи съгласно чл. 18 се записва цветът на очите. Подписът на лицето се сменя при издаване на лични документи (чл. 26 от Закона за българските лични документи) и също може да се използва за биометрична идентификация на по-късен етап.

Съществуват и много други методи за биометрична идентификация, но пръстовият отпечатък и лицевото изображение вече са налични в масивите на МВР, поради което няма да се разглеждат други варианти.

В редица страни биометричната идентификация се използва за идентифициране на граждани и на лица, граждани на други страни, при влизане в страната.

В Република България биометричната идентификация се използва от бизнеса доста активно. Идентификация на потребителите с използване на биометрична идентификация или електронен подпис се прилага най-често в банковия сектор, телекомуникациите, както и в системите за достъп до фирмени информационни системи.

2. Съвързани изследвания

През последните години се наблюдава засилен научен интерес по темата за биометричната идентификация и нейните приложения конкретно при електронно гласуване. Добър критичен литературен преглед може да бъде намерен в [9], [10],

[11]. Основаните цели на тези изследвания са свързани с анализ на положителните ефекти по отношение на сигурността и надеждността в системите за гласуване, които използват биометричната идентификация и биометричната криптография.

Може да си посочи интересен пример за използване на биометрични системи за идентификация в Бразилия [12]. Въпреки че технологията, свързана с този вид услуга, се е развила, цената на нейното прилагане не е достъпна за повечето страни. Авторите на това изследване поставят акцент върху търсенето на концептуални модели, които се отличават не само с високо ниво на сигурност и надеждност, но и върху такива с висока степен на лекота на използване и ефективност на разходите. Много полезни в това отношение биха били допълнителни изследвания на различни методи за биометрично удостоверяване. В [11] авторите сравняват три различни метода, използвани за прилагане на биометрично удостоверяване посредством мобилното устройство. Те разглеждат: (1) AES криптиране на биометричното изображение, (2) AES криптиране на биометрично изображение, базирано на вълни, и (3) генериране на шаблон на биометрично изображение. AES алгоритъмът, базиран на вълни, ускорява процеса на криптиране и намалява използването на процесора на мобилното устройство. Експерименталният анализ на три метода показва, че производителността на AES криптирането, базирано на вълни, е много по-добро от AES криптирането и генерирането на шаблони. Анализът на сигурността на трите метода сочи, че AES и базираното на вълни AES криптиране показват по-добра сигурност от защитата, базирана на биометричен шаблон.

3. Възможности за използване на биометрична идентификация в изборния процес

Снемането на пръстови отпечатъци с електронни устройства е технологичен проблем, който е решен в края на XX и началото на XXI век. Подобни устройства са широко достъпни на пазара. Едно търсене за сензор за пръстов отпечатък (fingerprint sensor) в Microsoft Bing [13] показва над 1 900 000 резултата, голяма част от които са за конкретни устройства, достъпни на пазара. МВР разполага с електронни устройства за снемане на пръстови отпечатъци.

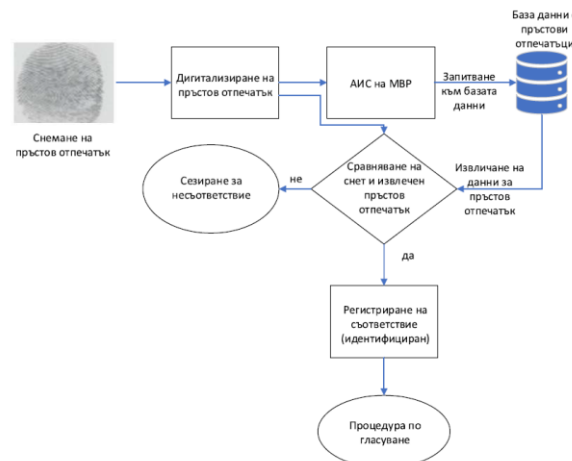
Добре познатите разпечатки на избирателите в дадена избирателна секция съществуват в електронен вид, преди да бъдат отпечатани, и могат да бъдат заредени на всеки съвременен компютър. Към компютъра е включен стандартен сензор за пръстови отпечатъци. Гласоподавателят предоставя личната си карта на член на комисията в избирателната секция, който отбелязва в списъка, че гражданинът се е явил за вота. Гражданинът предоставя своя пръстов отпечатък през скенера за пръстови отпечатъци. Цифровизираният пръстов отпечатък се изпраща през сигурна интернет връзка или през единната електронна съобщителна мрежа на държавната администрация до административната информационна система (АИС) на базата данни на МВР, заедно с ЕГН на гражданина. Извършва се верификация дали ЕГН и пръстовият отпечатък, предоставени от гражданина, съвпадат с тези, съхранявани в базата данни на МВР.

При отрицателен резултат лицето се предава на органите на МВР и прокуратурата за търсене на отговорност за фалшификация на документи, кражба на самоличност или друго в съответствие с Избирателния закон и Наказателния кодекс.

При наличие на съответствие АИС на МВР отбелязва в избирателния списък, че гражданинът се е явил за гласуване. Гражданинът получава съответния брой бюлетини или карти за гласуване и отбелязва своя глас в съответните електронни или хартиени бюлетини. След пускането на хартиените бюлетини в съответните урни или след електронното гласуване

гласоподавателят отново с пръстов отпечатък обявява в кои избори е участвал.

На фиг. 1 е показана принципна схема на системата за биометрична идентификация. Представен е вариант с използване на пръстов отпечатък. Същата схема може да се приложи и за други типове биометрични данни. Самият процес на гласуване може да бъде с хартиени бюлетини или с машина или отдалечено по електронен път.



Фиг. 1. Принципна схема на системата за биометрична идентификация

При този вариант се изисква осигуряване на гарантиран и сигурен достъп до АИС на МВР, т.е. трябва да се осигури мрежова свързаност между всяка една изборна секция и АИС на МВР. Техническите възможности за това са няколко и са предмет на конкретно техническо решение, което е извън обхвата на тази публикация.

Възможно е скенерът за пръстови отпечатъци да генерира хеш функция с параметри цифровизирания данни от пръстовия отпечатък. В базата данни на МВР може да се пазят тези хеш функции и верификацията да се свежда до проверка за съвпадение на хеш функциите. Така обемът на обменяните данни се съкращава значително.

При въвеждането на чип в личната карта или друг електронен носител (USB памет, мобилен телефон и др.) хеш функцията с параметри цифровизирания данни от пръстовия отпечатък може да бъде записана на чипа. В този случай верификацията на хеш функцията, генерирана от скенера за пръстови отпечатъци, може да се извърши чрез сравняване с хеш функцията, записана на личната карта на самия скенер. Такива устройства също са достъпни на пазара [13]. В този случай се избягва необходимостта от наличие на мрежова свързаност между секцията и АИС на МВР.

Възможни са вариации и оптимизация на така описания процес на гласуване с използване на биометрични данни за идентификация на гласоподавателите. Дали ще се използва пръстов отпечатък, лицево разпознаване, разпознаване на ирис, разпознаване на саморъчен или електронен подпис, е въпрос на решение на законодателя. При използване на квалифициран електронен подпис вместо базата данни на МВР се използват базите данни на доставчиците на удостоверителни услуги (ДУУ). Процедурата по верифициране на квалифициран електронен подпис отдавна е доказала своята ефективност.

Двуфакторната или многофакторната идентификация (биометрична + електронен подпис, ПИН, токен, SMS или друго) позволява да се реализира много сигурно дистанционно гласуване по електронен път. При такъв подход възможностите за манипулиране на вота се минимизират. Дистанционното електронно гласуване не отменя, а допълва гласуването в

избирателни секции, но вероятно ще увеличи избирателната активност. Най-малката полза ще бъде улесняването на изборния процес за българските граждани с право на глас в чужбина.

4. Предимства на предложения концептуален модел за гласуване с биометрична идентификация

- Премахва се възможността едно лице да гласува повече от един път.
- Предотвратява се възможността едно лице да гласува вместо друго.
- Броят на гласувалите граждани не може да се манипулира на ниво секционна избирателна комисия.
- При наличие на връзка с АИС на МВР броят на гласувалите граждани се отчита в реално време.
- При наличие на законово изискване за задължително гласуване бързо и навременно могат да се вземат адекватни мерки за реализиране на законовото задължение на всеки гражданин. Мерките не са предмет на разглеждане в този материал.
- Подобрява се контролът върху членовете на секционните комисии и се намаляват възможностите за манипулиране на вота на гражданите в съответната секция.
- Спестява се ръчен труд по въвеждане на данни от хартиени избирателни списъци в електронна база данни за лицата, гласували в съответните избори. Предотвратяват се волни и неволни грешки при въвеждане на данни.
- В избирателните секции в чужбина се избягва ръчното въвеждане (дописване) на избиратели в изборните книжа. Автоматично се удостоверяват избирателните права на лицата, които искат да гласуват.
- Създава се възможност за гласуване в друга секция, тъй като идентификацията на гласоподавателя се извършва в АИС на МВР. (Премахва се необходимостта от подаване и обработка на заявление за гласуване по настоящ адрес.)

5. Недостатъци на предложения концептуален модел за гласуване с биометрична идентификация

- Страх от непознатото;
- Въвеждане на нови административни процеси;
- Промяна в действащите нормативни актове;
- Продължителната и настойчива пропаганда и саботаж срещу електронното гласуване ще премине в яростна реакция срещу биометричната идентификация;
- Разрушаване на добре отработения модел за манипулиране на хартиения вот;
- Съпротива от страна на МВР за използване на вече събраните биометрични данни;
- Минимизиране на разходите за провеждане на избори (с хартиени бюлетини).

6. Изводи и заключения

Предложеният концептуален модел за гласуване с биометрична идентификация е технически реализуем. В България съществува необходимият за реализирането на системата технически капацитет – както в ИКТ фирмите, така и в определената в Закона за електронното управление [14] като единен системен оператор фирма „Информационно обслужване“. Една система за биометрична идентификация би била относително евтина, тъй като бази данни с данни от

биометрична идентификация вече са изградени в МВР и са отработени процесите по събиране, обработка и съхранение на биометрични данни, както и по поддръжка и развитие на системата. Налични са и устройствата за събиране на биометрични данни.

Подобна система ще затрудни значително манипулирането на изборните резултати. Манипулирането на такава система изисква задълбочени технически познания и голям финансов ресурс. Необходим е и достъп до базите данни и преносната среда, които са или би следвало да са добре защитени.

Използването на хартиени бюлетини, наличието на голям брой невалидни бюлетини при хартиен вот, процедурите по преброяване на гласовете, саботирането на електронното гласуване и т.н. показват, че гласуването с хартиени бюлетини е овладян процес, при който може да се получи желан резултат.

Въпрос на политическа воля е да се реализира система за гласуване с биометрична идентификация, която гарантира висока степен на сигурност и честност на изборния процес и изборните резултати.

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The Role of Consumer Feedback in Driving Innovation

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Abstract: This article focuses on the important role that consumer feedback plays in fostering innovation in business. It discusses the importance of listening to and understanding consumer views and preferences when developing new products and services. The article clearly analyses ways to effectively gather and interpret consumer feedback to improve the innovation process and ensure the success of new initiatives. It also discusses the challenges that can arise in processing and interpreting feedback. The article also highlights the benefits of actively involving consumers in the innovation process, including creating loyal customers, satisfied customers, improving competitiveness and minimizing the risk associated with new product launches. Based on a review of recent research and case studies, this article offers insights and guidance for entrepreneurs and managers seeking to effectively integrate consumer feedback into their innovation processes.

Keywords: CO-DEVELOPMENT, CONSUMER FEEDBACK, CUSTOMER, INNOVATION, MANAGEMENT

1. Introduction

The concept of feedback is found in various areas of human life, but its essence remains the same in every sphere – it provides the system with important information. Feedback serves as a pivotal instrument within behavioral data analysis, offering elucidation not merely on operational occurrences within a business framework, but also on the underlying rationales thereof. Without feedback, we would perceive business processes only subjectively, which could lead to erroneous and inaccurate decisions [1, 2]. Furthermore, it can be delineated as a form of customer communication specifically pertaining to a particular product or service offering. In the realm of traditional marketing, customers were often seen as passive consumers, merely purchasing and using products. Yet, a contemporary viewpoint has emerged, positing customers as active participants, contributing to the creation, development, and production of the products they wish to purchase and use. Innovation has evolved into a cyclical process involving interaction between customers and producers [3].

2. Consumer feedback and its processing

Manufacturers are increasingly leveraging customer feedback as a strategic tool to distinguish themselves within competitive markets while concurrently aligning with industry benchmarks. Following the introduction of novel product offerings, corporations' endeavor to actively engage their consumer base, incentivizing them to furnish invaluable perspectives, critiques, and suggestions for enhancements [4]. The notion of feedback is inherently intertwined with the construct of customer satisfaction. Milner and Furnham [5] elucidate customer satisfaction as the degree to which products and services align with the unique expectations of individual clientele, thereby underscoring the symbiotic relationship between feedback mechanisms and the attainment of consumer contentment. Consumer feedback provides information about how we are performing - whether we are meeting customer expectations or, conversely, not even meeting basic standards. Drawing upon a comprehensive review of extant literature, various methodologies have emerged for soliciting essential insights from customers. These methodologies include:

a. Questionnaire surveys

Questionnaire surveys are one of the most common methods of obtaining feedback. It is important to design the questionnaire correctly and to create questions that will offer us the best possible picture of our customers' opinions. If the questions have been asked appropriately and the sample of customers has answered truthfully, we will get an objective view of the product. Contemporary business practices tend to favor online surveys over traditional modes such as telephone or face-to-face interviews, reflecting the evolving landscape of consumer engagement in the digital era. This is mainly due to the lower cost or the independent time management of the respondent's answer. Nevertheless, incomplete questionnaire responses or ambiguous replies to open-ended queries may pose

challenges, potentially undermining the efficacy of the feedback mechanism [2, 6].

b. In-depth interviews

In-depth interviews are inductive in nature and arise from individual processes. Their goal is to define a category based on the data obtained and then analyze the relationships between the created categories. We use it if we want to find out from the customer his more detailed opinion on the given product, either independently or in connection with questionnaire surveys. It is important to properly manage the interviews and ask questions relevant to the characteristics of the respondent and their proper adaptation [2, 7].

c. Group discussions

Group discussions represent a prevalent qualitative research approach due to their cost-effectiveness and provide valuable insight into the opinion of the target group. Typically facilitated by the sponsoring company, these sessions convene a cohort of approximately eight to ten participants, comprising both internal personnel and external experts, for in-depth deliberations on the company's offerings. Such discussions extend over several hours, affording ample opportunity for comprehensive exploration of pertinent product and service-related matters. According to Isson and Harriott [2], the advantage of these sessions is the possibility of direct communication between the company and the target group. On the other hand, it is necessary to be careful with group discussions, because they do not always go in the desired direction, or a small sample that does not provide sufficient objectivity can also be portrayed as a disadvantage [7].

d. First-line feedback from employees

Employees are one of the main sources of information. Not only do they obtain information about customers, where they find out what they liked or disliked, but on the other hand they also act as a subject who can independently spot possible necessary changes in certain processes or products. They can either improve individual organizational processes and innovate products and services themselves, or they can pass on useful and valuable information to competent places. In this case, it is very important to reserve space and allow the right way for employees to express themselves, as it is the lack of an open corporate policy within the company that can act as a problem [8].

e. Direct interaction with the customer

It is directly related to the previously mentioned method and thus can be a valuable source of information. It furnishes invaluable perspectives on organizational strengths and weaknesses, encapsulating both commendations and grievances. However, the views collected need to be recorded and categorized, and consumer attitudes need to be analyzed on a regular basis. Without regular analysis, it loses its meaning [2].

f. Social media

With the invention of the internet, the digitization of information has made it easier to collect data. It has enabled the capture of word of mouth and more open communication about products, not least because of its potential anonymity. Moreover, this way of gathering information is not only affordable but also systematic and represents access to a large number of customers. However, the disadvantage of feedback via social media is the public sharing of individual opinions, which can be seen by the general public and that can be an influence factor. It is also important to properly separate relevant opinions from irrelevant or false or misleading ones. Moreover, this method can be time-consuming, given the quantity of users on social networks, and in many cases thorough selection is necessary [9].

3. Integrating consumer feedback into innovation processes

Utilizing consumer feedback is paramount in comprehending customer needs and preferences. Proactively soliciting and attentively heeding customer input empowers businesses to glean invaluable insights, which in turn can steer and refine their product innovation endeavors. Through consumer feedback, companies can pinpoint deficiencies in their offerings, grasp customer pain points, and unearth novel ways for enhancement.

Involvement of consumers can be delineated into two primary categories: consumer involvement as a source of information and consumer involvement as a co-developer. In contrast to the conventional approach of including consumers solely as information providers in new product development, engaging them as co-developers offers manifold advantages but also poses substantial challenges. Companies engage consumers in new product development to address their needs effectively and facilitate market entry. Consumer involvement in co-development facilitates the integration of fresh concepts, knowledge, and insights into their requirements. The exchange of information between consumers and companies represents a fundamental aspect of co-development [10, 11].

The consumer serves as a valuable resource, supplying information crucial for generating product development ideas. This role can manifest in several forms, including validating designs, prioritizing product features, and specifying product requirements. It is important to state that the development team need to work in alliance with marketing, technical and manufacturing expert in the company throughout the development process [11].

One frequently cited benefit is the enhancement of product quality, as consumer involvement tends to exert a positive influence on product refinement. Involving consumers in the process of developing new products fosters greater innovativeness. Nevertheless, certain studies have identified impediments that hinder companies from fully leveraging consumer engagement in new product development; these include the risk of information overload and the intricacies associated with managing new product initiatives [12, 13].

Co-development is also very neatly tied with consumer satisfaction. Findings show, that engaging in co-development enables the company to create a novel product tailored to meet the customer's requirements, consequently enhancing their satisfaction levels. As a result, customer satisfaction emerges as an outcome of this collaborative process [14]. Vazquez [15] elucidated that active consumer participation in the value creation process significantly enhances consumer satisfaction, potentially reducing time to market for products. This dynamic confers a competitive edge upon companies and augments product performance. Furthermore, in co-development, additional value or features are integrated into the product [16, 17].

Based on theoretical insights and empirical evidence, we claim that consumer involvement in new product development creates mutual benefits for both consumers and companies. From the company's standpoint, consumer engagement in the development process facilitates deeper understanding of customer preferences

and market dynamics, leading to the creation of products aligned with customer needs and expectations. Research indicates that consumer involvement accelerates the company's new product development process and mitigates the risk of product failure, consequently enhancing marketing effectiveness [15, 18].

Consumer involvement in the development process also serves as a potent marketing strategy. Engaged consumers can narrate the product's development journey to new or potential customers, effectively promoting the product and expanding its market reach. This word-of-mouth marketing can significantly influence purchase decisions and enhance overall sales performance [18].

Undoubtedly, consumer co-development presents its share of challenges, notably in the realm of integrating customer-provided information seamlessly into the development process, which can introduce complexity. From a theoretical view point, the abundance of consumer data heightens the complexity of information processing, potentially fostering miscommunication that could influence the use of consumer information [11, 19].

In table 1 we summarize the positive and negative features of using consumer co-development for innovation management, to which we have referred in this chapter.

Table 1. Positive and negative features of using consumer co-development for driving and managing innovation.

Positive features	Negative features
Influence in product quality	Information overload
Customer satisfaction	Difficulty of information processing
Reduction of the product time to market	
Increase of product performance	
Minimalization of sale and service cost	
Increase in buyer retention	
Speed up product development process	
Reduction of the risk of product failure	
Word-of-mouth marketing	

4. Implementation of consumer co-development

Theoretical insights suggest that effective new product development hinges on adept leadership, relationship management, and communication. Cultivating strong consumer relationships necessitates skillful navigation of these elements, it is very important to know how to manage the relationship through leadership and communication [20].

Trust is another very important factor or element for a successful relationship in a consumer involvement. Based on empirical findings, trust emerges through transparent discussions regarding product development, sharing comprehensive development insights, and granting customers access to the company. Trust is further fostered by the exchange of knowledge and technical expertise within development teams. In an environment characterized by openness and honesty from both company and consumer, mutual comfort is established, enabling the free exchange of viewpoints and collaborative refinement of concepts. Research indicates that trust is essential for successful consumer relationship management, and in some cases, can be cultivated through formal contracting. Consequently, trust assumes paramount importance in fostering positive consumer relationships throughout the co-development process [20, 21]. Establishing trust is instrumental in cultivating customer loyalty. Aligning with these

insights, integrating consumer relationships into the new product development framework enables companies to mitigate sales and service costs, thereby enhancing buyer retention [22].

Communication is another point that we consider as a key factor used within a co-development. Communication is a major driver during the product development process. Communicating a new concept is a major starting point for customer involvement in new product development. There is efficacy of communication through visual aids, examples, and best practices, illustrating the potential inherent in novel ideas, technologies, and products. Communication between the consumer and the company must be two ways. Effective management of the development process necessitates the establishment of an interactive dialogue among development teams, comprising both company and consumer representatives. This interactive dialogue facilitates improved communication and proper sharing of information between the teams [23, 24].

Effective communication plays a pivotal role in strengthening the bond between a company and its consumers. Conversely, miscommunication represents a potential drawback that can undermine this relationship, resulting in negative implications for both parties involved. To avoid misunderstandings during the development phase, it's advisable to clearly delineate specific details, such as the anticipated outcome of the product development, to the consumer. We advocate for utmost transparency from the company throughout the development journey, aiming to mitigate information imbalances as highlighted by Von Hippel [26].

We found, that transparency is another important concept worth considering. In simple expression, transparency means being open and honest about the development process. Establishing trust and fostering commitment from consumers are, again, integral aspects of the new product development process, as underscored by both theoretical frameworks and qualitative data. However, intentional lack of transparency by the company, aimed at safeguarding certain information, can potentially lead to project failure. Consumers inherently appreciate being valued by companies, and failure to convey this sentiment can detrimentally impact the development outcome, potentially signaling to consumers that their input is not taken seriously [25].

In Fig. 1 we graphically represent the elements that create the successful relationship and alliance between consumer and the company in driving innovation, that we have presented in this chapter.

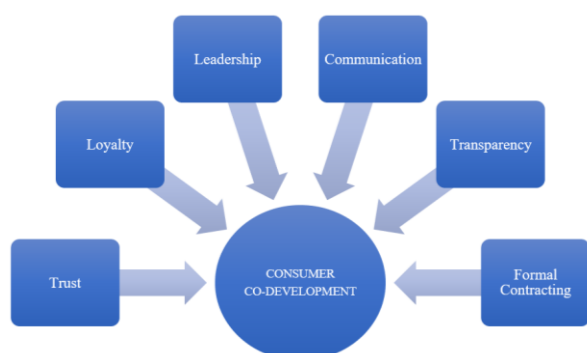


Fig. 1 Elements creating alliance in driving innovation between company and consumer.

5. Conclusion

Through a comprehensive examination of literature and empirical data, we have shown the significant influence of consumer involvement on the new product development process. Consumer involvement in new product development entails a collaborative partnership between the company and the consumer, aimed at jointly resolving challenges to generate innovative product solutions.

Based on both theoretical frameworks and empirical evidence, involving consumers in the new product development process creates superior value compared to traditional approaches. This customer-centric approach is increasingly adopted across various

industries, fostering creativity and generating impactful ideas that enhance product value. Moreover, consumer involvement fosters satisfaction by ensuring products are purposefully designed to meet customer needs. Ultimately, this collaborative process cultivates sustainable customer relationships by attentively addressing customer requirements and preferences.

Addressing customer needs and ensuring customer satisfaction are crucial for a company's long-term viability. Economically, involving consumers in product development lowers development costs while simultaneously enhancing customer satisfaction. This approach accelerates time-to-market and reduces the risk of product failure. From an economic sustainability perspective, collaborative product development proves more profitable than solitary development endeavors.

Customer relationships and satisfaction are paramount considerations in the co-development process, particularly given its inherent uncertainties. It is imperative for managers to clearly clarify the co-development plan—including roles, duration, and expectations—to involved consumers prior to start of co-development process. Additionally, fostering regular communication and providing feedback strengthens the manager-customer relationship and keeps customers informed. Ensuring that customers possess a robust level of trust and commitment is essential for successful project execution. Co-development necessitates diverse expertise to identify potential needs and glean insights from consumer experiences, behaviors, and preferences. Consequently, managers should assemble multidisciplinary teams encompassing backgrounds in engineering, marketing, finance, behavioral science, among others.

By obtaining feedback from consumers, we are able to build a comprehensive picture of the products and services we offer. But the important step is to process this feedback, i.e. to make the economic decisions of the business important enough and bring about the improvements and innovations that consumers demand. Theoretical and empirical evidence underscores the necessity for openness and flexibility in the new product development process, facilitating mutual understanding between company and consumer teams. Effective integration and implementation of novel insights are imperative for refining the overall product solution.

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European development trends in innovative advanced materials area

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Abstract: Current materials science and materials engineering focus on the development of innovative advanced materials. According to Organisation for Economic Co-operation and Development (OECD) advanced materials are intentionally designed and engineered materials to have new or enhanced properties, and/or targeted or enhanced structural features to achieve specific or improved functional performance. Advanced materials include both high and low tech materials. Innovative materials are previously known classic materials used in new applications that have commercial potential. Published in February 2022, the Materials 2030 Manifesto calls for the creation of “a strong European Materials ecosystem to drive the green and digital transitions alongside a sustainable inclusive European society through systemic collaboration between upstream developers, downstream users, and citizens and all stakeholders in between.” The problem of lack of access to new (functional, circular) advanced materials urgently needs to be solved due to the following risks of not delivering on Green Deal and Digital Agenda, loss innovation markets, loss of jobs, relying on polluting and hazardous materials, as well as future geopolitical dependency. The activities undertaken by the Advance Materials Initiative (AMI2030), established in June 2022, led to the development of the Materials 2030 Roadmap and the Strategic Materials Agenda. These documents set European development trends in innovative advanced materials area.

Keywords: ADVANCED MATERIALS, INNOVATIONS, AMI2030, TWIN TRANSITION, MATERIALS DEVELOPMENT TRENDS

1. Introduction

Currently, over 100 thousand different engineering materials are known and used in the world. From the time of Henry Ford, who in 1914 proclaimed: „A customer can have a car painted any color he wants as long as it's black” the relationship between the manufacturer and the customer has changed dramatically. Currently, the manufacturer, wishing to meet both global and local competition, is a subsidiary that manufactures materials and products made from them, in accordance with the requirements and needs specified by the customer. The priority of modern material technologies and manufacturing processes is the production of Materials on Demand (MOD), and more and more often also mass customization, i.e. tailoring products to the individual needs of the customer on a mass scale. Over the course of their history, materials engineering and materials science have developed their own paradigm [1], expressed by the 6E rule. The materials engineering paradigm says that the expected by the customer utility functions of the products will be ensured if the expected engineering material is used for their production, processed with the use of the expected technology, in order to obtain the expected shape of the final product with the expected structure as well as expected mechanical and functional properties.

The economy based on knowledge and innovation, which has been developing in the European Union for over a decade, has been strengthened over the past few years by the European Green Deal [2] and the Digital Decade [3], which are to ensure a twin transition – green and digital. One of Europe's long-term strategic priorities is to maximise innovation, which is a valuable innovation that involves the introduction of new or significantly improved solutions into business practice. It is essential that R&D&I must contribute to meeting citizens' expectations for smart, safe and sustainable materials and products that are fully in line with the principles of the circular economy. In order to gain public support, broad educational activities are necessary to provide reliable information, as well as to dispel any doubts and controversies accompanying any transformation.

2. Innovations vs advanced materials

According to the Technology Readiness Level (TRL) chart (Fig. 1), in chronological order, basic research (TRL 1) is carried out first, which aims to meet the need for understanding. Basic research is used to acquire and disseminate new knowledge about the foundations of phenomena and observable facts, but without focusing on their direct practical application. Practical applications are targeted at industrial research (TRL 2÷6), aimed at acquiring new knowledge in order to develop completely new or only significantly improved products or processes, and experimental development work (TRL 7÷9). The development work is also

expected to result in new or improved solutions, but created by acquiring, combining, shaping and using the currently available knowledge. The completion of development work immediately precedes the implementation of newly developed products or processes into business practice. However, only 4% of all original ideas reach the prototype stage, of which only one in three is commercialized (Fig. 2).

Pillars	Technology Readiness Level	Type of research works
Pillar 3. Competitive production	Level 9. Industrial-scale production launched	Experimental development works
Pillar 2. Product demonstration	Level 8. Examination and demonstration of the final form of technology completed	
	Level 7. Demonstration in operational conditions	
Pillar 1. Technological research	Level 6. Demonstration in conditions similar to real conditions	Industrial research
	Level 5. Verified in environment close to real environment	
	Level 4. Verified in laboratory conditions	
	Level 3. Confirmed analytically and experimentally	
Basic research	Level 2. Technology concept established	Basic research
	Level 1. Basic principles of the given phenomenon have been observed	

Fig. 1 Technology readiness level (TRL) chart

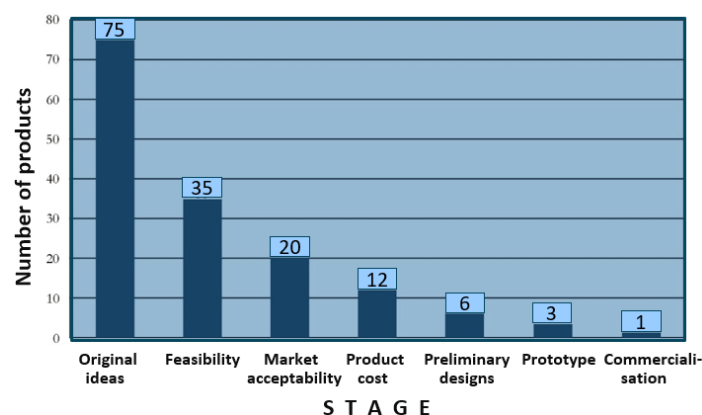


Fig. 2 Stages leading from an original idea to commercialization [4]

Scientific research, and the innovations based on it, are of key importance, because in the long run, there are no new implementations without applied research and the basic research that precedes it. The challenge in this area is to direct the stream of resources that guarantee the expected progress to the most effective fields of science and industries that bring the greatest added value.

The chain of this added value always starts with the materials, without which it is impossible to produce any product and there is no industry [5]. Thus, materials, especially advanced ones, are the basis and source of prosperity of industrial society.

Advanced materials drive innovation, as ca. 70% of all technical innovations can be directly or indirectly attributed to advances in materials science [6]. Advances materials are understood as intentionally designed and engineered materials to have new or enhanced properties, and/or targeted or enhanced structural features to achieve specific or improved functional performance [7]. Advanced materials include both new emerging materials from innovative manufacturing processes, i.e.: high tech materials and materials that are manufactured from traditional materials called low tech materials. Progressive groups of materials are arranged in the acronym NIEBO (which in Polish means sky), consists of the following prefixes: nano, info, eco, bio and opti (Fig. 3). This means that the current civilization challenges include, in turn, nanotechnology, IT support in a very wide range, ecology with the circular economy, biocompatibility and bioinertness of all products, and optimization of the functional properties of products and related economic outlays.



Fig. 3 Progressive groups of materials [8]

3. Materials 2030 Manifesto

Recent years have brought a new perspective indicating that advanced materials will play a decisive role in the process of radical transformational changes in the 21st century. Historically, Europe has been the site of numerous inventions of groundbreaking importance for humanity, but in recent decades the USA, Japan or China have increasingly taken the lead in this area. Globally, the European Union (EU) accounts for 15% of patents on advanced materials, compared to 28% from the US and 24% from Japan [9]. A trend analysis shows that the number of patents granted in the EU remains stable, while in China, the US and Japan it is increasing, is even more worrying. In addition, the annual expenditure of the European Union on R+D is over 40% higher than in Japan, which generates 9% more inventions globally (Fig. 4).

Closer analysis shows that the EU is lagging behind in various key industries, such as security, industrial biotechnology, nanotechnology, robotics, artificial intelligence, micro- and nanoelectronics, and big data. A comparison of key technologies, based on data on the number of new technologies generated and start-ups created and the skills of the workforce, is presented graphically in the graph (Fig. 5).

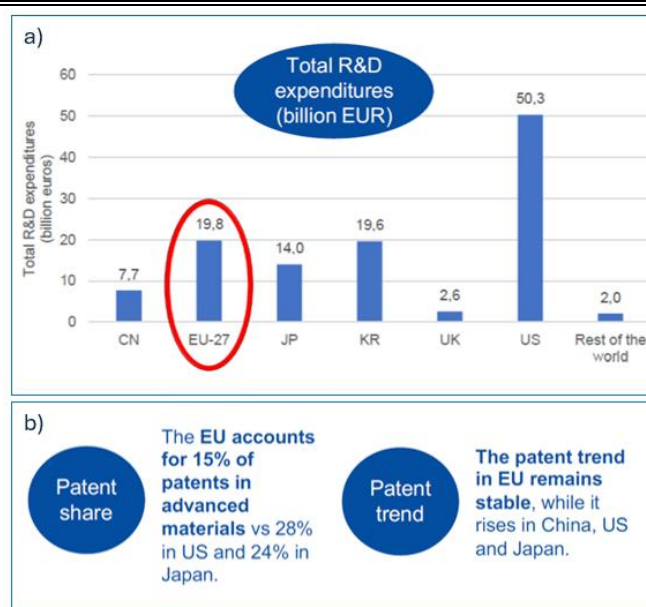


Fig. 4 Annual R&D expenditure in the world's leading countries. Data from 2020 (a); EU patents compared to the world's leading countries (b) [9]

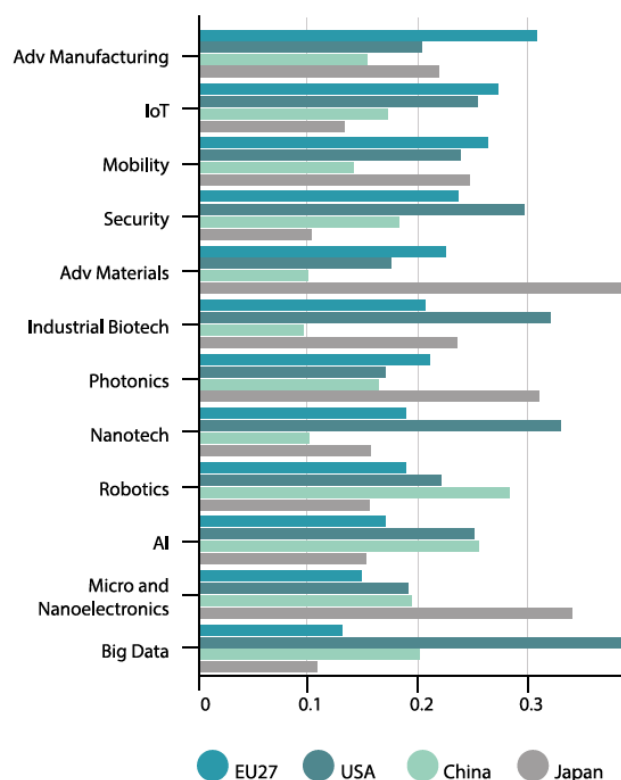


Fig. 5 Comparative analysis of key emerging technologies in the EU, the US, China and Japan, including strategic industries [10]

Advanced materials play a key role in all industries that need to be strengthened. Therefore, it is their development, combined with maintaining the current dominant position of the EU in the area of advanced manufacturing, that will determine the future competitiveness of the European economy on the global market. Europe is now striving to create a globally unique ecosystem that seamlessly synchronises discovery-based basic research with application-oriented industrial research and development works and synergistically connects it with industry, including small and medium-sized enterprises (SMEs).

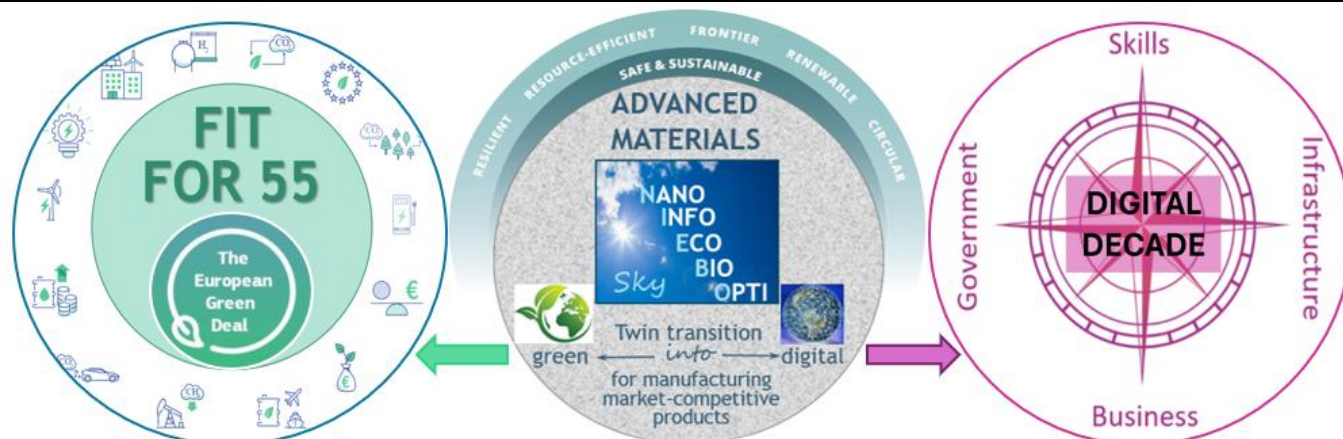


Fig. 6. Twin transition of European economy

This view was reflected in the Materials 2030 Manifesto [11] announced on July 7, 2022, presenting the following vision: „A strong European Materials ecosystem to drive the green and digital transitions alongside a sustainable inclusive European society through systemic collaboration between upstream developers, downstream users, and citizens and all stakeholders in between.” According to this Manifesto, the development of advanced materials is based on four basic pillars, including: (i) Maintain Europe's leadership in advanced manufacturing; (ii) Reducing the environmental footprint through the use of advanced materials; (iii) Ensuring Europe's strategic autonomy; (iv) Targeting markets for innovation in advanced materials.

Meeting the growing demand for new materials and products requires a twin transition – green and digital (Fig. 6). According to the European Green Deal, the EU aims to achieve climate neutrality by 2050, through the Fit for 55 package, which aims to reduce net greenhouse gas emissions by 55% by 2030 [12]. The proposed smart approach assumes the implementation of circular strategies, which include responsible and ethical sourcing of raw materials,

reducing the use of depleting critical raw materials and the development of new production technologies. The success of the double transition is to be ensured through the application of advanced material solutions combined with pro-ecological activities, including re-use, re-purposing, dismantling, recycling and refining, as well as with modern digital technologies, such as tracking & tracing or digital twins. Strengthening the circular economy and responsible practices can not only ensure that the harmful environmental impact of materials is reduced, but also spur economic growth and reduce local dependence on imported raw materials.

4. Advanced Materials Initiative 2030

In order to implement the assumptions of the Materials Manifesto 2030, the European Advanced Materials Initiative 2030 (AMI2030) [13] was established, working for the benefit of the planet, people and prosperity, which is referred to as the 3Ps for short.

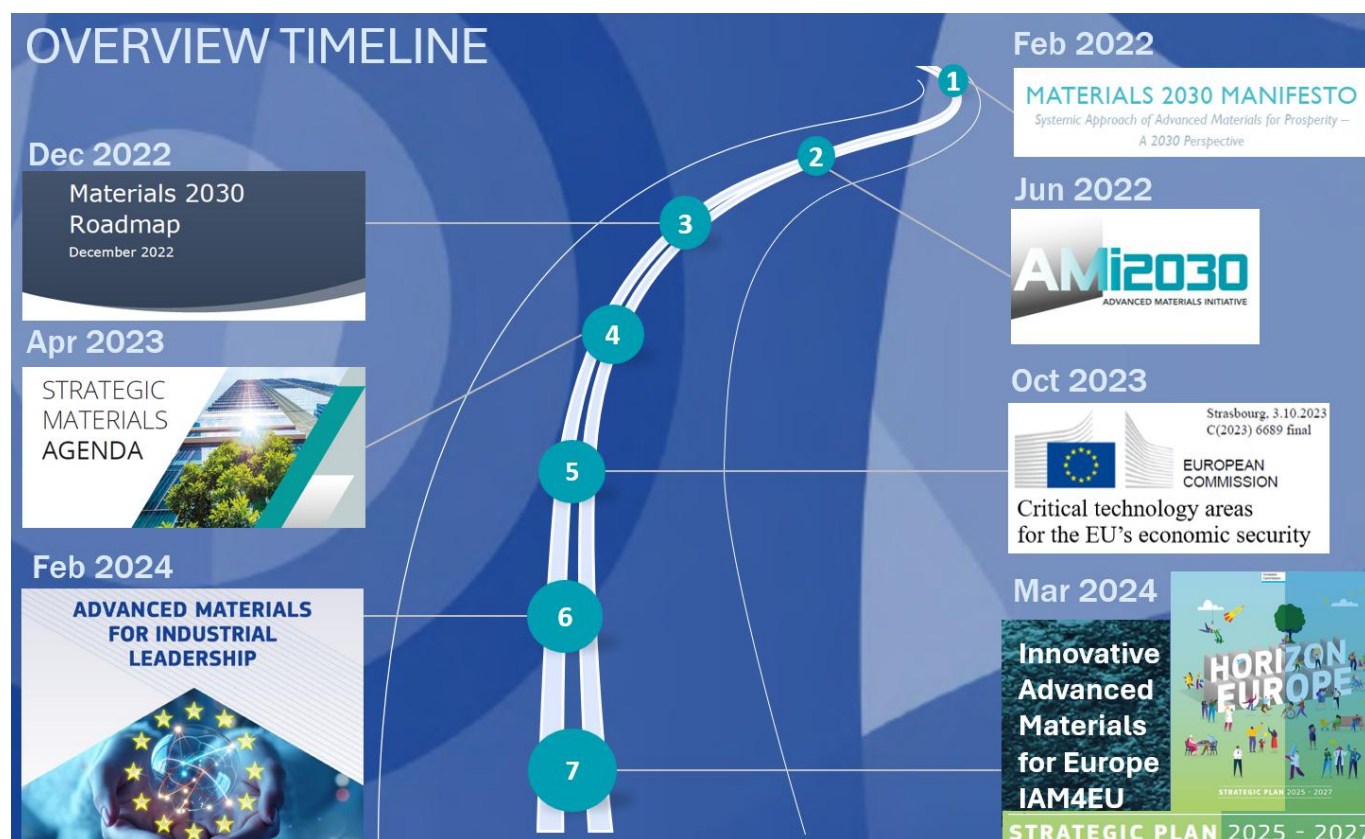


Fig. 7 Results of AMI2030 work carried out in 2022-2024



Fig. 8 Materials Innovative Markets (MIMs)

The aim of this initiative is to call for new forms of cooperation to overcome the current fragmentation of the European R&D sector. The advanced materials value chain is made up of researchers, developers, manufacturers, and B2B and B2C end-users, and is also influenced by EU policymakers distributing funds. A holistic view of materials that are used simultaneously in different industries fosters synergy effects. Advanced materials have many cross-sectional features in common, which occur regardless of the markets served and the represented industrial sectors, and the resulting essence of the new view, called overflow, is based on "flowing" advanced materials from the industries in which they have proven themselves to other sectors of the economy. The common cross-cutting features of materials relate to the circular economy, zero pollution, contribution to the climate and traceability, understood as the ability to determine the source of raw materials and trace the next links in the value chain.

The effects of the AMI2030 work carried out in 2022-2024 include as following (Fig. 7): Materials 2030 Roadmap, Strategic Materials Agenda, Critical technology areas for the EU's economic security, Advanced Materials for Industrial Leadership and Innovative Advanced Materials for Europe IAM4EU. The Materials 2030 Roadmap [14], which juxtaposes advanced materials and technologies and cross-cutting R&D challenges with their relevance to nine Materials Innovation Markets (MIMs), which include: healthcare, construction, new energies, transport, home & personal care, packing, agriculture, textiles, electronics (Fig. 8). According to the adopted concept, the digitization of materials development is a major opportunity to accelerate all aspects of materials design and development, and reliable and easy access to data is to be the key to success. It is also necessary to increase the scalability of new materials by facilitating their spread to other markets and applications through process optimization, decarbonization, mass customization, zero defect production, improved multi-material manufacturing and new manufacturing technologies.

5. Conclusions

According to the European Commission's Communication on Advanced Materials for Industrial Leadership [15], published on 27 February 2024, advanced materials are an important factor in the competitiveness of European industry and are crucial for the EU's stable position and strategic autonomy. Advanced materials are explicitly listed in the list of 10 technological areas of critical importance for the economic security of the European Union [16]. Advanced Materials offers a wealth of solutions to successfully implement the twin green and digital transition. They drive innovation in new clean energy technologies, can replace certain critical raw materials and hazardous substances, improve the environmental performance of products and processes, and facilitate circularity. These materials also play a leading role in strategic areas such as next-generation semiconductor manufacturing, aerospace, space development and defence, as well as in the fertilisers, packaging, agri-food, pharmaceutical and medical industries.

The announcement of the Materials 2030 Manifesto, the development of the Materials 2030 Roadmap and the Strategic Materials Agenda, as well as further activities carried out by the AMI2030 group, currently bringing together, in addition to 870 independent experts, over 560 organizations, including both leading international companies and SMEs, indicate the focus of the attention of the World of Science and Industry on advanced materials. The new overflow approach to materials, which reflects

the long-awaited recognition of their key role in Europe's economic development, heralds rapidly approaching changes, supported by large-scale financial support. Horizon Europe partnership Innovative Materials for EU assumes in the years 2025-2027 co-financing from public and private funds in the amount of at least EUR 500 Million.

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Positioning a holistic approach for integration of renewable energy powered charging stations into a nationwide electrical power distribution system

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Abstract: This paper explores various models of integrating independent Electric Vehicle Charging Stations (EVCSs) into Montenegro's electricity distribution system (EDS) and energy market. It examines different possibilities by applying a multidisciplinary approach to the EDS integration coupled with market frameworks to form a novel holistic perspective for participations and influences of various stakeholders. The primary goal is to envisage and achieve a more efficient integration of different prosumers models that own and engage independent EVCSs with photovoltaic systems into the EDS and transport infrastructure. This approach is aimed at reducing CO₂ emissions, promoting electromobility, engagement of citizens, and facilitating distributed renewable electricity generation at the point of consumption. Through the analysis of each of the three identified prosumer models, we give specifics of the integration within the grid, solar energy exploitation potentials, practical options for energy provisioning during and outside sunny periods etc. Economic, legal, and technical implications are integrated, and recommendations are provided using economic modelling and game theory formulations between the relevant actors and within regulatory provisions to optimize electric mobility in Montenegro.

Keywords: SOLAR (PV), RENEWABLE ENERGY SOURCES (RES), ELECTRICAL VEHICLES (EV), ELECTRICAL VEHICLE CHARGING STATION (EVCS), PROSUMERS, ECONOMIC MODELING

1. Introduction

Nowadays, the living world faces numerous challenges due to reliance on conventional energy sources. Namely, the emission of carbon dioxide, sulfur oxides, and nitrogen oxides caused by the excessive use of fossil fuels is threatening and increasingly pointing towards the complete degradation of the environment and living world, including humans. Pollution emitted into the atmosphere leads to the occurrence of acid rain and global warming. A true breakthrough would be achieving economic and social development without compromising short-term climate goals and contributing to global efforts to achieve the long-term goal of limiting the temperature increase to less than 2 °C [1], but preferably up to 1.5 °C.

The integration of Renewable Energy Sources (RES) into the electric power grid, with a particular emphasis on the distribution grid, is highly relevant and desirable in order to mitigate the negative impact of fossil fuel consumption. Nowadays, there are numerous types of RES (e.g. solar, wind) and their installations (e.g. wind or solar farms) with stimulating degrees of cost efficiencies and shares of energy contributions in overall power productions within a region or a distribution grid system.

Our project focuses the exploitation of RES for further electrification of green transport in Montenegro as a whole, that is, as an optional type of EVCSs across the country's transport infrastructure. This approach specifically refers to involvements of independent and geographically distributed energy producers via solar panels and their integrations in the transport network with other EVCSs via novel models configurations discussed in this paper. As part of our project, we have already conducted a complementing study on optimal distributions of EVCSs across Montenegro's cities, roads and regions taking into considerations various factors such as population and traffic densities, seasonal upsurge in demand due to tourism, availability of electric grid infrastructures etc. [2]. We highlight here that these energy producers are mainly considered to be outside the energy production system of conventional power companies, and generate solar energy subject to its natural availability. They are considered here as novel models of prosumers with charging of unowned EVs as their extended capability. Therefore, this charging would be an optional commercial activity for wider public EVs, not only for personal use.

Opening up of the energy market and transport infrastructure to nation-wide large scale involvement of independent prosumers-based EVCSs, in addition to existing "typical" EVCSs, requires diverse multidisciplinary investigation. Some of these include: a) economic issues of divestiture of market power of the existing power companies [3] across the green transport; b) legal and

regulatory aspects of involvement of novel models of prosumers in the energy system and markets; c) operational and engineering implications of integrating novel prosumer models into the existing energy system, this being the foundational topic of this paper.

Generally, prosumers are electricity consumers who produce electricity from renewable sources, consume it, store it for future needs, or distribute it further into the grid. As such they emerge as an acceptable solution in the distribution grid with various incentive for formulating different prosumer types [4]. We observe that there are variations in definitions and perspectives of how prosumers and associated configurations are defined. While some observe a prosumer setup from an engineering point of view of the necessary composition of operations and components [5], a view from European Environment Agency (EEA) [6] includes individual energy producers of, for example solar energy, but also citizen collectives, public institutions, and communities. In fact, the EEA emphasizes that prosumers' activities are not their main commercial activities. While we originate with the same view on the definition of prosumers, the addition of the exclusive EVCS-to-EV charging capability using renewable but variable solar energy, opens various technical and exploitation models for prosumers on a one-to-one energy exchange basis. Hence, in this paper, we apply the terms with this flexibility of interpretations.

The paper's sections are: Section II describes incentives for considering novel prosumer models; Section III outlines some prosumer models with charging capabilities; Section IV outlines an essential economic model setup for integrations of the prosumers into the energy market; Section V gives the concluding remarks.

2. Incentive for defining different prosumer models

The integration of prosumers into the electrical distribution grid holds significant global importance. However, indiscriminate and poorly planned intentions behind integrating such energy entities can slow down and obstruct the processes of energy transition, decarbonization, and electrification of transportation.

Namely, the aim of a prosumer is to produce electrical energy at the point of consumption, thereby reducing losses (both financial and technical), relieving the burden on transmission and distribution lines, and contributing to the overall energy production mix of a state (or system). However, if a prosumer or a cluster of prosumers acts contrary to the design guidelines and agreed-upon principles, it can cause harm to the power system. It thus degrades its role or, worse, renders it entirely meaningless, where the prosumer becomes "damaging" and represents a hindrance to the optimal functioning of the power system.

On one hand, the technical and economic benefits of integrating RES and prosumers within the electrical grid are evident, such as relatively inexpensive electrical energy, low CO₂ emissions, and

lower operational costs. However, the integration of RES also brings about a couple of challenges and problems regarding: power system management, such as reduced system inertia and stability, lower quality of electrical energy (manifesting as higher harmonics), higher short-circuit currents, variability, and unpredictability of weather conditions, and so forth [3].

In order to efficiently integrate prosumers into the electrical distribution system (EDS), it is imperative to develop appropriate models and analyze their impact to optimize production and consumption while minimizing the negative effects that prosumers may potentially cause.

The task of this paper is to analyze a specific type of prosumer, namely EVCSs symbiosis with photovoltaic panels, and to find suitable models and their configurations. In addition, we aim to position a holistic multidisciplinary analysis of the operations and functioning of such a prosumer type within the national power distribution systems and in balance with all stakeholders affected by it.

This is to ultimately reveal most optimal energy pricing, power divestiture and regulatory boundaries where these players would be

incentivized to achieve an equilibrium contributing to overall public welfare.

3. Proposal of Three Prosumer Models (EVC + PV)

Under the concept of a prosumer, we consider EVCSs that can produce/consume and, when existent, directly provide renewable (solar) electrical energy to EV(s) having other owners with a direct commercial incentive and arrangement. EVCSs could also feed some energy it produces back to the grid subject to its overall consumption and circumstances. The profitability and commercialization potential of these solar EVCSs are affected by the variability in charging due to unpredictable occurrences and volumes. Thus, they remain seen as prosumers within the flexible boundaries of our definition but span many configuration options and commercialization potentials as discussed in the following text.

We define three types of EVCSs prosumer models and give detailed explanations in the consequent subsections:

- 1) Off-grid prosumer;
- 2) On-grid prosumer with virtual "storage" system;
- 3) On-grid prosumer without virtual "storage" system;

PV system 500kW output power													
Slope 36 deg (optimum); Azimuth 0 deg (optimum) System losses 14%													
P(kW)													
Podgorica (BIG Fashion parking) 2020													
Time/Date	15-Jan	15-Feb	15-Mar	15-Apr	14-May	15-May	15-Jun	15-Jul	15-Aug	15-Sep	15-Oct	15-Nov	15-Dec
4:00					7.25	0.62	34.88	11.95	0.60				
5:00				74.86	48.26	13.17	118.03	9.69	61.70	25.36			
6:00		29.35	66.89	187.32	14.19	23.32	201.77	49.15	148.67	121.56	13.74	9.20	
7:00	88.00	143.63	25.09	283.06	67.06	71.21	269.33	248.93	221.61	136.07	19.95	74.33	81.12
8:00	172.48	224.32	15.63	346.16	225.04	59.34	321.24	307.19	281.59	227.96	30.02	133.22	159.61
9:00	218.69	278.87	18.36	389.81	329.90	45.74	358.23	341.33	322.36	193.08	101.71	170.07	202.82
10:00	238.74	301.86	38.58	403.56	356.92	51.44	319.40	359.48	336.43	296.17	16.70	130.85	220.31
11:00	235.36	298.34	41.85	394.05	346.72	48.26	70.55	355.92	331.13	238.84	16.31	169.68	207.53
12:00	200.27	266.06	174.57	364.02	91.83	54.79	48.56	335.87	314.06	245.79	13.61	80.75	174.42
13:00	145.22	208.43	180.03	307.80	43.45	89.60	290.08	272.23	263.63	192.89	14.75	60.77	113.28
14:00	70.65	133.12	178.27	225.55	58.61	55.66	185.25	227.10	127.55	120.91	4.99	15.53	37.93
15:00	1.51	40.81	84.74	128.15	24.05	24.13	82.82	144.57	121.11	70.44	0.66		
16:00			10.38	36.34	14.37	6.13	74.05	72.44	47.73	10.97			
17:00					2.36	0.20	9.31	20.00	7.25				
18:00													
19:00													
20:00													
Average power (kW)	171.18	192.48	75.85	261.72	135.03	45.23	194.94	226.99	214.80	208.89	25.75	105.55	113.10

Fig 1. Daily irradiance for the 15th of each month in 2020 (exception May 14th).

Date (month)	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Year(2020)
Energy (kWh)	27240.84	30700.77	48556.54	60599.17	71087.85	76208.69	81320.07	73781.98	56938	43741.93	28810.57	24306.84	623293.3
Average daily energy (kWh)	878.74	1096.46	1566.34	2019.97	2293.16	2540.29	2623.23	2380.06	1897.93	1411.03	960.35	784.09	1704.30
Average hourly power (kW)	109.84	109.65	142.39	168.33	191.10	211.69	218.60	198.34	158.16	156.78	106.71	98.01	161.04
Estimated average working hours	8	10	11	12	12	12	12	12	12	9	9	8	10.58333

Fig 2. Presentation of average values of produced energy and output power per month in 2020(500kWp), along with the estimated effective operating time of the prosumer per month.

3.1 Off-grid prosumer (EVC + PV)

The off-grid prosumer model consists of a photovoltaic system that operates independently of the EDS and as a additional specificity of this study, lacks a storage system or battery for excess electrical energy. Specifically, the only consumers would be EVs potentially connected to one of the outputs of a shared EVCSs. Although this system has certain drawbacks compared to conventional EVCSs, it still possesses significant advantages that can enable it to compete fairly in the market and play a significant role in the electrification of transportation and sustainable management of the electrical power system. Because this system is not connected to the electrical distribution system (EDS), it has no negative impact on the system. Issues such as harmonic distortion, variability, delivery of surplus electrical energy when electricity prices are low in the market, and the need for additional quantities of electrical energy are all avoided. The cost of powering vehicles from such systems should typically be lower, as the electricity is produced on-site and directly delivered to the electric vehicle user without additional transmission or storage costs.

For the purposes of this analysis, a public parking lot in front of the BIG FASHION shopping center in Podgorica city (42°26'14.8"N, 19°14'04.5"E) was considered. A canopy with 500 kWp photovoltaic (PV) panels was modeled on a portion of the parking lot surface (~2600m²) and around 150 parking spaces, with the panels oriented at a 10° inclination and -29° azimuth-southeast using the K2 base software package. Simulation calculations were performed using the PVGIS software tool, providing actual solar irradiation data for the year 2020 on an hourly basis for each day of that year. Due to the complexity and large amount of data obtained, Грешка! Източникът на препратката не е намерен. displays actual data for the fifteenth day of each month in 2020, while data for the month of May is also shown for the fourteenth day to provide a more realistic representation. This accounts for the fact that data from a single day may not necessarily reflect irradiation throughout the entire month, and there may be significant deviations from day to day.

Fig 2 presents average data for each month, as well as the total forecasted electricity production per month, allowing for data

averaging and displaying the average power and energy expected at the output of the electric vehicle charging station.

The fundamental idea behind such a prosumer model is to provide price incentives for EV users to utilize their time spent at shopping malls, workplaces, and other locations where they plan to stay for an extended period of time to charge their vehicle batteries at slightly lower electricity prices, while simultaneously avoiding burdening the electrical distribution system and harnessing the cleanest source of electrical energy by simultaneously taking electricity at the point of production.

Specifically, this type of prosumer would ideally have 20-50 connections (parking spaces with chargers) for electric vehicles, with power evenly distributed based on the number of connected vehicles and the currently available power. The operating hours of such prosumers would be defined by weather conditions and the month of the year, with an average of 10.5833 hours per day, as shown in

Fig 2. During one working day, the average power that this prosumer could deliver would be 161.04 kW throughout all working hours, which is sufficient to charge approximately 37 average electric vehicles (with a battery capacity of 77 kWh) bringing them from 20% to 80% (in total ~46kWh) within one day, if the energy is evenly distributed.

With appropriate software solutions, the ability to control energy distribution, and a management system, this prosumer model could provide the cheapest electricity for electric vehicle users while significantly reducing the negative effects on the EDS that could be caused by the mass integration of photovoltaic (PV)

systems within the EDS. Implementing this prosumer model at production sites such as large company parking lots, public institutions, shopping centers, and similar locations is straightforward. With proper energy management, all negative aspects of this model, particularly production variability and spillage/loss of generated energy, could be overcome.

3.2 On-grid prosumer with "virtual" storage system (EVC+PV+grid storage)

Compared to the first model of charging stations for electric vehicles, the second proposed model operates under a slightly different system. In particular, this model is connected to the EDS, which earns it the designation of a "on-grid" hybrid system. However, that's not the only difference. This model has a significantly lower installed capacity of photovoltaic modules than the first model, which in this case is 100 kWp. The operating pattern is designed so that the EDS of this type of charging station guarantees a constant power of 20 kW in order to ensure users a certain level of security and reliability in the power supply. During the sunny hours and the generation of electricity by the photovoltaic system, the charging speed of the vehicles as well as the amount of energy delivered to the consumers would increase, as shown in (Fig 3). The data was obtained based on the PV Gis software package for a 100 kWp output power photovoltaic system simulated at the following location (42°26'14.8"N, 19°14'04.5"E).

Date (month)	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Year(2020)
Energy (kWh)	8231.7	8007.57	11248.32	12589.18	13602.36	14060.96	15245.04	14930.85	12741.06	11219.44	8297.62	7715	137889.1
Average daily energy (kWh)	265.54	285.98	362.85	419.64	438.79	468.70	491.78	481.64	424.70	361.92	276.59	248.87	377.25
Average hourly power (kW)	33.19	28.60	32.99	34.97	36.57	39.06	40.98	40.14	35.39	40.21	30.73	31.11	35.65
Estimated average working hours	8	10	11	12	12	12	12	12	12	9	9	8	10.58333

Fig 3. Presentation of average values of produced energy and output power per month in 2020(100kWp), along with the estimated effective operating time of the prosumer per month.

The average daily energy produced by such a system without predetermined system losses of 14% is 377.25 kWh, enough to supply 8.2 electric vehicles with 46 kWh of electrical energy. From the present analysis, it can be concluded that this type/model of charging station/prosumer would have the capacity to provide 46 kWh of electrical energy (~300 km range) for about 8-9 electric vehicles in one day. However, it can happen that the photovoltaic system produce more energy than needed at certain times or when no electric vehicles are connected. If that happens at that time, the system has the capability to deliver the surplus electrical energy to the electrical distribution system for its needs. In this way, the electrical distribution system plays the role of a "virtual" energy storage system, that enables the photovoltaic system to retrieve the same energy when needed, namely when electric vehicles are connected. This introduces a concept of "virtual" energy storage with financial compensation for the electrical distribution system, which in this model serves as a storage facility for surplus energy and reclaims it when needed.

This provides for regulation of the maximum power supplied and demanded in order to ensure the stability of the electrical distribution system. This also allows for a legal regulation of the billing for such activity. It is proposed that the operating hours of such charging stations be linked to the operating hours of the facility they are integrated with. In this way, the charging of electric vehicles can take place within a certain period of time, e.g. from 08:00 to 23:00. This encourages consumers to draw electricity during sunlight hours, minimizing the energy stored in virtual energy storage and consequently reducing storage costs and the burden on the electrical distribution system. Such a model would be suitable for restaurants, hotels, supermarkets and similar establishments with an parking area of around 500 m².

3.3 On-grid hybrid prosumer with guaranteed power (EVC+PV+ grid)

The third model aims to provide safe and fast charging for electric vehicles when users need it most. The output power of such a charging station would be 100 kW at any time of the day. More specifically, this type/model of prosumer has a constant supply or guaranteed power from the electrical distribution grid of 100kW, while the installed power of photovoltaic system would be a maximum of 50kWp and anything less. The idea behind the third model comes closest to conventional charging stations, especially when drivers need them most, as these models significantly reduce the anxiety and fear of potential electric vehicle drivers of getting stranded on their journeys. This type of charging station is best suited for locations such as gas stations, farms near highways and freeways, and some locations along major roads where user convenience and satisfaction are much more important than the cost of charging the vehicle. Such a system requires a roof area of up to 250 square meters, which may consist of the roof area of the building itself and a canopy for the cars, much like today's gas stations. In this scenario, the energy generated by such a photovoltaic system with a nominal output of 50 kWp has a lower impact than the energy and power drawn from the electricity grid. However, the energy from a photovoltaic system with an average output of 17.83 kW can reduce the energy drawn from the grid during sunny hours and thus help to reduce the financial costs of the charging station. As can be seen in Fig 4, once the analysis is completed, this system primarily relies on the support it receives from the electricity distribution system to enable efficient, fast and safe charging of electric vehicles, but it is also the heaviest burden on the system itself, as its peak load is extremely high and the variability factor changes rapidly. Therefore, the expected number of such charging stations (within the boundaries of a country) is the lowest compared to other models, and at the same time the smallest number of parking spaces or connections for vehicles belongs to this type of charging station. Nevertheless, this model/type of charging station is extremely important at strategically vital

locations to reduce the anxiety and uncertainty of drivers, especially

those who use electric vehicles for intercity/interstate travel.

Date (month)	Jan-20	Feb-20	Mar-20	Apr-20	May-20	Jun-20	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20	Year(2020)
Energy (kWh)	4115.85	4003.78	5624.16	6294.59	6810.18	7030.48	7622.52	7465.43	6370.53	5609.73	4148.81	3857.51	68953.57
Average daily energy (kWh)	132.77	142.99	181.42	209.82	219.68	234.35	245.89	240.82	212.35	180.96	138.29	124.44	188.65
Average hourly power (kW)	16.60	14.30	16.49	17.48	18.31	19.53	20.49	20.07	17.70	20.11	15.37	15.55	17.83
Estimated average working hours	8	10	11	12	12	12	12	12	12	9	9	8	10.58333

Fig 4. Presentation of average values of produced energy and output power per month in 2020(50kW), along with the estimated effective operating time of the prosumer per month.

4. Economic Modeling Setup of Optimal Prosumer models

Our study aims to establish both technical and multidisciplinary foundations, including regulatory, economic, and operational aspects, for integrating prosumer models into the energy system and transport infrastructure. We can observe the market of EVCSs as a novel space for emergences of various combinations of: markets players, energy distribution, purchase models, and price creation mechanisms. Given the favourable conditions in Montenegro for a clean slate approach, we explore how prosumers can engage in the electric transport market and expand their commercialization potential beyond traditional tariff arrangements, such as feed-in tariffs. From our three examples of solar EVCSs presented earlier it can be deduced that the magnitude of energy productions can vary, and so can the ambitions for commercialization, ranging from a significant business venture to a modest supplementary source of income. Such potentials and contributions can be sporadic if based on a small and discontinuous production of solar energy, or they can be continuous in combination with regular energy supplies. Likewise, the numbers and distributions of these individually-owned, solar EVCSs [2] can be such that they can present an important element of the energy supply within the traffic infrastructure.

From a regulatory or governmental perspective, these prosumers can become significant players in the energy market. This perspective calls for a reconsideration of electricity payment models (e.g. Power Purchase Agreements) on a one-to-one retail-level basis, as well as new energy price market dynamics and a regulatory framework that can boost supply availability and expand locations. Ultimately, citizens would benefit through increased engagement of prosumers and enhanced public welfare.

To further explain the dynamics within the electric vehicle charging station (EVCS) market, we employ a theoretical game theory approach. This framework allows us to define the key players, their strategies, and utility functions, facilitating a clearer understanding of the strategic interactions and potential outcomes. By analyzing these interactions, we can identify optimal strategies and policies that promote the efficient integration of prosumer models into Montenegro's energy system.

First, we consider the role of the State/Regulator. This player is crucial in developing and enforcing regulations, promoting public welfare, balancing energy prices, and ensuring system stability. The State/Regulator's strategy involves determining optimal regulations and incentives that maximize public welfare and system stability. They must navigate the complexities of providing adequate subsidies, setting fair tariffs, and ensuring a stable energy supply while fostering an environment conducive to the growth of RES and prosumer participation. The utility function for the State/Regulator can be expressed as:

$$U_s = \alpha W_{soc} + \beta R_{reg} + \gamma S_{stab} - \tau S_{gov}$$

Where W_{soc} represents the welfare of society, R_{reg} indicates the effectiveness of regulatory policies, and S_{stab} reflects the stability of the energy system, S_{gov} cost of subsidies for installation of PVs and subsidies for EV users. The coefficients α , β , γ , and τ denote the relative importance of each factor in the overall utility.

Second, we consider the Energy Company Montenegro (ECM) and Electrical Distribution System (EDS)¹. Their primary objectives

are to ensure grid stability and efficiency, manage energy supply and demand, particularly during peak and off-peak hours, and maintain profitability while balancing this with sustainable development. ECM plays a crucial role in purchasing surplus energy from prosumers and potentially "storing" energy from On-Grid Charging Stations with Virtual Storage on the grid. This storage mechanism allows ECM to utilize energy without immediate costs, though they must later return equivalent energy to the charging stations upon request.

ECM's strategy involves optimizing these interactions to maximize their utility, which includes revenues from energy sales, costs of purchasing surplus energy, and costs related to maintaining grid stability. Additionally, EPCG's preference for On-Grid Charging Stations with Virtual Storage over conventional charging stations stems from the increased flexibility and potential cost savings associated with the virtual storage model. This preference aligns with their objective to integrate more prosumers into the grid, enhancing overall system resilience and sustainability.

The utility function for ECM can be formulated as:

$$U_{ecm} = \gamma R_{energ} - \epsilon C_{buy} - \delta C_{stab} + \theta P_{strg}$$

Where R_{energ} represents the revenue from energy sales, C_{buy} costs of buying the electricity from prosumers, C_{stab} costs associated with maintaining grid stability, and P_{strg} captures the premium from providing virtual storage services.

Third, we consider the On-Grid Charging Station with Virtual Storage (PM2), as defined in the second proposed model. Their primary objective is to maximize profits from providing EV charging services. These stations offer a distinct advantage by utilizing stored surplus energy, produced from renewable sources like photovoltaic systems, to provide charging services at lower costs. The marginal cost of this stored energy is effectively zero, allowing PM2 to set their prices below the market value that conventional on-grid charging stations incur as input costs.

The PM2 also incurs costs related to the installation and maintenance of the photovoltaic systems. Additionally, they would have to pay a premium for the virtual storage service provided by EDS. Despite these costs, PM2 benefits from the added stability and reliability that comes with virtual storage, allowing them to manage energy supply more effectively and reduce fluctuations in charging availability.

The strategy for PVS involves balancing these costs with the revenue generated from EV charging services. Their utility function can be formulated as follows:

$$U_{pm2} = \eta R_{charge} + \tau S_{gov} - k C_{pinst} - \theta C_{cinst} - \lambda C_{maint} - \phi P_{strg} + \epsilon B_{chstab}$$

Where R_{charge} denotes the revenue from providing EV charging services, S_{gov} government subsidies for installing photovoltaic systems, C_{pinst} installation costs of the photovoltaic systems, θC_{cinst} installation costs of the charging infrastructure, C_{maint} maintenance costs, and P_{strg} premium paid for virtual storage services, B_{chstab} overall benefit of stability and reliability of charging that comes with virtual storage. By strategically setting their prices and managing their costs, PVS can attract more customers, maximize their profits, and contribute to a more stable and sustainable energy system.

Fourth, we consider the Conventional On-Grid Charging Station (OCS). Similar to the On-Grid Charging Station with Virtual Storage, OCS benefits from a stable supply of electricity due to its connection to the grid. However, unlike PM2, the OCS does not

¹ Elektroprivreda Crne Gore AD and CEDIS in the Montenegrin system respectively

produce its own energy and therefore incurs higher costs for purchasing electricity at market value. This reliance on external energy sources means that OCS typically has higher operational costs compared to PVS. OCS can offset these higher costs by setting higher prices for their fast-charging services, catering to EV owners who prioritize speed and convenience. Although OCS avoids the premium costs associated with virtual storage, they still face installation and maintenance expenses for their charging infrastructure. Furthermore, the high-power demand of fast chargers can negatively impact grid stability, increasing the overall costs associated with grid management for EDS.

The primary goal for OCS is profit maximization. To achieve this, they strategically set their prices to balance the higher cost of electricity with the revenue from fast charging services. Their utility function can be formulated as follows:

$$U_{ocs} = vR_{charge} + \omega S_{gov} - \sigma C_{pinst} - \pi C_{maint} - \vartheta S_{stab}$$

Where R_{charge} represents the revenue from providing fast charging services, S_{gov} government subsidies for installing photovoltaic systems, C_{pinst} installation costs of the charging infrastructure, C_{maint} maintenance costs, S_{stab} and costs related to the impact on grid stability.

Lastly, we consider the EV Owners. Their primary objectives are to minimize charging costs, ensure the availability of charging stations, and reduce range anxiety. EV Owners are faced with the decision of choosing between different types of charging stations, which offer varying trade-offs between cost and charging speed. While some EV Owners may prioritize lower costs and opt for slower charging at On-Grid Charging Stations with Virtual Storage (PVS), others may prioritize speed and convenience, opting for faster charging at Conventional On-Grid Charging Stations (OCS) despite higher costs.

The EV Owners' strategy involves balancing these factors to optimize their overall utility. Their utility function can be formulated as follows:

For the PVS, although they bear the cost of virtual storage, P_{strg} , this cost is offset by the benefits of increased stability and reliability, S_{stab} which enhance their operational efficiency and attractiveness to customers.

This structured analysis highlights the importance of coordinated policies and practices in achieving optimal outcomes for integrating prosumer models into the energy system. By identifying Nash Equilibria and Pareto Optimal outcomes, policymakers can design strategies that promote cooperation and maximize public welfare.

Conclusion

This paper presents a study of possible operational types of charging stations fully or partly powered by RES and being positioned for integration into the EDS and energy market of Montenegro. The charging stations' autonomous ownerships formulate them as prosumers. As such they pose various technical, economic, regulatory challenges in becoming parts of the energy system, transport infrastructure, and energy market within the country. The three proposed prosumer models currently would not have a decisive effect on the successful electrification of transportation. However, if conventional sources of electricity are gradually replaced with alternative "green" production capacities, there is an immediate need to plan and define new energy generation models, engage citizens, and enforce new economic models for their integration. Then, combinations of these three prosumer models in the correct proportion can relieve the EDS, reduce the highly financially demanding investments in the EDS, and provide enough electricity for all EVs. We will further look into how prosumer model selection is incentivized by price, thus enabling successful redistribution and precise management of energy and power.

$$U_{ev} = \mu B_{choice} - \nu C_{charge} - \xi R_{anxiety} + \tau S_{gov}$$

Where B_{choice} denotes the benefit derived from having multiple charging options, C_{charge} cost of charging, which varies based on the type of charging station chosen, $R_{anxiety}$ range anxiety and S_{gov} government subsidies EV driver receive for purchasing of EVs, which is influenced by the vicinity of charging stations.

By modelling the cooperation and non-cooperation between the State/Regulator and EPCG, we can analyze the effects on the utilities of PVS, OCS, and EV Owners. This approach demonstrates how cooperative behavior can lead to improved outcomes for all stakeholders by enhancing stability, reducing costs to EV drivers, and increasing overall welfare.

In the cooperative scenario (CC), the State/Regulator provides subsidies, EPCG purchases surplus energy from regular prosumers, and provides virtual storage. Although the State/Regulator incurs a cost represented by S_{gov} , this cost is justified because $\tau S_{gov} < \alpha W_{soc}$, indicating that the welfare gain for society outweighs the cost of subsidies.

For the PVS, the installation cost C_{pinst} is effectively reduced by the subsidy S_{gov} , making it more competitive in the market. This reduction in initial costs allows PVS to offer lower prices for charging, attracting more customers. Additionally, EV owners benefit from reduced costs when purchasing vehicles, thanks to the subsidy τS_{gov} , and they also enjoy lower prices for charging from PVS while still having the option of fast charging from OCS.

When EPCG cooperates, they incur the cost of purchasing surplus energy, C_{buy} , but this cost is mitigated by the premium P_{strg} , they receive for providing virtual storage. Furthermore, the overall benefit of improved grid stability, C_{stab} , adds to their utility, making cooperation advantageous.

Acknowledgment

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Performance of digital content distribution channels

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Abstract: Digital marketing is currently a key pillar for the success of businesses in an environment of constant changes in online channels. Within this dynamic environment, it is imperative to continually review and analyse the effectiveness of digital content distribution channels. This article aims to systematically review the theoretical background in digital marketing with an emphasis on digital content distribution channels. In order to provide a holistic assessment of the performance of these channels, the thesis combines a critical perspective on existing theoretical framework models with an analysis of current digital marketing trends and practices. The proposed theoretical frameworks provide a basis for further developments in the field of digital marketing. It concluded by further discussing the implications of the findings for marketing managers and proposing recommendations for optimizing the use of digital content distribution channels in order to achieve maximum success in the online environment.

Keywords: DIGITAL MARKETING, DISTRIBUTION CHANNELS, SOCIAL MEDIA, WEBSITE

1. Introduction

Nowadays, the Internet has seamlessly integrated into our everyday lives, evolving into an indispensable component of modern society. We inhabit an era where reliance on the online realm is pervasive, with digital marketing emerging as a cornerstone for business triumph [1]. This form of marketing stands as one of the most potent avenues for engaging existing clientele and enticing prospective customers through the vast expanse of the internet. This prominence underscores the contemporary significance of digital marketing, which has surged ahead, outpacing traditional marketing methods in both efficacy and competitiveness [2, 3].

The landscape of digital commerce is intricately interwoven with the dynamics of distribution channels on the Internet. In recent years, we've borne witness to the swift evolution of Internet technologies alongside shifts in consumer preferences. These transformative forces have precipitated the emergence of novel distribution channels, reshaping the digital commerce landscape. As such, staying attuned to these burgeoning avenues is imperative for businesses seeking to navigate the ever-changing currents of the online marketplace effectively [4].

2. Internet shop

The primary purpose of the Internet was to serve the academic community for research purposes. It was not until 1991 that the government in the United States of America decided to use the Internet for business purposes, and it has grown rapidly in just a few years [5]. An online store or e-shop sells products or services online. The aim is not only to showcase the products but also to sell them [6]. Shopping through online stores is very widespread in the world and in recent years, because of the COVID 19 pandemic, its function has grown considerably. Slovakia is a very important player in this area [7, 8].

The CEO of the website Heureka.sk, Tomáš Braverman, claims that Slovakia, due to the size of the population, is a very strong market for e-commerce. Therefore, diversification of goods and services in the online environment is existentially important for businesses [9]. Janouch argues that one of the main reasons why customers come to brick-and-mortar stores is because they have previously found their products or services online [10].

3. Social media

The next type of website is social media. Almost everyone is registered on at least one of the many social networks that the Internet offers or has at least heard of them. These websites also have a great advantage in areas such as marketing. Social networks have a high potential, for example in discovering new opportunities, establishing business partnerships and new contacts or getting feedback from customers [11, 12].

Social networking can be characterized as a service that allows you to connect with other people with similar interests and backgrounds. It usually includes a profile and diverse ways to

communicate. Often it also includes the possibility to create groups according to the same interests [13].

According to Statista, the most used social networks include Facebook, YouTube WhatsApp, and Instagram [14].

4. Survey results

In the practical part of the article, the possibilities of content dissemination on the Internet and their impact on the readability of articles were investigated. The main aim of the research was to find out what impact the different platforms have on the readability of articles on the website www.aktuality.sk [15].

As shown in Table 1, the survey was conducted from 07 February 2023 to 01 March 2023. During this period, data collection, and hence selection of articles based on being found on certain social networks, took place. Initially, articles found exclusively on the website were selected. This means that they are not shared on other social networks (5 articles). Gradually, we searched for articles that are distributed on the website and Facebook (12 articles). Other articles were distributed on social networks such as Instagram and Instagram Bio. These articles are in terms of fulfilling the objective.

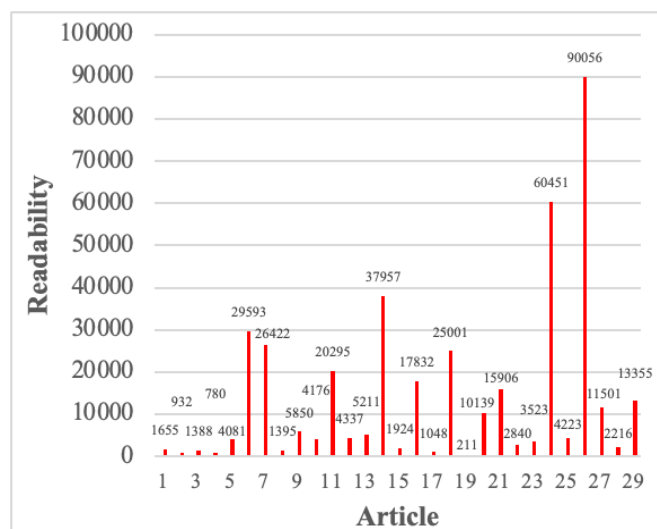


Fig. 1 Overview of the readability of the articles on the website *Грешки!*
Источникът на препратката не е намерен.

Through Figure 1, an increasing trend in readership has been revealed, but with increasing numbers, and therefore readership, come other opportunities for the dissemination of content on the Internet. Articles 1-5 are articles that are found exclusively on the website and are not disseminated on other distribution channels. Based on the data collected, the average readership of articles found on the website is 13,941.3.

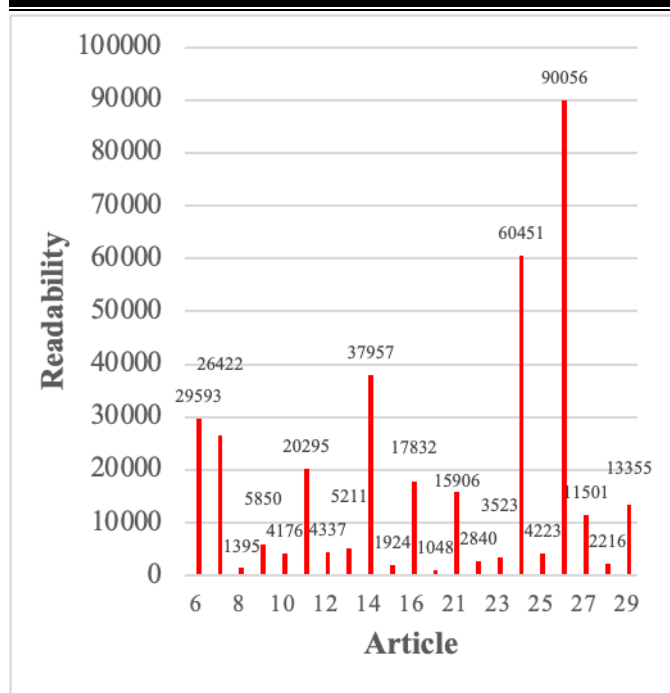


Fig. 2 Overview of the readability of the articles on Facebook ²

Based on the data in Figure 2, we found that although the readership of articles found on the website and Facebook increased compared to the previous ones (found only on the website), it still has lower numbers than articles distributed on other social networks as well. These are mainly articles 6-17, found exclusively on the website and Facebook. The average readership of articles on Facebook is 17,148.1.

Table 1. Average readability values of individual distribution channels

Distribution channel	Average readability
Website	13 941,3
Facebook	17 148,1

Recommendations for aktuality.sk

Based on the analysis of Aktuality.sk and the research conducted for this thesis, we have concluded that although the selected company is taking steps to increase the success rate of its articles, it may share more content related to specific articles with a hyperlink within certain distribution channels (namely Instagram).

Based on the analysis and original research conducted, we make recommendations aimed at improving the distribution of articles on each distribution channel.

5. Conclusion

Recommendations focused on the website

Article sharing on the website, all articles produced by Aktuality.sk are on the main website from which we have drawn data dealing with the readability of individual articles. In terms of the distribution of articles on the website, we do not find any specific ideas that could help to increase its traffic and subsequent readership. specific ideas that could help to increase its traffic and subsequent readership.

Recommendations focused on Facebook

Facebook still ranks first in terms of popularity among social networks in Slovakia. For this reason, the Facebook profile of aktuality contributes largely to the traffic and readership, as the posts contain a direct link to the specific article on the main website.

As in reality, in our conducted research in Figure 2 we can see that Aktuality.sk adds a high percentage of articles from the website to their Facebook profile. However, there are several reasons why

blogs should not share almost all articles on Facebook. These include, for example, redundancy, which can be annoying and people start to ignore the content. Other reasons include loss of credibility, for example, which raises questions about the quality of the content on the blog or accusations of spamming. For these reasons, it is important to share only the most interesting articles and not overwhelm readers.

Based on the average readership shown in Table 1, that is, the average readership of articles shared on Facebook is lower compared to the average readership of articles shared on Instagram, we recommend that the News portal reduce the number of times it adds articles to its Facebook profile.

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Exploring educational inequalities in the context of the Program for International Student Assessment (PISA).

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Abstract: The Program for International Student Assessment (PISA) assesses the key knowledge and skills that adolescents need for their future success in modern society. Until now, however, little is known about the relationship between the results shown in the International Student Assessment (PISA) and the school performance of the students in the schools covered by the study. The results achieved by Bulgarian students in a program for international assessment of students developed by the Organization for Economic Cooperation and Development (OECD) were obtained as a result of solving entirely logical, practical tasks that are universal and show the extent to which the logical thinking of the students is developed. Since thinking is a universally valid indicator against which students around the world can be compared, PISA's main task is to understand what the quality of education is like in different countries. The findings of our research contribute to the analysis of existing educational inequalities and provide valuable opportunities for the formulation of proactive strategies to address this issue.

KEYWORDS: GLOBAL COMPETENCE; PISA 2022; GLOBAL CITIZENSHIP EDUCATION; BULGARIAN EDUCATION

1. Introduction

The quality of education significantly impacts the social mobility and personal welfare of citizens and is directly linked with a number of indicators about quality of life, such as improved health, longevity, successful parenting and active civic engagement, [1]. Ever since its establishment in the year 2000, the OECD's Programme for International Student Assessment (PISA) defines fostering equality in education as its main priority. Over the past two decades, the open datasets of the results from the international student assessment (PISA) published by OECD have established themselves as a main source of objective data about the quality of education in the different countries participating in this assessment. [2], [3], [4]. Analyzing educational inequalities based on the open datasets from the results of the international student assessment (PISA) is a topic that has earned a firm place in research literature. [5], [6], [7]. A very good up-to-date literature analysis of this impressive collection of research papers is presented in [8]. The authors of the referenced literature analysis focus on four main topics: (1) Equality of opportunities, (2) Equality of results, (3) Segregation and (4) Sustainability. Based on the fact that one of the main issues which countries face is bridging the gap in educational achievements [9], they conclude that 20 years after the establishment of PISA, the participating countries, with some rare exceptions, have not managed to significantly improve the situation with regards to educational inequalities.

By using the open datasets published by OECD for PISA 2018 Xi Wu, Yanan Zhang apply a hierarchical linear modeling in order to study the effects of individual qualities, family origin and school characteristics on the educational results of students in six countries.

Having researched the factors which contribute to the global competency of students, their analysis finds that the gender of students, their self-efficiency and fear of failure, their economic, cultural and social status, as well as the intercultural attitudes of teachers, have a significant impact on the results from the international student assessment PISA 2018 in Chile, Korea, Croatia, Hong Kong, Malta and Panama. Substantial regional differences between the countries included in the study were established with regards to the effect of various factors on the results from the PISA 2018 assessment of students. [10].

An up-to-date publication from Vietnam serves as a confirmation of the significant regional differences established in a number of other studies with regards to the effect of various factors on the results from the PISA assessment. Despite being the poorest or the second poorest participant, Vietnam surpasses all other developing countries and wealthier countries in the 2012, 2015 and 2018 PISA marks. Vietnam's strong performance in the 2012, 2015 and 2018 PISA assessments raises the question as to why they performed so well and whether other countries can improve their students' learning by applying 'what works' in Vietnam. The

authors of this study look for an explanation for this performance in several directions: (1) The 15-year-olds who participated in PISA in Vietnam are not a representative sample of 15-year-olds in Vietnam; (2) the level of inclusion of 15-year-olds in school education in Vietnam is much lower than in other countries participating in PISA; (3) Vietnamese students are more motivated and put a lot more effort into their participation in the international PISA assessment than students from the majority of other countries; or (4) Vietnamese schools apply a targeted educational approach in order to increase their students' results in PISA. According to the authors, the open datasets from the PISA assessment explain to a very small degree (around 30%) how Vietnamese students have surpassed those in other countries, [11].

An interesting point of view regarding the factors influencing the achievement of high results in the 2018 PISA assessment is presented in [12]. Its authors study the following research questions:

Research question 1: How does the accumulation of digital capital in schools vary in the countries participating in PISA 2018? How is digital capital accumulated differently in schools and by teachers and students in the different countries?

Research question 2: How are the differences in the accumulation of digital capital related to the differences in students' achievements in the individual countries?

Research question 3: Are there any links between the different dimensions of digital capital when it comes to improving student learning?

The main results from this study show that not every development in the field of information and communication technologies (ICT) leads to the integration of these technologies in schools or to the improvement of the digital skills of teachers and their students that are applicable in the learning process. The development and improvement of the software infrastructure at schools is positively related to students' achievements, but this is not true for the ICT hardware at schools. The digital skills which students apply in the learning process have a significant positive effect on their achievements. When combined with the digital skills applied by teachers in the learning process, the digital competency of students is even better linked to their academic performance.

2. Research background.

The results from various standardized exams and tests are a broadly applied assessment tool for both the knowledge and skills of students, but also for the assessment of the quality of the educational process and the efficacy of teachers, schools and even of entire national educational systems. Examples in this respect are the National External Assessment in Bulgaria and the OECD's Programme for International Student Assessment (PISA).

So far, however, little is known about the link between the performance of students who have participated in a PISA assessment and their academic achievements, such as the results from the National External Assessment in Bulgaria or their final marks for the respective school year. The reasons for this are objective and are to a large extent related to the way in which the national representative samples of students who participate in a PISA assessment are formed, and the way in which their results are published in OECD open datasets.

That is why the results published in 2022 in [13] are extremely interesting. The authors of the study establish a moderate correspondence between the results from PISA and academic achievements, where the PISA levels of mastery are linked to the school marks and remain the same after taking into account the impact of the gender and the socio-economic status of students. The results from this study show that the PISA test assesses a wide range of academic achievements.

In a number of cases, however, the results from PISA and other similar standardized exams and tests have no consequences for the test taker (low-stakes tests). Unlike high-stakes exams, in low-stakes tests the results demonstrated by students are always influenced not only by the level of knowledge and skills, but by various other circumstances. The subjective and group variability in the degree of inherent motivation (or other variables related to the stakes of the test) among different students or groups of students can lead to having the comparisons of the results achieved be influenced by differences in the test stakes level for individual participants or groups of participants in exams. Ignoring this aspect of low-stakes exams can cause policymakers to make incorrect conclusions and to potentially distort the development of effective policies. [14].

In the already referenced publication [14] Yuval Ofek-Shanny experimentally establishes that the lower level of engagement of test takers from minority groups included in his study and participating in low-stakes exams can lead to results that are twice as low than when these results are received from high-stakes exams. This difference in the results of high-stakes and low-stakes exams may lead to distorted or misleading conclusions in the assessment of students' skills. If the main objective is to focus on cognitive skills, high-stakes testing is better because it is less sensitive to the various levels of engagement of test takers. Marks from low-stakes exams could be better, if the main objective is to forecast future results on the labor market of the test takers since these tests are able to detect a combination of cognitive and non-cognitive skills, including inherent motivation for achieving high results regardless of the stakes.

3. Unpacking the PISA 2022 data for students' effort.

In the context of PISA 2022 the students participating in the study self-assess their motivation for participation by responding to the following three questions:

(Q1) : How much effort did you put into doing well on the PISA test?

(Q2) : How much effort would you have invested if your results from the PISA test were going to be counted in your school marks?

(Q3) : Now think about the PISA questionnaire you just answered. How much effort did you put into giving accurate answers?

The responses of students are provided using a scale where the highest score is (10) for a situation in which the students have made everything possible and have done their utmost to do well, whilst the lowest score is (1) for a situation in which students have not made an effort and have not tried to do well at all.

In order to analyze whether and to what extent the students' origin country has influenced the responses to these questions, for each of the countries participating in the international student assessment program PISA 2022 we initially calculated an LE indicator which equals the percentage of students that have responded with 1, 2 or 3 to questions Q1, Q2 and Q3, and an HE indicator which equals the percentage of students that have responded with 8, 9 and 10 to Q1, Q2 or Q3. The results we obtained are listed in Table 1.

Table1: LE and HE indicators.

Country	Q1LE	Q1HE	Q2LE	Q2HE	Q3LE	Q3HE
Albania	12.4%	63.5%	7.7%	73.8%	7.5%	68.7%
Argentina	6.8%	58.6%	3.9%	83.0%	5.4%	62.7%
Australia	7.2%	46.0%	2.7%	84.7%	3.7%	72.7%
Austria	10.7%	42.6%	5.8%	77.6%	10.1%	54.2%
Baku (Azerbaijan)	10.5%	54.6%	7.1%	69.1%	8.1%	61.2%
Belgium	7.1%	42.2%	3.3%	81.2%	6.3%	55.3%
Brazil	6.9%	62.1%	4.9%	77.6%	5.4%	70.4%
Brunei Darussalam	5.7%	39.7%	5.2%	62.0%	4.1%	57.3%
Bulgaria	14.2%	49.8%	8.3%	67.7%	10.5%	55.5%
Cambodia	6.7%	56.1%	7.3%	54.1%	6.0%	54.0%
Canada	7.7%	48.1%	2.9%	85.8%	5.7%	66.6%
Chile	4.3%	57.2%	1.9%	86.3%	4.0%	68.1%
Chinese Taipei	10.2%	54.4%	3.3%	79.1%	4.3%	67.4%
Colombia	3.6%	72.1%	2.6%	83.4%	3.0%	74.8%
Costa Rica	4.3%	70.5%	1.9%	90.1%	3.6%	79.3%
Croatia	5.4%	53.5%	3.5%	81.1%	4.7%	68.1%
Czech Republic	8.3%	48.6%	5.1%	77.4%	7.4%	55.9%
Denmark	7.2%	46.2%	1.8%	89.5%	4.2%	66.5%
Dominican Republic	12.2%	68.3%	10.4%	71.8%	9.1%	69.7%
El Salvador	5.2%	72.9%	3.6%	81.5%	3.6%	76.2%
Estonia	3.7%	54.2%	2.0%	84.6%	3.4%	65.1%
Finland	12.5%	47.5%	4.8%	79.1%	9.9%	57.3%
France	6.8%	41.5%	3.5%	77.9%	6.8%	53.7%
Georgia	10.0%	63.1%	8.0%	73.3%	7.0%	71.8%
Germany	11.1%	41.2%	4.0%	82.0%	6.9%	68.3%
Greece	9.7%	41.6%	5.4%	74.8%	7.9%	58.2%
Guatemala	3.8%	78.5%	2.5%	89.0%	3.2%	80.1%
Hong Kong (China)	11.8%	38.1%	3.0%	77.2%	6.3%	53.5%
Hungary	6.8%	47.1%	3.9%	78.2%	5.1%	61.7%
Iceland	11.3%	41.2%	5.1%	78.5%	8.2%	60.6%
Indonesia	7.2%	71.5%	6.0%	75.9%	5.3%	75.1%
Ireland	3.8%	52.9%	1.6%	88.2%	2.1%	75.8%
Israel	10.2%	48.9%	4.0%	85.0%	7.2%	60.6%
Italy	5.2%	56.0%	2.7%	82.7%	3.8%	67.0%
Jamaica	7.9%	51.3%	6.1%	72.5%	5.9%	70.3%
Japan	28.1%	26.3%	4.2%	74.4%	6.9%	60.1%
Jordan	12.9%	49.1%	9.4%	60.5%	8.9%	55.1%
Kazakhstan	4.2%	74.9%	3.1%	82.7%	3.8%	76.5%
Korea	4.7%	65.0%	1.8%	86.6%	3.2%	76.9%
Kosovo	12.4%	63.4%	8.5%	70.7%	6.9%	69.5%
Latvia	4.1%	59.9%	2.6%	80.1%	3.6%	66.2%
Lithuania	4.8%	60.8%	2.9%	80.7%	4.2%	66.5%
Macao (China)	5.3%	57.3%	2.0%	82.4%	2.6%	68.3%
Malaysia	7.5%	56.3%	6.5%	62.8%	5.9%	60.4%
Malta	9.9%	43.8%	5.0%	78.4%	6.3%	64.6%
Mexico	2.9%	76.9%	1.8%	88.8%	2.3%	81.3%
Mongolia	4.8%	70.5%	3.3%	79.0%	3.4%	75.3%
Montenegro	8.7%	53.3%	5.5%	76.6%	7.1%	62.7%
Morocco	9.8%	56.1%	7.0%	67.1%	7.8%	61.6%
Netherlands	5.8%	48.9%	2.5%	85.0%	4.4%	61.5%
New Zealand	4.7%	50.8%	2.1%	84.0%	2.5%	70.6%
North Macedonia	9.7%	58.7%	6.5%	74.3%	7.4%	65.1%
Norway	15.1%	35.5%	4.6%	82.6%	10.1%	51.1%

Country	Q1LE	Q1HE	Q2LE	Q2HE	Q3LE	Q3HE
Palestinian Authority	12.5%	55.0%	8.4%	62.2%	7.9%	61.4%
Panama	5.2%	65.4%	3.7%	78.5%	4.2%	70.5%
Paraguay	4.6%	70.1%	3.0%	86.0%	4.7%	73.0%
Peru	4.8%	60.0%	3.0%	81.5%	3.9%	68.0%
Philippines	9.3%	71.3%	7.6%	71.9%	7.3%	72.5%
Poland	6.9%	50.3%	3.9%	76.7%	7.2%	57.6%
Portugal	3.5%	55.2%	1.6%	87.3%	3.0%	69.3%
Qatar	11.6%	49.2%	7.8%	71.0%	8.9%	60.5%
Republic of Moldova	5.8%	62.7%	4.1%	74.8%	4.2%	69.9%
Romania	6.6%	59.1%	4.3%	78.0%	5.8%	65.5%
Saudi Arabia	7.5%	70.3%	5.7%	77.3%	5.8%	73.7%
Serbia	9.0%	51.8%	5.0%	78.2%	7.3%	60.0%
Singapore	5.3%	50.7%	1.2%	88.4%	2.5%	73.2%
Slovak Republic	13.1%	44.5%	8.2%	68.0%	10.4%	56.6%
Slovenia	8.5%	46.5%	4.6%	76.5%	6.8%	55.2%
Spain	4.5%	53.4%	2.0%	85.6%	3.5%	68.5%
Sweden	7.6%	43.7%	2.2%	89.8%	5.5%	63.6%
Switzerland	8.0%	42.3%	4.0%	78.7%	7.2%	53.0%
Thailand	7.8%	55.1%	6.2%	60.1%	6.1%	57.7%
Türkiye	4.9%	72.1%	3.3%	83.7%	3.4%	80.8%
Ukrainian regions	8.6%	56.1%	6.2%	72.0%	8.3%	59.0%
United Arab Emirates	8.2%	58.8%	5.4%	76.9%	5.8%	70.8%
United Kingdom	8.1%	42.3%	2.4%	87.5%	5.0%	64.4%
United States	2.5%	68.9%	1.3%	90.7%	1.7%	83.4%
Uruguay	5.3%	55.5%	2.7%	84.5%	4.3%	62.1%
Uzbekistan	9.3%	74.1%	7.6%	74.9%	6.8%	76.5%
Viet Nam	1.3%	80.1%	1.1%	84.7%	1.2%	82.6%

The results presented in Table 1 demonstrate significant differences between the individual countries. In Vietnam, for example, under 2% of students have responded with 1, 2 or 3 to these questions, whilst over 80% of them have responded with 8, 9 and 10. On the other hand, 28.1% of students in Japan have responded with 1, 2 or 3 to Q1, and only 26.3% have responded with 8, 9 or 10 to the same question.

According to our hypothesis, the countries participating in PISA 2022 can be grouped in two clusters based on the LE and HE indicators calculations we performed, and this can be checked through a non-hierarchical clusterization using the K-means clustering method. The results from the cluster analysis of this data applied by us are illustrated in Table 2 and Table 3.

Table2: Final Cluster Centers.

Indicator	Cluster 1 42 countries	Cluster 2 38 countries
Q1LE	5.98%	9.81%
Q2LE	3.78%	5.08%
Q3LE	4.37%	7.06%
Q1HE	63.70%	46.80%
Q2HE	81.32%	75.33%
Q3HE	71.83%	59.72%

Table3: ANOVA.

Indicator	F	Sig.
Q1LE	26.713	0.000
Q2LE	7.431	0.008
Q3LE	46.102	0.000
Q1HE	103.188	0.000
Q2HE	13.808	0.000
Q3HE	107.513	0.000

4. Discussion and conclusions.

The results we obtained and presented in Table 2 show that in 42 of the countries participating in PISA 2022 (Cluster 1) a relatively small number of students (5.98% on average) are less likely to make an effort in order to do well in the exam. As regards the percentage of students who would put less effort into the PISA exam in the countries included in Cluster 1, the effect of the potential recognition of the results achieved by them and counting the results towards their school marks would be smaller (Q2LE = 3.78%). As regards Cluster 2, the average percentage of students who are more likely not to make an effort to do well in the exam is significantly higher (Q1LE=9.81%) and for these countries the effect of the potential recognition of the results achieved by students when forming their school marks is bigger (Q2LE =5.08%).

As regards the percentage of student who would make a significant effort in order to do well in the PISA 2022 assessment, we have noticed a significant difference in the results for Cluster 1 (Q1HE=63.70%) and Cluster 2 (Q1HE=46.80%), and in both cases the effect from the potential recognition of the results achieved in the PISA 2022 assessment for the purpose of forming their school marks is significant. For Cluster 1 Q2HE=81.32% is nearly 18% higher than Q1HE=63.70%. For Cluster 2 Q2HE=75.33% is nearly 29% higher than Q1HE=46.80%. Again, the positive effects of the potential recognition of the results achieved in the PISA 2022 assessment for the purpose of forming the school marks would be bigger in the countries from Cluster 2.

Based on the results obtained, Bulgaria is positioned in Cluster 2 which gives us a reason to believe that increasing the motivation of students participating in the PISA assessment would have a significant positive effect.

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Managing Digital Transformation

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Abstract: Recent studies indicate that over 80% of organizations have initiated their digital transformation journey, yet only approximately 25% perceive tangible benefits from these endeavors. Delving into the reasons behind these perceptions, it becomes evident that digital transformation lacks practical implementation. This research treats digital transformation as a project, adhering to project management principles. It delineates a pragmatic approach to digital transformation project management, highlighting key considerations at each stage. Furthermore, insights from an interview with Huawei Türkiye's R&D director, HR business partner leader, and payroll and personal affairs manager shed light on Software as a Service (SaaS) as a pivotal component of contemporary digitalization. SaaS is believed to expedite successful integration, positioning companies favorably against competitors in remarkably short durations.

Keywords: DIGITAL TRANSFORMATION, PROJECT MANAGEMENT, INDUSTRY 4.0

1. Introduction

With the latest trends in project management and project process management, especially in Intelligent Computing Technology (ICT)/Software areas like Agile and DevOps, management goes from vertical to horizontal structure rapidly. So, what to do in 2020s to survive as a leader or influencer in industry? And how to build a talented team that would work fully dedicated for getting success in organizational Digital Transformation (DT) projects? How an organization go from traditional to digital with quickly launched digitalization projects? How to make this transformation more effective, practical and smooth without losing vision to catch technology train that drive very rapidly in today's business environment.

Many firms stated that they have already started to work on digitalization, but outputs do not meet expectations with a high percentage. Business owners should accept digitalization as a vision of their organizations and hold it in another place from daily works or short/mid-term projects. This paper influenced from these two clichés, and outlined the important points that need to be observed in care while managing digitalization projects. Many Software/ICT projects driven by so called traditional firms today already for being digital. Research projects on SaaS products, mobile APPs, remote management and many similar projects are helping these firms in a pre-defined schedules with a small/mid-sized talented team effort.

Experts in this area explained some systems, applications or platforms to migrate into business to be successful like: IoT (Internet of Things), cyber security monitoring tools, digital marketing with immersive advertisement channels, artificial intelligence algorithms, robotics, and smart factory plants etc. How to implement or manage them is important after starting to take real actions on being digital. In the following parts, the latest Project Management Institute (PMI) structure with main things to take care for being successful in DT projects are presented with some hints on each step.

This study also includes an interview and is entirely research-based. It reexamines sources from a different perspective, incorporates past experiences and cases that require further examination, reinterprets research results, and provides rich references. The interview focuses on the term SaaS, which can perhaps be called the catalyst of digitalization for today, and which is thought to be able to put companies ahead of their competitors with successful integrations in a really short time.

2. Background

Digitalization projects require more than customary IT execution, have a high potential to trigger hierarchical change, and need a joined scene on innovation and business. Although very little research has been dedicated specifically to DT projects, related studies can teach us something about how these projects are managed. By uniting disengaged experiences, we expect to make a more comprehensive image of DT projects [1]. The project team structure can be based on a hierarchy system, a flat one or a matrix

system. These have different ways of organizing the relationship between the management team and employees. It is better to share the structure of the team regularly for new mates especially. Otherwise, employees will always have questions in their minds and regularly the project manager, director or other managers should struggle against these questions.

[2] define the five KSFs (key success factors) as follows: (1) Top management support is critical for defined responsibility and empowerment leadership. (2) More horizontal hierarchies and inter-functional collaborations are of great importance. (3) People management forms another component and is partially aligned with a digitally savvy culture and vision. (4) Use of data and digital technologies supports DT. (5) Customer-focused KPIs. All these factors are of vital importance for successfully digitalizing the structure.

[3] extends the concept of writing skills in the digital setting while emphasizing the importance of developing abilities such as adaptability and insight. She categorizes skills into tangible ones like learning, integrating, planning, and restructuring, which provide concrete, empirically proven strategies for navigating external environments and achieving advanced levels of digital transformation. To illustrate the continuous and nonlinear nature of the process, she uses the concept of change to more accurately reflect digital development. She identifies specific relationships between an organization's ability to leverage IT to support its key processes and the degree of digital transformation achieved.

In Business Horizons, [4] advise four levers to enable digital transformation by creating an innovative digital project team including diverse and targeted team composition, iterative goal setting, continuous learning, and talent management. They also outline some challenges with traditional IT team like project leadership associated with project management versus coaching and mentoring and adding tips to overcome these ones like train and mentor digital team members through leadership and onboarding programs to help shifters.

3. Managing Digital Transformation

Digital transformation is the integration of new generation technologies into all business areas of a company, fundamentally changing the way business is done and transforming products into value-added products. It is also a cultural and structural change that requires organizations to constantly challenge traditional methods, engage in an experimental team, and be comfortable with flexibility.

In this paper, theoretical approaches and literature studies related to the general structure and analysis of digital transformation processes are presented in a systematic way. This structure has been established to be as similar as possible to the structure currently used by PMI in general. In accordance with the PM-BOK (Project Management Body of Knowledge) flow, it started with people and continued with the details of process and work environment. In addition, literature information is given in a way that allows the previous studies on the subject to be followed in the same flow. It

can be a supporting material for digital transformation projects, as well as the main sources used on project management.

4. People

In July 2012, the London Symphony Orchestra performed a composition entitled *Transits – Into an Abyss*. One reviewer called it “artistic and delightful”. The event marked as the first time that an elite orchestra had played music composed by a machine.

The above research is not an opinion, actually; it is from Martin Ford’s famous book - *The Rise of the Robots: Technology and the Threat of Mass Unemployment*. The book earned “Business Book of The Year” award given by a press and a research company. Then, why did Project Management Institute (PMI) place the title “People” in the first place of their new exam content outline? What are the things behind PMIs’ trust on humankind, especially in 2020s while human cannot decide about serious issues in their own – in other words, without getting help from analytics applications?

Aside from the fact that human beings pollute nature and cannot use the world’s resources in a sustainable way, even dragging it towards the end of its life; unfortunately, our lives are not easy at all. These days are not that easy, and when we think of natural disasters, wars and epidemics, we are trying to deal with all of them at the same time.

It is necessary to examine these problems not only with their material but also with their spiritual dimensions. Human beings are such an entity that they constantly multitask, not only when they are at work. For example, we often become what we want the other person to see, not the emotion we feel. We think that when we must decide about our own life, we must consider everything, and everyone involved in our life. Perhaps for all these reasons, we can say that every person is a leader, whether by birth or learning, but successful but mediocre.

4.1 Employer Branding

As it is understood from Human Resource Business Partner (HRBP) in corporate offices, “Employer Branding” is a bit virtual definition occurred from some of the governmental regulations related to management of Research and Development (R&D) Centers. But basically, struggles given by companies to hire more talented and developed candidates; in addition to using them for multi-tasking like both Software development and algorithm research.

Organizational mission, modern-day employees, business enterprise culture, and the possibility to boom your company gives great pleasure. Prospective applicants want to understand the core aspects of what it’s like to work at your company before they apply. The key to conveying this essential information is to build your employer brand.

The agency emblem is what allows potential task candidates purchase into what the business enterprise is all about—your culture, humans, and purpose. Your agency emblem efficiently highlights those characteristics that make your company a unique vicinity to paintings, placing you other than the crowd, humanizing the company, and in the end inspiring applicants to use to consideration.

4.2 Recruitment

Experts predict that by 2020, the global workforce population will predominantly include younger workers. Millennials will make up 35% of the global workforce and Generation Z will account for 24%.

To many recruiters, hiring millennials is still a big mystery. To attract and recruit this generation, the first thing should be understood is which industries they are moving to, which they are leaving from, and why? See Figure 1.

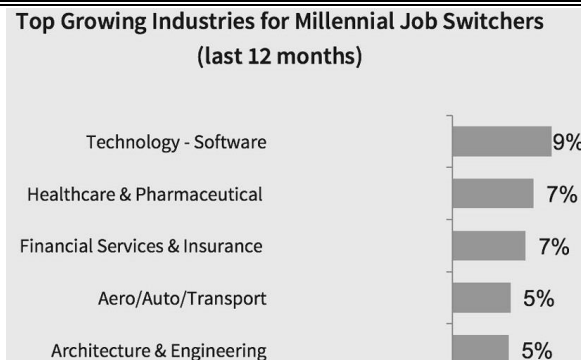


Fig. 1 The Top Industries Gaining Millennials According to LinkedIn (2017)

The research shows that “being visionary” (not only in words but also in practice) is the most attractive thing for employers when payroll regulations and salary are not much different from each other. So, what kind of digital innovation for recruitment period can show the organizations more visionary?

Publish the job opening on popular social and career applications or websites in addition to your company’s website. And better to allow people apply the job easily with their profile or early prepared resume instead of redirecting them to companies’ website career tab and asking many unnecessary questions which many of them already included in their resume or profile information. This will show that organizations are running regulations in a more practical way and allowing employees to accomplish real tasks without stressing out of limited time period because of time wasting procedures.

Request to do online test or remote task from applicants. This action will leave “more selective company” effect to job seekers. And HR and technical reviewers will be saved from massy interview counts, so potential employees can enter more details in their low count interviews and select more suitable or talented new mates for the company.

Do more online interviews instead of face-to-face ones via a mature online interview or conversation tool. A job seeker might live far away from the office and even then, can apply for an open position that does not fit him/her entirely, however the company can post another job fitting this applicant wholly later. Applicant will absolutely encounter distance between the office and home for attending a second interview. Thus, to prevent this kind of issue like potential employees might be perfect fit for the company enabling online interview would provide time, reputation and attitude for the company.

4.3 Building and Leading a Team

First, it is better to recruit new colleges whose visions are highly matching with the organizational DT vision and strategy. Then, express the strategy, vision, structure etc. These things will affect the project in every step, or all stakeholders should be aware of the entire working period for the organization or project. Go from Human Resources to Human Resources Business Partner, and let the team give feedback to a friend not to a formal employee from another department. Having this approach would positively affect team-members’ motivation and project efficiency.

Another issue is that the company cannot transform by just the bottom line of triangle; there are also mid-level managers who have crucial roles in the project success. And for those individuals sharing the digitalization vision would never be enough, the company must get their opinions and create a partner vision for this long-term journey. Also planning new training about using digital assets in managing, encouraging them to give feedback about missing parts and continuous improvements.

4.4 Stakeholder Management

[5] defines stakeholders as any group or individual who can affect or is affected by the ecosystem's services. Stakeholders are separated inside and in a roundabout way, yet additionally as indicated by their level of significance, and they are delegated such. Thus, it tends to be resolved which stakeholder should be spoken with first and the desperation of this.

[6] combine elements of previous researches to develop a multi-dimensional framework called the Triple Oscillation Model. As shown in Figure 2, it consists of stakeholder classes, functional roles and business ecosystem lifecycle.

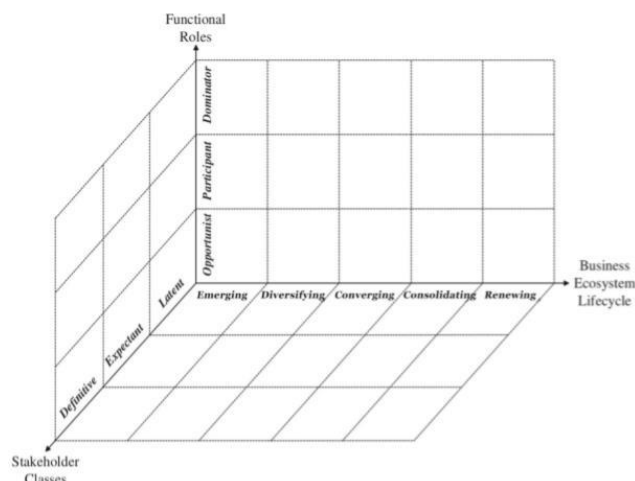


Fig. 2 Triple Oscillation Model [6]

Successfully managing stakeholders is related to communication with 50%, in main belief; after getting much training and research. See Figure 3.

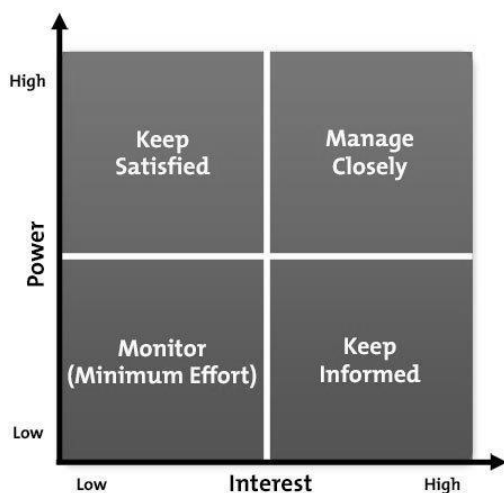


Fig. 3 Stakeholder Prioritization

4.5 Continuous High-Performance Culture

There are two different terms that need to be cared about if a team or organization wants to catch a continuous high-performance culture while doing their daily/target works beside. One of them is project performance and the other one is employee performance as known. However, both have similar processes like evaluating the performance, tracking it continuously and of course steps need to be taken to improve performance.

5. Open A Place for A Tech Giant in Saas Business

Currently, cloud computing is significantly more stable and proven than it was a decade ago. As a result, numerous large and small companies have migrated even their most critical assets to the cloud. Moreover, it offers the most logical options that can be useful to catch up with your competitors in the way of digitalization. SaaS, on the other hand, is like giving automatic payment instructions for some of your tax debts or invoices while you are already there in a bank branch where you trust to keep your money, as well as buying insurance, taking a new investment step or changing your accountant's business with a set of products that this bank offers for you. Moreover, it is very easy to integrate and maintained largely by the cloud provider. Their convenience is not limited to this either, when you need any assistance with your own admin operations in the foreground, the cloud/product provider's advisor will probably be a click or a phone call away. Moreover, these services are now available not only to small entrepreneurs who might worry about future support, but also to established companies, which we can refer to as technology giants.

One of them is Huawei. The company's R&D center in Türkiye has already started to offer a set of products in SaaS form to the end user in 2020. While some of them are software already owned by the company, some of them were written completely in line with today's needs. It has been tested by many beta users and internal units of the company before it is offered to the end user, and partnerships have been established with local cloud providers for regions that do not have access to Huawei Cloud. We made Interview about this hot topic including producer and customers. Interview is not just only covering company's SaaS products, it is also touching to digitalization, projects may be handled by practical tasks like SaaS product owning, and new business environment after pandemic. We did an interview with Huawei's R&D director and Human Resources Business Partner (HRBP) leader and also Payroll and Personal Affairs Manager of another company about SaaS adventure of High Technology Research and Development Center (HTRDC) China compliance with today's conditions and strategies.

When asked how innovation can help businesses support their business in today's volatile business environment to R&D director and he said:

DT is a hot topic! And innovation is critical for SMEs, but it is a real challenge for big companies. Huawei focuses on ICT as a specific area and provides some telecom solutions, smart devices, software, cloud and AI solutions to support businesses to facilitate innovation. For example, after 4G, many innovations have been made in video and mobile content. The world is changing, and innovation should be divided layer by layer. As Huawei, we are constructing highways; and the customers are building cars. Building which car depends on themselves, but we should support either Mercedes or any others.

Together with Huawei's R&D director, we explored the SaaS solutions offered by HTRDC and examined examples to understand how they support the new work-from-home (WFH) principles. Regarding the rest of conversation, it is understood that SaaS solutions provided by Huawei are not specialized for work from home principle. But somehow, they support people to be more convenient and flexible. For instance, an online coding platform provided by R&D center is also supporting all candidates to have an exam remotely. Previously, candidates were coming to the office to take the exam from PC or paper but now companies can use it for remote recruitment.

Online is important not just for WFH, but also for every condition. These online solutions were designed for virtualization in every step of life in the beginning; but after the pandemic, everybody understood that they are the best fits for current challenging environment.

Another example would be WeFocus. Managers or HRBP can come across employees every day in the old routine and make a judgment about their situation; if necessary, they could

communicate with them one-on-one and act. Thanks to the announcements, surveys and feedback they receive on WeFocus; this communication disconnection can be minimized. HTRDC was the first to use this product.

As we continued, we tried to examine the customer feedback and demands that guide the SaaS strategies of both the director and the R&D center as a leader in the sector. SaaS production or development is a really challenging process, because there are a lot of people working in this field. Even some individual ventures are the competitors, and as a team you must make a difference to show yourself in front of customers.

Huawei prefers to take more challenging tasks like putting AI algorithms into each product. And try these solutions at first internally to get feedback from different people or departments to outline pain points and improvement areas. So, initial borders of the SaaS products were formed. They collected feedback from customers and beta users to redefine categories and borders.

When trying to learn the SaaS strategies of the R&D center of the pandemic impact on social or business life, through examples or sensations, R&D director replied as follows and detailed his personal expectations for the days ahead:

Huawei was lucky about pandemic effect on SaaS, of course it supports ideas to benefit from SaaS solutions. It should be unfortunately stated that the pandemic had very serious negative effects for other sectors. But people also learned a lesson from this and the online transition in every area was accelerated. In addition to the working principles, this change includes the way business, education and even healthcare are made.

Pandemic situations changed many minds belonging to businesspeople, and companies started to hire more software engineers to adopt virtual operations into their businesses. So, there is a huge demand for recruiting tech people. Thanks to being a technology company, Huawei have already enough resources and more than enough knowledge on the software domain. In China, all the top universities started to record each course; and anyone from public can watch any course.

When we asked what the future plans of their organizations regarding the SaaS product range and sales strategies are, what factors will be encountered while shaping these strategies:

They said: We had chosen to build small teams first, then grow with the customer engagement and feedback. Now, there is a unified sales team working closely with the SaaS teams, different from the rep-office marketing department. Probably, this team will be larger in parallel to SaaS technical group.

Finally, he was asked whether he is an enthusiast who believes digitalization is a vision, or one of the practical leaders who believe in embarking on new digital transformation projects to catch the train. He said: Digitalization is the future. Digitalization or virtualization was one of the topics in Chinese universities at a time between 2001 and 2005. But, not seen so real or closer enough to that day's business or social life from the student's side. To put it into a company's vision, those years were suitable; however, it is a need now and professionals should start to adapt it into their business as soon as possible.

Not just changing minds or business, cultures should evolve together with virtualization. If someone is talking about technology, he/she should have hands on it. Being practical is already today's philosophy. No one can deal with technology without getting their hands dirty.

Only mobile phone is enough for Chinese to survive in daily life. All the verticals have some different background and have some differences while adopting technology. Anyway, all of them should work on it combining both technical and operational units.

Then similar questions were asked to Payroll and Personal Affairs Manager of a company using SaaS products of Huawei. Due

to today's conditions, she believed that they are in a process where organizations have started to carry out all processes in the digital environment. That's why using products that support processes like WeFocus helps their business a lot and speeds up the work, as well as providing support and solutions to known problems. These solutions help them to understand the problems of employees more quickly and clearly, making them happier and increasing loyalty. Using SaaS solutions has been developed in a more optional and facilitating way, such as getting data in a more understandable and clear way, allowing problems to be resolved faster.

They aim for maximum digitalization. And she is expressing that they have changed working style in respect to customers new way of working in pandemic days. As she, they had to deal with remote working negative effects and understand best practices about WFH. With SaaS products it would be better to digitalize in a short time and start to use its benefits as soon as possible.

Customer and employee needs had been their important inputs to go digital with SaaS solutions. The company is lucky to be informed about SaaS solutions of Huawei, like WeFocus.

As a HRBP working for a fast-paced company like Huawei, she believed that they must deal with multiple operational tasks daily, and again managers must double check each of the processes in order to ensure zero-mistake implementations are made. Innovative solutions can help HR to automate each step in daily routine and ensure high quality output within a limited time and effort. She expressed that they can easily track and assess employees and even candidates in current abnormal situations via their valuable feedback. They can address the shortcomings and provide solutions with efficient results, thanks to SaaS applications that allow organizations to digitalize in a short time with the quick projects managed in a practical manner.

6. Conclusion

This study tried to evaluate digital transformation as a project by adhering to the principles of project management. The study is endeavoring to explain how a practical digital transformation project management can be implemented by stating which points should be given extra attention. Many technology producers have separated their corporate sales channels today, unlike the traditional structure. Through these channels, solutions such as SaaS, Cloud Services, IoT, and Cyber Security are offered to companies that manufacture end-user products or provide user services.

As a summary of the academic interviews, the participants generally gave fresh parallel answers. It is believed that a practical transformation with the help of quick and easy solutions such as SaaS benefit companies in this way. In this context, a study to be conducted with academicians and consultants can eliminate the deficiencies of the topics covered and the support given to the organizations with this study, if any, by revealing the points that should not be ignored in the theoretical principles.

Although a very specific field has been chosen as the subject, a study has been made in the right field thanks to the literature review and the difficulties encountered in the next stages. Because although there are many resources under the titles such as digital transformation, industry 4.0, project management; the number of resources that offer them by blending them with each other is few. It has been tried to benefit greatly from several events analysis that have already been made for other purposes for most of the inferences made. Considering this point of view, researchers can conduct more case analysis directly about this study.

During such a study, it can be mentioned about the failures experienced while trying to realize the digital transformation through projects. In fact, it is obvious that such a study will not only support our study, but also have the characteristics of several lessons that should be considered for those who are interested in this study.

In addition to all this, subsequent researchers can also work on the digitization of project management. In this study, this subject has been partially addressed, and it has not been focused on. Where deemed necessary, it is sufficient to refer to the printed examples and some recommendations are given. In addition to the research to be done, it is also possible to create a project related to this subject. It can be a new generation project management tool or a specific application targeting digitalization projects.

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Waste reduction - a factor for intelligent and sustainable growth and higher competitiveness

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Abstract: This publication analyses the process of transforming the online economy into a circular one. The focus of the analysis is on the progress of the European Union member states in reducing waste. Member States' progress towards a circular economy is slow. The circular business model should not be seen as wishful thinking, because it will be crucial for companies in the future. The circular economy is at the heart of the European Green Deal and plays a key role in decarbonisation and achieving climate neutrality by 2050 and in the fight against pollution. Circular economy means smarter use of resources. The circular economy is built using sustainable economic models based on innovation and technology to allow the repeated use of the same resources. Achieving a zero carbon footprint on the natural environment by 2050. is the top priority. This would only be possible if the world moves towards a circular economy, and this is one of the highlights of the Green Deal, while also aiming to increase the competitiveness of the economy.

Keywords: CIRCULAR ECONOMY, RESOURCES, WASTE, RECYCLING, SUSTAINABLE DEVELOPMENT

1. Introduction

The linear economy will inevitably be displaced by the alternative circular economy. A linear economy is a model of producing products from various resources that are used and then discarded. In the circular economy, after the end of the useful life of a product, it again becomes a resource for reuse. This is done by repairing it, recycling it, reusing it, etc. Our planet's resources are limited and at some point they will simply run out. This necessitates a rethinking of consumption, and the need to reorient towards a circular economy and build intelligent productions that efficiently use resources is becoming increasingly clear. The linear principle - "take, produce, use, throw away" is no longer applicable.

Accelerated global growth in commodity consumption has led to overexploitation of natural resources. The EU's goal is until 2030. to reduce waste disposal below 10% and to turn it into a resource through high-quality recycling. The goals are to do this with 65% of household waste and 75% of packaging waste. By 2030 this means 65% recycling, 25% recovery and 10% municipal waste disposal. This poses a number of challenges both to the industry and to the state and society.

2. Waste management

The EU generates about 2.5 billion tonnes of waste (about 5 tonnes per capita). The majority of these come from the construction, mining and manufacturing sectors. Household waste represents 9% of the total amount of waste generated. (Fig. 1) Construction waste includes materials scrapped during the demolition or renovation of old buildings, as well as materials scrapped during the construction of new buildings. The wastes generated in the mining and extractive industries are mostly materials treated to provide access to mineral resources, causing irreparable damage to the natural landscape, flora and fauna. In manufacturing, waste is all materials discarded during production processes. Manufacturing waste includes a wide variety of materials. Municipal waste includes both mixed municipal waste and separately collected waste. The other waste category includes materials discarded during waste processing, including during sorting and recycling. 5 tons of waste generated per capita, 4.5 tons are treated.

The main idea behind the circular economy concept is to extend the time for efficient use of products, materials and resources while minimizing waste. By using advanced technologies, they can separate and recover valuable materials from waste streams. This process of moving from a linear to a circular economy requires a high degree of responsibility and commitment both from society as a whole and from each individual. This can only be done by building a new type of public attitude and culture of responsibility towards nature and future generations.

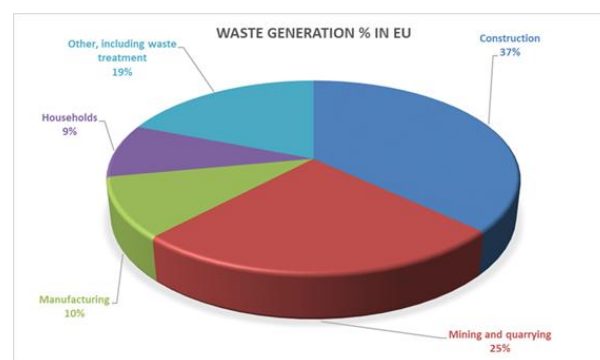


Fig. 1 Distribution of types of waste generated with the EU. Data source: EPRS, Infographics, 2018. Грешка! Источникът на препратката не е намерен.

Recycling turns waste into new resources, and in some cases it also involves generating energy from waste materials. Not all materials can be recycled to the same extent. The degree of recycling of different materials depends on their properties, wear and tear and ability to acquire new properties or regain old ones. [5].

Waste minimization can be done in three main ways: reduce, reuse and recycle. [3] Some standards developed by the International Organization for Standardization (ISO) related to recycling are widely applied in practice, such as ISO 15270:2008 [10] and ISO 14001:2015 [11]. There are also very effective good practices that are gaining more and more popularity in the context of the circular economy.

Materials that are subject to recycling are glass, paper, cardboard, metal, plastic, tires, textiles, batteries and electronics. Food and plant waste are biodegradable waste and can also be recycled through the technology of composting. [2].

The recycling of a material produces a new quantity of the same material. Some types of materials, such as metals, can be recycled many times without losing their purity and properties. [4]. Other materials lose or change properties when they are recycled. Recycling some materials is technologically difficult or too expensive compared to extracting them from natural sources. Such materials can be reused in the production or recycling of other materials. Extracting materials from end-of-life products, either because of their specific value or rarity, is also a form of recycling, such as lead from batteries and gold and silver from printed circuit boards, or because of their hazardous nature, such as the removal and reuse of mercury from thermometers, barometers or other devices containing or working with mercury or other hazardous substances. According to Eurostat data, in the period 2010 - 2022, a smooth but permanent trend towards an increase in the amount of recycled materials is outlined (Fig. 2)

Recycling requires: a source of recyclable waste, a system for collecting, sorting and processing recyclable materials from the waste stream, an enterprise that can treat and recycles them and a demand for recycled products. [2]

An important indicator of recycling efficiency is the energy intensity of the processes. In general, it takes much less energy to produce recycled materials than to produce materials from natural resources. In some cases, however, the cost of recycled materials exceeds the cost of materials produced from raw materials.

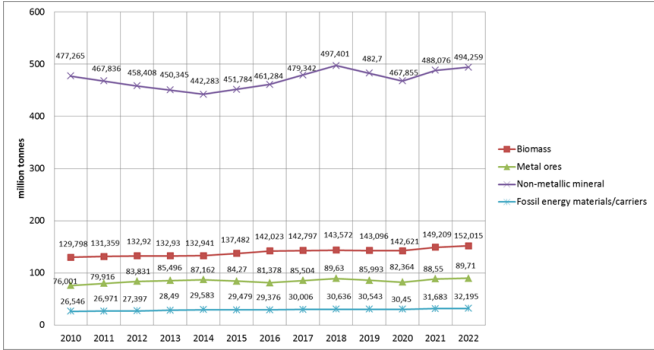


Fig. 2 Materials going through recycling in European Union for the period 2010 ÷ 2022 according to data extracted from Source: Eurostat (env_ac_mfa, env_ac_sd, env_wassd) [7]

In EU, the 'waste hierarchy' is a guiding principle for waste management. It sets a priority order for waste prevention and management options:

- Preventing the generation of waste by reducing packaging or extending the shelf life of products. Prevention is more about product design and consumption than waste management.
- Reuse. This can include repurposing items or using durable goods that have a longer life - for example reusing packaging through deposit schemes or remanufacturing electronics (telephones, decoders).
- Recycling - involves processing used materials into new products, reducing the need for raw materials and reducing the overall impact on the environment - for example, ferrous metals, non-ferrous metals (eg aluminum, copper), glass, paper and cardboard, rubber, plastic, wood and textile waste, whether hazardous or non-hazardous.
- Restore (energy). Combustion of waste in incinerators; in most cases the energy produced is used to generate electricity and/or heat (used for example in industrial processes or central heating systems).
- Disposal: Landfill.
- The polluter pays principle is one of 27 fundamental principles adopted by the Rio Declaration (1992) on which nations base their decisions and policies, taking into account the environmental consequences of socio-economic development. Adherence to this principle obliges polluters to be responsible and bear the costs associated with the environmental pollution they cause, including the costs of the measures taken to prevent, control and remedy the pollution.[9]

These principles aim to promote responsible and sustainable waste management practices and encourage people and businesses to be more mindful of their consumption and disposal habits.

- The circular economy opens up opportunities for:
- Socio-economic impact;
 - Cost savings for the business;
 - Quality jobs;
 - Climate impact.

3. Municipal waste management in Europe

Municipal waste covers waste generated from households and other sources. The overall goal is to reduce unsorted, mixed household waste, regardless of origin.

Separate collection is key to sustainable waste management and development towards a circular economy. Success requires four elements: economic incentives, enforcement, customized facilities, and engaging communication.

A zero waste idea is not possible without waste segregation. If waste is separated, it is not waste, but a resource. Waste can be separated at source – ie. the citizen sorts the waste or finally – i.e. a waste company separates the waste after it has been mixed. When the two options are compared, systems with separate collection at source not only significantly outperform mixed collection in terms of both material quality and deviation rate, but also cost less. In separate collection at source, there are ways to optimize the process and achieve the highest levels of material purity. Experience has shown that separate door-to-door collection yields much better results than separate collection in containers. European best practices in waste management use this system. (env_wasmun, 2016)

Flanders in Belgium is the region with the highest percentage of separate collection and recycling in Europe. Most collection is door-to-door, and some areas use the Pay-as-you-Throw (PAYT) system, where citizens pay according to the amount of residual waste they produce. Flanders currently separates 75% of its waste, and some municipalities recycle over 80%.

In Italy, more than 1,500 municipalities have adopted door-to-door split collection and already have over 55% source separation. 20% of them (300 municipalities) have over 80% separate collection at the source. All Italian zero-waste municipalities use the door-to-door separate collection system“.

Following the successful Italian initiative, the first door-to-door split collection in Spain takes place in Catalonia, where more than 100 municipalities currently use this system. The success encouraged other municipalities (Hernani and Oiartzun) to join the zero-waste strategy and separate waste at source, and both currently recycle more than 80% of their waste, while reducing waste generation with measures such as home composting. Currently in Spain, the separate collection rate for these municipalities with door-to-door collection is almost triple that with containers.[12]

Zero Waste practices from around the world prove the environmental and social convenience and cost-effectiveness of door-to-door separate collection. Door-to-door collection introduced in EU Member States varies from one container (residual waste collection only and relying on recyclable and bio-waste delivery systems) to six separate bins or sacks.(Fig. 3), (Table 1)

Collection type	Paper	Glass	Plastic	Metal	Bio-waste
Door-to-door (single fraction)	AT, BE, BG, CY, DE, DK, FI, HU, IT, LU, LV, NL, SI	BG, FI, LU, LV, NL, SI, MT	AT, LV, NL, DK	FI, NL, DK	AT, BE, CZ, DE, FI, EE, IT, HU, LU, NL, SI, SE, IE
Co-mingled ...plastic + metal			BE, BG, CY, DE, FR, IT, HU, LU, SI		
...3 fractions	RO, MT: paper, plastic, metal				
...all in one bin	EL, IE: paper, glass, plastic, metal				
Bring points	CZ, EE, ES, FR, HR, LT, PT, PL, SE, SK	AT, BE, DK, CY, CZ, DE, EE, ES, FR, HR, IT, HU, LT, PT, PL, RO, SE, SK	SE	AT, EE, SE	ES
Civic amenity sites	Primary collection: CZ (metal waste), SK (metal and bio-waste), LV (metal) Addition collection of all waste streams: all countries PL: rare distribution of civic amenity sites				

Fig. 3 Overview of collection systems in place in EU countries (primary systems only). [8]

Strict separate collection usually results in higher recycling rates. Among collection methods, door-to-door collection systems result in the highest rates of capture and recovery of recyclables.

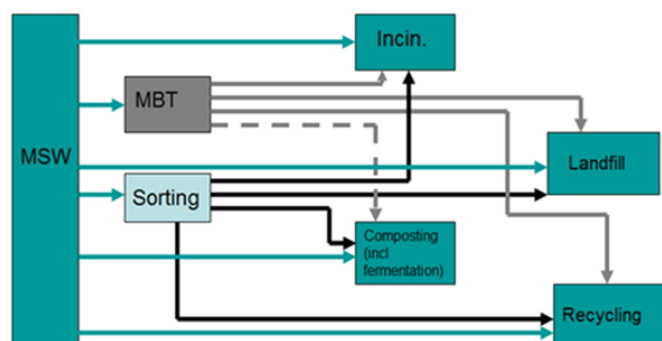
Table 1: Primary waste collection systems in EU countries. (Author)

Country	Separate Door to door collection					Mixed Door to door collection					Bring points				
	Glass	Paper	Plastic	Metal	Biowaste	Glass	Paper	Plastic	Metal	Biowaste	Glass	Paper	Plastic	Metal	Biowaste
Austria	0	1	1	0	1	0	0	0	0	0	1	0	0	1	0
Belgium	0	1	0	0	1	0	0	1	1	0	1	0	0	0	0
Bulgaria	1	1	0	0	0	0	0	1	1	0	0	0	0	0	0
Croatia	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0
Cyprus	0	1	0	0	0	0	0	1	1	0	1	0	0	0	0
Czech	0	0	0	0	1	0	0	0	0	0	1	1	0	0	0
Denmark	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0
Estonia	0	0	0	0	1	0	0	0	0	0	1	1	0	1	0
Finland	1	1	0	1	1	0	0	0	0	0	0	0	0	0	0
France	0	0	0	0	0	0	0	1	1	0	1	1	0	0	0
Germany	0	1	0	0	1	0	0	1	1	0	1	0	0	0	0
Greece	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0
Hungary	0	1	0	0	1	0	0	1	1	0	1	0	0	0	0
Ireland	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0
Italy	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0
Latvia	1	1	1	1	0	0	0	0	0	0	0	0	1	0	0
Lithuania	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0
Luxembourg	1	1	0	0	1	0	0	1	1	0	0	0	0	0	0
Malta	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0
Netherlands	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
Poland	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0
Portugal	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0
Romania	0	0	0	0	0	0	1	1	1	0	1	0	0	0	0
Slovakia	0	0	0	0	0	0	0	0	0	0	1	1	0	1	1
Slovenia	1	1	0	0	1	0	0	1	1	0	0	0	0	0	0
Spain	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
Sweden	0	0	0	0	1	0	0	0	0	0	1	1	1	1	0
Σ	7	13	4	3	12	2	4	12	12	9	18	10	6	10	2

Legend: 1 – exist; 0 – not exists

The common household waste treatment operations are illustrated on the Fig. 4. Data on the treatment of municipal waste are divided into the following categories:

- Combustion (separately with and without energy recovery);
- Landfilling;
- Recycling (except composting or fermentation);
- Composting.

**Fig. 4** Options for the treatment of household waste

When waste pretreatment operations - mechanical-biological treatment (MBT) or sorting - are carried out, their results must be allocated to one of the four types of treatment operations - incineration, landfilling, composting or recycling as it is shown on the Fig. 4.

Combustion

Incineration is the thermal treatment of waste in an incineration plant. Household waste can be burned directly or after pre-treatment. Waste incineration is often used as a quick fix to growing amounts of municipal waste and decreasing space in regional landfills. In reality, incineration does not solve municipal waste problems, but creates a number of health and environmental risks and stops the development of municipal systems for more recycling and composting. Waste-to-energy is defined as the incineration of waste to "recover energy" under an energy efficiency criterion, as well as the co-incineration of waste in power plants or industrial facilities such as cement kilns so that the resulting energy can be used to generate heat or electricity.

Landfilling

Landfilling of waste includes its storage in or on land, including in specially designed landfills, as well as temporary storage for more than one year at permanent sites. Landfills are often created in abandoned or disused quarries, mine shafts or pits. Landfilling covers both on-site disposal and off-site disposal. Municipal waste can be landfilled directly or after pre-treatment operations. The pre-treatment of waste prior to its landfill must contribute significantly to reducing the quantity or hazardous properties of the waste, to reducing the risk to human health and limiting the harmful impact on the environment caused by the disposal of the waste throughout the landfill's life cycle.

Composting

Composting and digestion are processes that subject biodegradable waste to aerobic or anaerobic decomposition. The products of these processes are compost or residue, which is used in agriculture. Municipal waste can be composted and digested directly or after pre-treatment operations.

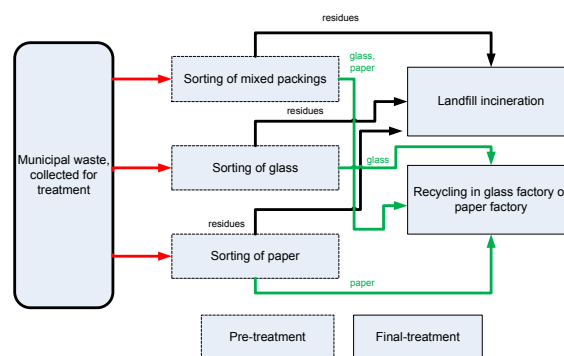
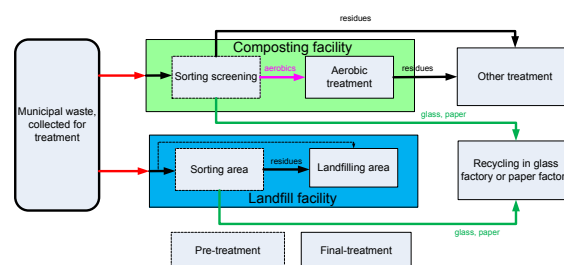
Recycling

Recycling is a form of recovery where waste materials are processed into products, materials or substances intended for reuse. Household waste can be recycled directly or after pre-treatment.

The treatment of waste, its recovery or disposal begins with preparatory activities such as mixing, repackaging, temporary storage, etc., which change the characteristics of the waste, reduce its volume or hazardous nature, facilitate handling and increase the efficiency of its utilization.

Mechanical-biological treatment is a tool for pre-treating waste before landfill or for preparing municipal solid waste to be used as fuel. Mechanical-biological treatment plants significantly reduce moisture by extracting, reducing and stabilizing the organic content in the waste. These treatments include mechanical separation of the waste, biological treatment of the organic fraction and additional mechanical separation if necessary.

The processed waste from the mechanical-biological treatment plants is significantly reduced in weight and stabilized. Emissions from mechanically-biologically treated waste can be reduced by approximately 90–98% compared to untreated waste under landfill conditions. In some countries, mechanically-biologically treated waste is used as landfill cover if contamination is low enough, or it can be landfilled directly. The quality of treated waste is generally not acceptable for widespread use due to contaminants associated with both inert content (glass, plastic, etc.) and heavy metal content resulting from other wastes entering the waste stream such as batteries and etc. Other products are combustible fractions and recyclable materials (eg metals, plastics). Different methods of sorting and processing household waste are shown in Fig. 5 and Fig. 6.

**Fig. 5** Sorting and treatment of municipal waste**Fig. 6** Integration of pretreatment in facilities.

4. Distribution of waste treatment methods

EU member states have different approaches and practices to the treatment of household waste. Municipal waste are usually

landfilled, incinerated {in most cases with energy recovery), recycled (e.g. paper, glass or metal) or composted. Recycling and composting are generally preferred over incineration. Landfilling is the least preferred option. According to the data of EPRS [6] the share of recycling and composting among waste treatment methods varies from 67% in Slovenia to 8% in Malta (EU average is 46%); eight Member States landfill less than 5% of their municipal waste, while eight Member States landfill over 60% of their municipal waste (the EU average is 25 %). [1]

Another important indicator is the amount of household waste per capita per year. It varies from 261 kg in Romania to 777 kg in Denmark (EU average is 483 kg).

Fig. 7 ÷ 9 present summary of information on Distribution of waste treatment methods that are most often used in EU member states - Landfill, Combustion, Recycling and composting.

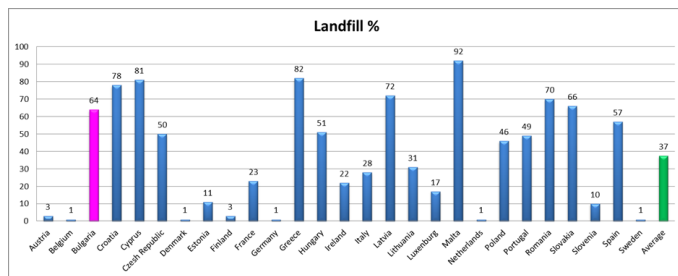


Fig.7 Breakdown of landfill method. (Author)

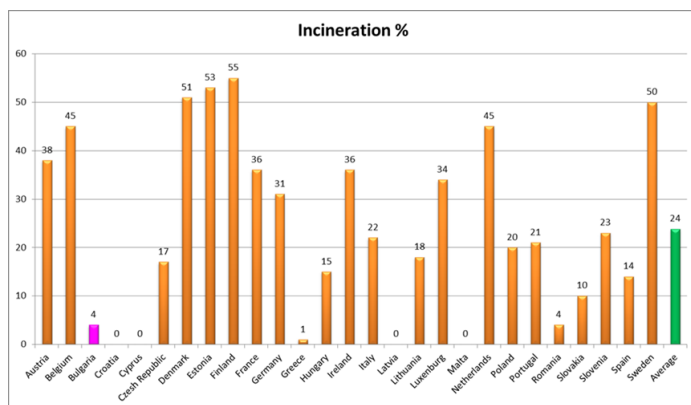


Fig.8 Breakdown of incineration method. (Author)

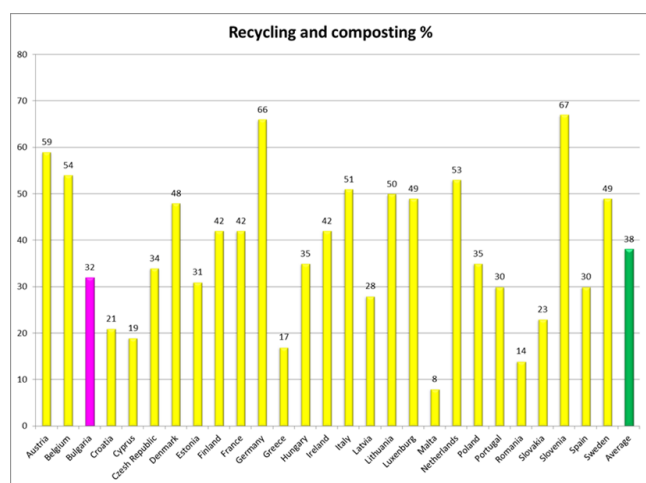


Fig.9 Breakdown of recycling and composting method. (Author)

5. Conclusions

The growing consumption of material resources continues to generate a large amount of waste. Waste is becoming an

increasingly serious problem for the planet. Waste management is a multifaceted field that will become increasingly relevant in our time and for the future. Responsibility and commitment of every single person in society is necessary. In order for this to happen, a new mindset and culture must be systematically built from an early age, so that young people can gain an understanding of recycling and be encouraged to be responsible for waste. This implies comprehensive scientific and scientific-applied research for many years to come.

Achieving sustainable development requires a balance between the economic, environmental and social aspects of human activity. Economic growth is associated with increased production, but this leads to increased energy consumption and growth in carbon emissions. That's why industries should focus on rational planning and energy efficiency. The industry as a whole needs to reorient itself from linear to circular processes that use recycled resources, reduce waste and minimize the carbon footprint on nature. Sustainable development is based on the idea and pursuit of economic growth that improves the well-being of people and society in the long term and is directly related to the need to solve global problems related to climate change, economic, social, environmental and demographic crises. Sustainable waste management is an important part of modern manufacturing processes as it helps companies achieve environmental goals and meet regulatory requirements. Scientific research shows how waste management can be used not only to achieve sustainable development, but also to address a wide range of social and environmental problems and increasingly become a factor for smart and sustainable growth and higher competitiveness.

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AI-driven strategies for category management profitability

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Abstract: Category Management (CM) is undergoing a transformation thanks to artificial intelligence (AI). AI automates tasks such as data analysis, market segmentation, and demand forecasting, which streamlines and simplifies the work of category managers. It also allows the creation of innovative strategies and campaigns that are relevant to customer needs. This paper focuses on identifying ways in which AI can help to create innovative strategies needed to optimize prices and product lines within category management with the aim to maximize profitability. The paper deals deeper with price optimization, where AI significantly impacts CM. AI analyzes price elasticity and suggests optimal prices for products, which affects the maximization of profitability. Thanks to AI, category managers no longer have to rely on manual analysis and intuition, but they can set prices with much greater accuracy and efficiency. Based on the findings and case studies in the article, the implementation of AI in CM brings companies significant benefits in terms of efficiency, innovation, and profitability. However, it requires strategic planning, investment in technology, and talented people. It is also important to be responsible and ethical when using AI to avoid negative impacts on customers and society.

Keywords: CATEGORY MANAGEMENT, UMEĽÁ INTELIGENCIA, OPTIMALIZÁCIA CIEN, ZISKOVOŠŤ, CENOVÁ ELASTICITA

1. Introduction

In the dynamic and competitive world of business, Category Management (CM) has emerged as a pivotal strategy for the success of retailers and manufacturers. CM transcends the realm of ordinary product management and focuses on strategic planning for product categories to maximize profitability and customer satisfaction.

CM is undergoing a profound transformation driven by advancements in Artificial Intelligence (AI), which opens up new possibilities for optimizing pricing, product assortments, and overall category strategy. This article explores the intersection of AI and CM and summarizes its impact on the work of category managers in the future.

This transformation presents both opportunities and challenges for category managers. They must learn to utilize AI-powered tools, interpret complex data analytics, and adapt their strategies to rapidly changing market conditions.

Traditional CM methods relied on intuition and manual data analysis, which was time-consuming and error-prone. AI introduces sophisticated algorithms and tools to process massive amounts of data from various sources, including sales, prices, inventory, marketing campaigns, and online reviews. With real-time analysis and predictive models, category managers gain deep insights into the market, customers, and competitors, enabling them to make more informed and strategic decisions.

CM is a strategic tool with significant benefits for retailers and manufacturers. Implementing CM can lead to revenue growth, increased profitability, enhanced brand image, and stronger customer loyalty. In the era of AI, CM becomes an even more powerful tool, empowering businesses to make informed and strategic decisions for sustainable growth and success.

2. The significance of pricing in CM

Category management is a strategic approach to managing product categories in retail. It aims to maximize category profitability and market share by optimizing product assortment, pricing, promotion, and distribution. Category managers collaborate with suppliers to achieve shared goals and ensure that category products meet customer needs.

Price is a crucial factor influencing product demand and category profitability. Lowering a product's price can lead to increased demand but also reduced profit margins per unit. Conversely, raising the price can decrease demand but potentially increase profit per unit.

Category managers must consider various factors when setting prices to find the optimal price that maximizes category profitability. These factors include:

1. Cost of production and distribution – Category managers must consider all costs associated with producing and distributing the product, such as materials, labor, transportation, and marketing.

2. Price elasticity of demand – This measures the extent to which product demand changes in response to price changes. Products with low price elasticity are less sensitive to price changes, while those with high elasticity are more sensitive. Understanding price elasticity allows managers to predict demand changes based on price adjustments.
3. Competition – Category managers must consider competitive product prices when setting their own. If competitors offer lower prices, customers may switch to their products. Conversely, higher competitive prices may attract customers to the company's products.
4. Customer expectations – Understanding customer price expectations is crucial for maximizing product line profitability. If a product's price is too high, customers may not buy it. Conversely, if the price is too low, they may perceive the product as low quality.

Factors affecting price elasticity of demand:

1. Product type – Basic products like bread and milk typically have low price elasticity, while luxury items like jewelry and cars often have high elasticity.
2. Availability of substitutes – If multiple product substitutes exist, demand for that product is likely more elastic. Conversely, with fewer substitutes, demand is less elastic.
3. Product importance to consumers – If a product is highly important, demand is likely less elastic. Conversely, for less important products, demand is more elastic.
4. Time horizon – Price elasticity may vary depending on the time frame. In the short term, demand may be less elastic, while in the long term, it may become more elastic [1, 7].

3. Practical applications of price elasticity in CM

Category managers can implement various pricing strategies to maximize profitability and achieve category goals by understanding price elasticity. This section delves into various pricing strategies and their practical applications in CM.

Penetration pricing involves setting a low initial price to gain rapid market penetration and acquire a large customer base. The goal is to attract a significant number of customers and establish a strong customer foundation. While initial profits may be lower, this strategy can lead to higher overall profitability in the long run if a substantial market share is achieved. This strategy is primarily suitable for new products, products with high price elasticity of demand, and products with high growth potential. Low prices not only motivate customers to buy but also stimulate demand and drive rapid sales growth.

In contrast to penetration pricing, skimming pricing involves setting a high initial price to maximize profits from products with high price elasticity of demand. The objective is to capitalize on the willingness of price-inelastic consumers to pay a premium for the product. Later, the price can be reduced to attract price-sensitive

consumers and increase overall sales volume. This strategy is primarily used for luxury products, high-value products, and products with low price elasticity of demand. Essentially, this strategy is suitable for products where demand is not significantly affected by price. Instead, price can strengthen the product's perceived value and increase its attractiveness to customers. Price-inelastic consumers are willing to pay a high price for luxury products.

Skimming pricing involves setting a high initial price for a product and gradually lowering it over time. The goal is to maximize profits from products with high price elasticity of demand in the initial phase while attracting price-sensitive consumers in later stages of the product's life cycle. Unlike the previous strategy, skimming pricing is primarily used for new products with a high degree of innovation, where demand for the product is very high in the initial market entry phase, and customers are willing to pay a high price due to the high value they perceive in the product. This type of strategy is particularly suitable for ICT products and their systematic advancement through the innovation process.

Psychological pricing utilizes various psychological factors that influence customer price perceptions to make products appear more attractive. Price determination assumes that the price will be perceived as more appealing to the customer.

One example of psychological pricing is the *"Baťa price"*, introduced by the renowned Czech entrepreneur Tomáš Baťa.

In this strategy, it is crucial that prices align with the overall pricing strategy and customer expectations. Excessive use of psychological pricing can lead to customers perceiving prices as unrealistic or manipulative (*"Baťa prices"* are becoming less effective). Therefore, it is necessary to test various psychological prices to determine the most effective ones for a given product category and target customer group.

While previous strategies focused on long-term price setting, promotional pricing involves temporarily lowering a product's price to promote the sale of specific products. The goal is to stimulate demand and increase sales in a short period. Promotional prices are often used to clear out excess inventory or introduce new models. This strategy is also applicable to seasonal products where the seller aims to increase revenue during the season. As the name suggests, promotional pricing is suitable for introducing new products to the market. To attract customer attention to new products, a *"promo"* price is set instead of or in conjunction with additional promotional materials, stimulating customers to purchase and try the new product. The most critical factor in using promotional pricing is to clearly communicate prices to customers and ensure they are time limited.

Personalized pricing involves setting product prices based on individual customer characteristics such as their purchasing habits, demographics, and interests. The goal is to maximize profit from each customer and build long-term relationships. Personalized pricing is becoming increasingly common as customer data becomes more accessible and artificial intelligence technologies advance.

This pricing strategy must adhere to data privacy regulations and protect customer privacy. It is the responsibility of every seller to ensure prices are transparent and customers understand how prices are determined. Optimal personalized pricing also involves identifying the most effective prices for specific products, product lines, and target customer groups.

This pricing strategy is most used in online environments, particularly e-commerce stores, where different product prices are displayed to different customers based on their purchase history and viewed products. The final pricing strategy discussed in the article is differentiated pricing. This strategy involves setting different prices for the same product to different customers or in different markets. The goal is to maximize profit from each sale and adapt to varying market conditions. Differentiated prices are often used based on various factors specific to a customer segment. Pricing is influenced by the customer's geographic location, with prices potentially varying depending on region, country, or even city. Local market conditions, competition, and purchasing power all

play a role in determining the appropriate price for a specific location.

Customer volume can also influence pricing. Businesses may offer discounts for larger purchases, encouraging bulk buying and increasing overall revenue. The channel through which a product is sold can also impact pricing. Online retailers may offer lower prices compared to physical stores due to lower overhead costs. Pricing strategies may evolve throughout a product's lifecycle. Initially, higher prices may be set to recoup development costs, while lower prices may be introduced later to attract a wider audience.

Businesses must ensure that differentiated pricing practices do not constitute price discrimination, which involves charging different prices based on prohibited factors like race, religion, or nationality. Clearly communicate pricing policies and the rationale behind differentiated pricing to customers to avoid misunderstandings and maintain trust. Pricing practices should be fair and non-deceptive, avoiding misleading or hidden charges that could disadvantage certain customer groups.

When implemented strategically and responsibly, differentiated pricing can be a powerful tool for businesses to maximize profitability, expand market reach, enhance customer satisfaction, and adapt to dynamic market conditions. By carefully considering customer segments, market characteristics, pricing objectives, and legal and ethical guidelines, businesses can leverage differentiated pricing to achieve their strategic goals and drive sustainable growth [2, 3].

4. Leveraging Artificial Intelligence in CM

AI has the potential to revolutionize the field of CM. AI tools and algorithms can analyze vast amounts of data on customers, products, competitors, and market trends, providing category managers with valuable insights for optimizing pricing and product assortments. This chapter delves into the intersection of AI and CM in the areas of pricing and product assortment optimization.

AI can significantly enhance pricing strategies by analyzing price elasticity. AI algorithms can scrutinize historical sales and pricing data to identify factors that influence product demand. This empowers category managers to set optimal prices that maximize profitability and cater to customer needs.

AI models can accurately predict future product demand based on various factors, including seasonal trends, marketing campaigns, and economic conditions. This enables category managers to optimize inventory levels, preventing stockouts or overstocking.

AI tools can analyze individual customer profiles and purchasing habits to offer personalized pricing. This personalized approach can boost customer satisfaction and drive sales growth.

AI algorithms can analyze sales, profitability, and margin data for individual products to identify underperforming items. This allows category managers to optimize product assortments, focusing on products with high profit potential.

AI-powered pricing automation involves dynamically adjusting prices in real-time based on various factors, such as competitor pricing, product demand, and inventory availability. This automation saves category managers time and resources while ensuring optimal pricing [4, 5].

Table 1. Practical applications of AI in CM

Company	AI applications
Amazon	Personalizes product prices for each customer based on their purchase history and preferences.
Walmart	Predicts product demand and optimizes inventory levels.
Procter & Gamble	Analyzes price elasticity and sets optimal prices for its products.
Coca-Cola	Develops personalized marketing campaigns and optimizes product distribution.
Unilever	Analyzes online reviews and customer feedback to improve products and services.

The integration of AI into CM offers a multitude of advantages, including:

1. **Enhanced Profitability** – AI empowers category managers to maximize profitability by optimizing pricing and product assortments. AI algorithms can analyze vast amounts of data to identify optimal price points and product mixes that align with customer demand and market trends, leading to increased revenue and profit margins.
2. **Elevated Customer Satisfaction** – AI enables category managers to deliver personalized experiences that enhance customer satisfaction. By analyzing customer data and purchasing patterns, AI can tailor product recommendations, pricing strategies, and marketing campaigns to individual customer preferences, fostering loyalty and satisfaction.
3. **Improved Efficiency** – AI streamlines processes and automates tasks, saving category managers time and resources. AI-powered tools can handle repetitive tasks such as data analysis, price adjustments, and inventory management, allowing category managers to focus on strategic decision-making and value-added activities.
4. **Enhanced Decision-Making** – AI provides data-driven insights that inform strategic decisions. AI algorithms can analyze vast amounts of data to identify trends, patterns, and correlations, enabling category managers to make informed decisions about pricing, product assortments, marketing strategies, and overall category management strategies.
5. **Increased Competitiveness** – AI empowers category managers to stay ahead of the competition. By leveraging AI for data analysis, pricing optimization, and personalized customer experiences, category managers can gain a competitive edge, attract and retain customers, and achieve sustainable growth [6].

5. Conclusion

Each Artificial intelligence (AI) holds immense potential to revolutionize Category Management (CM) practices in the future. As AI continues to evolve and innovate, category managers can expect to gain access to even more sophisticated tools and algorithms that empower them to achieve strategic goals.

AI is poised to enable category managers to create customized pricing offers and marketing campaigns for each customer based on their unique buying behavior, preferences, and demographics. AI models will also accurately predict product demand in real-time, allowing category managers to optimize inventory levels and minimize losses.

Dynamic pricing algorithms will adjust product prices based on various factors, such as competitor pricing, demand, and inventory availability, ensuring maximum profitability. Advanced data analytics will empower category managers to analyze vast amounts of data from diverse sources, gaining valuable insights into market trends, customer behavior, and competitive landscapes.

AI assistants will serve as intelligent partners, assisting category managers in tasks like information retrieval, data analysis, and decision-making.

The adoption of AI in CM will bring significant benefits to businesses in terms of efficiency, competitiveness, and profitability. However, it is crucial to emphasize that AI serves as a tool to augment category managers, not replace them. The human element will always play a pivotal role in strategic category management and building strong customer relationships.

AI stands as a powerful catalyst with the potential to elevate CM to new heights. By responsibly and ethically embracing AI, category managers can look forward to a future brimming with innovation, growth, and success.

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Robotic Applications in Medical Science: Current Advances and Future Prospects

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Abstract: Over the past four decades, the field of medical robotics has achieved remarkable advancements, revolutionizing various medical disciplines. The widespread adoption of robotic platforms across various medical disciplines has been remarkable. Currently, these devices play a crucial role in performing minimally invasive surgical procedures with enhanced precision, resulting in reduced hospitalization and increased safety for physicians. Beyond surgical applications, medical robots are increasingly proving their worth in performing routine tasks, thereby enabling less invasive and more informative diagnostic and therapeutic procedures. Furthermore, the integration of artificial intelligence (AI) holds great promise for developing new systems with higher autonomy levels and improving existing ones. This paper describes a short view on history of the development of robotics from the beginning to the current state along with a brief outline of the future direction of development of medical robotics. At first describes the process of development from the first medical robotic device prototype to the modern minimally invasive surgical devices currently used in medical practice. Then it presents expansion of robotics into other medical fields, including ophthalmology, gastroenterology, cardiology and cardiac surgery, physiotherapy, or radiology. Finally, it describes some perspectives for future development in medical robotics, as well as the obstacles, that need to be overcome to improve the efficiency and level of autonomy, in the systems.

Keywords: MEDICAL ROBOTS, SURGERY, INVASIVE INTERVENTION

1. Introduction

The concept of robot dates back to 1921, when Czech writer Karel Čapek introduced it in his play, inspired by the Czech word "robot" meaning forced labour [1]. Initially confined to industry, robotics has expanded into various sectors, including medicine, driven by the automation and efficiency principles of Industry 4.0 [2].

Over the past 35 years, robots have been pivotal in aiding surgeons during minimally invasive procedures, leading to enhanced patient outcomes. However, the origins of medical robotics extend further, with the initial concept emerging over 60 years ago in the military. During this period, robots were used to monitor vital signs and prevent hemorrhagic shock in the critical "golden hour" after injury [1]. This article explores the evolution of robotics in medicine, its current applications across diverse medical fields, and the most promising areas for future advancements.

2. History of Robotics in Medicine

The field of surgical robotics has a remarkable history marked by significant milestones. In 1985, the introduction of the Programmable Universal Machine for Assembly (PUMA) started a new era, facilitating delicate biopsies within neurosurgery and subsequently expanding its applications to other disciplines such as urology and gynecology [3]. Building upon PUMA's success, 1992 witnessed the debut of Robodoc, a pioneering image-guided system tailored for orthopedic surgeries. Robodoc transformed orthopedic surgery by offering high accuracy, particularly for procedures involving intricate bone work [4]. Furthermore, in 1994, the Automated Endoscopic System for Optimal Positioning (AESOP) was introduced. This system revolutionized endoscopic procedures with its innovative integration of voice control technology. This groundbreaking platform eliminated the need for foot pedals traditionally used for remote control, significantly enhancing surgeon dexterity and control during minimally invasive surgeries [1].

Introduced in 1998, the ZEUS system revolutionized the field of telepresence surgery with its innovative design. It consisted of three independently mounted arms on the surgical table, two of which could hold various surgical instruments, the ZEUS system offered unparalleled flexibility and control for surgeons. Its impact transcended various surgical disciplines, initially finding utility in gynecological procedures, and later expanding to complex cardiac surgeries [1]. Notably, it played a pivotal role in "Operation Lindberg", the transatlantic surgery conducted in 2001. This groundbreaking operation utilized a telecollaboration system called

SOCRATES, enabling a surgeon in New York to perform the procedure on a patient hospitalized in Strasbourg, France [5]. Although ZEUS was not the pioneering effort in telepresence surgery, earlier systems like Intuitive Surgical "Lenny" and "Mona" paved the way for its development. However, it was the ZEUS system's advanced capabilities and successful implementation in complex surgeries like Operation Lindberg that proved its status as a major milestone in telepresence surgery [1, 6].

The turn of the millennium was a significant moment for medical robotics, mainly due to the Da Vinci Surgical System. This period, often referred to as the "da Vinci era", brought a revolution in minimally invasive surgery. Even though the first Da Vinci model was commercially available in late 1998, it did not get FDA approval until 2000. Before the Da Vinci system, there were projects like DARPA at Stanford Research Institute trying to make remote-controlled surgery a reality, getting surgeons closer to where they were needed. However, the Da Vinci was a game-changer with its three key parts: a patient cart, a surgeon console, and an imaging system. These components enabled surgeons to concentrate more effectively during procedures, thus minimizing their fatigue [1].

One of the groundbreaking features of the Da Vinci system was its 3D endoscope equipped with an advanced optical system. This innovation eliminated the need for 3D glasses, delivering a truly immersive 3D experience for surgeons. Recognizing the challenge posed by hand tremors, a four-armed version of the Da Vinci was introduced in 2002. This not only improved dexterity but also preserved the surgeon's energy. The company's dedication to ongoing enhancement led to the release of the da Vinci S in 2006, which offered a significant upgrade with 3D high-definition (HD) camera vision among other benefits. Subsequent iterations included the improved da Vinci Si model in 2009, which introduced the concept of dual console surgery, facilitating supervised training for less experienced surgeons [1].

Other improvements included real-time fluorescence imaging and access to single-port surgery, which tackled the shortcomings of traditional laparoscopic procedures. The peak of this progress came with the da Vinci Xi, revealed in 2014 (Fig. 1). This system tackled many of the remaining issues regarding patient positioning and robotic arms, while also introducing new technologies that keep pushing the boundaries of robotic surgery [1].



Fig. 1 The da Vinci Xi Model - Surgeon Console [1]

3. Key Applications of Robotics in Modern Medical Practice

The current state of medical robotics showcases advancements, highlighting its potential to revolutionize healthcare. Its impact spans beyond surgery permeating various specialized areas within internal medicine and expanding its utility to broader aspects of healthcare delivery.

The da Vinci Xi surgical system addresses many limitations of previous models, particularly those related to patient access and instrument manipulation. This advanced platform has several upgrades that enhance robotic surgery. With improved instrument design and vision, the system offers advanced instrumentation, superior 3D-HD visualization with high magnification, and an immersive viewing experience. This allows surgeons greater control over the 8mm endoscope for precise maneuvering. Enhanced Dexterity and Flexibility are offered by redesigned robotic arms, which provide a wider internal range of motion, improving access to the surgical site and minimizing external arm collisions during operation. All the technologies are integrated for optimized workflow [1].

The da Vinci Xi integrates FireFly fluorescence imaging, which aids surgeons in real-time decision-making during procedures. Additionally, the In-table Motion (ITM) feature enables dynamic patient repositioning throughout the surgery. Streamlined workflow is provided by designed entry ports (robotic arms) and improved robotic stapling to further enhance surgical efficiency [1]. Robotic-assisted surgery is rapidly gaining traction due to its ability to overcome the inherent limitations of traditional laparoscopy. This technology has demonstrably proven significant benefits in various surgical fields, particularly visceral surgery, urology, and colorectal surgery [7, 8].

Robotic-assisted surgery with the da Vinci system has revolutionized minimally invasive procedures. Compared to traditional laparoscopy, it offers advantages for complex abdominal wall reconstruction during hernia operations. Similarly, in gynecology, it proves beneficial for technically demanding surgeries, such as specific cancer and endometriosis treatments. The evolution continues with the da Vinci Single-Port (SP) platform, FDA-approved in 2018 for urological applications. This innovative platform allows surgeons to perform complex urologic procedures through a single incision, potentially leading to improved cosmesis, reduced pain, and faster recovery for patients [1].

While the da Vinci system dominates the robotic-assisted surgery market, several companies are developing competing technologies. Transenterix's Senhance platform offers features like enhanced ergonomics and haptic feedback for surgeons. REVO-I surgical system, developed by Meere Company South Korea and approved by the Korean FDA, seeks a very cost-effective model [1, 10]. The other such contender is Titan Medical's SPORT (Single Port Orifice Robotic Technology) system, in 2020 rebranded to the Enos system currently under development [9, 10].

In addition to established players, several companies such as Auris Surgical Robotics, Silicon Valley, CA, USA (with their Monarch system), Cambridge Medical Robotics (Versius), MiroSurge, and Avatera Robotics GmbH (Avatera Surgical System) are also actively engaged in the development of robotic surgery platforms [10].

The future of robotic-assisted surgery lies in enhancing the surgeon's experience and optimizing patient outcomes. Companies are actively developing improved human-machine interfaces (HMIs) to prioritize surgeon comfort, safety, and decision-making during procedures. This includes the exciting integration of modern technologies and Artificial Intelligence (AI). AI has the potential to provide surgeons with richer data from the operating field, potentially leading to more informed decisions and improved surgical outcomes [10].

3.1 Ophthalmology

Ophthalmology, particularly ophthalmic surgery, is emerging as another field embracing robotic and cybersurgical techniques. While this technology is a recent addition to the field, several platforms are already making an impact. Existing robotic systems, like the da Vinci system, are being adapted for microsurgical steps like sclerotomy, the Intraocular Robotic Interventional Surgical System (IRISS) assists with various ocular procedures like capsulorhexis and vitrectomies, the Johns Hopkins Steady-Hand Eye Robot offers shared control of surgical instruments during posterior segment surgeries. Advanced smart instruments are being developed to enhance technical performance and minimize surgical complications. While not yet integrated into ophthalmology, cybersurgery remains a prominent subject of discussion and research. Several projects are underway to develop miniaturized surgical robotic prototypes for potential future applications [11].

3.2 Gastroenterology

In gastroenterology, endoscopy has long been the standard for visualizing the digestive tract. However, capsule endoscopy has emerged as a less invasive alternative. These pill-sized cameras offer a convenient way to examine the gastrointestinal (GI) tract. Numerous companies, such as Medtronic (PhillCam series), Olympus (EndoCapsule), and Intro-Medic (MiroCam), now produce capsule endoscopes. The future lies in capsule robotics, which takes capsule endoscopy a step further. These advanced capsules go beyond diagnosis, potentially offering therapeutic capabilities. The following sentences offer a glimpse into the potential of capsule robots. Sensing Capsules can gather various data within the GI tract, including temperature, pH levels, and potential signs of cancer or bleeding. Targeted Drug Delivery can be managed by microcapsules like SOMA and IntelliCap can deliver medication directly to specific areas of the GI tract for a sustained release effect. Future capsule robots might perform minimally invasive procedures like gastric bleeding treatment, ulcer intervention, or even eradication of *Helicobacter pylori* with photodynamic therapy. Challenges remain, however, the power supply, localization within the gut, and safe navigation are key challenges to overcome. Microrobot development holds promise for addressing these challenges and expanding the possibilities of capsule robotics in the future [12].

3.3 Cardiology and Cardiac Surgery

The field of cardiology is exploring the exciting potential of soft robotics. These next-generation devices are being developed to address damaged heart tissue, offering a potentially groundbreaking treatment option. However, significant challenges lie ahead. Mimicking the complex biomechanical and hemodynamic properties of a healthy, beating heart is no easy task. Researchers are actively working to optimize these soft robots to ensure they function seamlessly within the human body [13]. Interventional cardiology is another area where robotics holds promise. A recently introduced soft robotic platform offers a minimally invasive

approach to cardiac procedures. This innovative device collapses for insertion through small openings and then expands and locks securely within the heart. This platform has the potential to revolutionize interventional cardiology by enabling a wider range of minimally invasive procedures and potentially reducing healthcare costs associated with more complex procedures. However, the platform's safety and efficacy need to be validated through in vivo testing before widespread application can be considered [14].

3.4 Orthopedics

Robotic surgery is revolutionizing orthopedic procedures, offering several key advantages. By enhanced precision robotics minimizes errors, leading to more accurate surgeries and improved outcomes. With personalized treatment, robotic systems allow surgeons to tailor procedures to a patient's unique anatomy. Employing minimally invasive techniques, facilitates smaller incisions, thereby leading to quicker recovery times and diminished pain for patients. Robotic assistance ensures precise implant positioning for optimal functionality. Several innovative robotic systems are currently used in orthopedic surgery, each offering distinct benefits. MAKO System (Stryker) excels in joint replacement surgeries, promoting accurate implant placement. ROSA (Zimmer Biomet) provides guidance for various procedures, including spine surgery. NAVIO (Smith & Nephew) aids surgeons in knee surgeries, enhancing precision and potentially improving patient outcomes. MAZOR X Stealth Edition™ (Medtronic) assists with precise screw placement during surgery. Stryker Mako Total Hip Arthroplasty System optimizes total hip replacement surgery for improved results [15].

3.5 Advanced Rehabilitation and Physiotherapy Techniques

Robotics is making significant strides in physiotherapy and rehabilitation, offering innovative tools to support healthcare professionals. These robotic systems aid patients with various conditions, including injuries, stroke, and neurological or musculoskeletal diseases. Continuous Passive Motion (CPM) technology facilitates rehabilitation after orthopedic surgeries, for instance, by improving knee flexion recovery following total knee replacement. Electromagnetic Tracking Systems (ETS) represent a newer and more user-friendly approach. ETS utilizes 3D limb kinematics measurement to provide a more comprehensive evaluation for patients undergoing ACL reconstruction, both before and after surgery. Robotic gait training devices are particularly beneficial for patients with spinal cord injuries, assisting with gait training and enhancing body weight support during neurorehabilitation therapy. By incorporating these robotic technologies, healthcare professionals can potentially improve patient recovery times, enhance treatment effectiveness, and empower patients on their path to regaining function [16].

Beyond hospital settings, home-based rehabilitation technologies are empowering patients to continue their recovery journey at home. These innovative tools offer several advantages. Inertial Sensors track joint movement during exercise, providing valuable data for rehabilitation programs. Telehealth Applications through video conferencing platforms enable patients to continue therapy sessions remotely with healthcare professionals. Commercial gaming technology can be also incorporated into rehabilitation exercises, enhancing motivation and engagement. The future holds even more promise with the potential of virtual reality (VR). VR technology holds the potential to personalize treatment plans, enhance motivation, and monitor patients' progress over time [16].

By combining these home-based technologies with in-hospital robotic advancements, healthcare professionals can create a comprehensive rehabilitation ecosystem that supports patients throughout their recovery journey.

3.6 Radiology

AI is already making waves in radiology, and its future potential in interventional radiology (IR) is particularly exciting. This field stands to benefit significantly from the integration of robotics, which can be broadly categorized into navigation and robotic systems. Navigation Systems guide instruments during IR procedures, enhancing accuracy and potentially reducing radiation exposure for both patients and medical staff. Robotic Systems provide active guidance for instruments used in both percutaneous (through the skin) and endovascular (within blood vessels) procedures. CT-guided interventions are a prime example of how robotics is improving IR. For percutaneous procedures like biopsies, ablations, and infiltrations, robotic CT systems can improve accuracy, by leading to more precise instrument placement, and reduce radiation exposure by precise movements, which may minimize the need for repeat imaging, lowering radiation dosage. Maxio (Perfint Healthcare) and iSYS (iSYS Medizintechnik GmbH) are currently the leading robotic CT systems used for image-guided interventions. MRI-guided robotic procedures are also gaining traction, offering diverse clinical applications. However, limited patient access to the MRI scanner remains a challenge. While significant progress has been made, incorporating robotics into routine endovascular procedures is still a hurdle. The future of IR is undoubtedly intertwined with robotics. However, further development is necessary to overcome technical limitations and ensure seamless integration into various IR procedures [17].

4. Current State of Autonomy in Medical Robotics

The increasing role of AI in medical robotics is also leading to a rise in the autonomy of these devices. Surgical robot autonomy has been categorized into six levels (Table 1).

Table 1 Six levels of autonomy in medical robotics, currently used in clinical care: level 0 - no autonomy, level 1 – 3, higher levels of autonomy – level 4 - 5 [20]

Autonomy level	Description
Level 0 (No Autonomy)	The surgeon has complete control, manipulating the robot with no assistance. (Current Standard)
Level 1 (Robotic Assistance)	The surgeon interacts with the robot for guidance or support during tasks, maintaining full control
Level 2 (Task Autonomy)	The robot can perform specific tasks after receiving instructions from the surgeon (e.g., tip retroflexion in magnetic colonoscopy).
Level 3 (Conditional Autonomy)	The surgeon sets parameters for a task, and the system can define specifics autonomously (e.g., advanced suturing in abdominal surgery).
Level 4 (High Autonomy)	The robot interprets pre-operative and intra-operative data to develop an intervention plan, then executes it with surgeon supervision.
Level 5 (Full Autonomy)	The robot performs surgery entirely on its own, without human input.

Currently, surgical robots in clinical use operate at the Level 3 (Conditional Autonomy) stage. However, the future holds promise for higher levels of autonomy, particularly in organ and tumor resections. This has the potential to improve surgical outcomes through minimally invasive procedures [20].

5. Future: The Increasing Role of AI in Medical Robotics

AI plays an increasingly crucial role in medical robotics. By integrating new AI-powered assistance systems, these robots are not only enhancing medical interventions but also progressing toward greater autonomy. The COVID-19 pandemic served as a significant test for AI applications in healthcare. AI proved valuable in managing the crisis by reducing pressure on healthcare workers

and minimizing patient contact. AI-powered tools like chatbots helped manage patient inquiries and basic screening, alleviating some of the workload on overwhelmed staff (Fig. 2). Chatbots and interactive robots like CRUZR helped screen visitors, take temperatures, and interact with them, reducing the risk of infection from close contact [18].

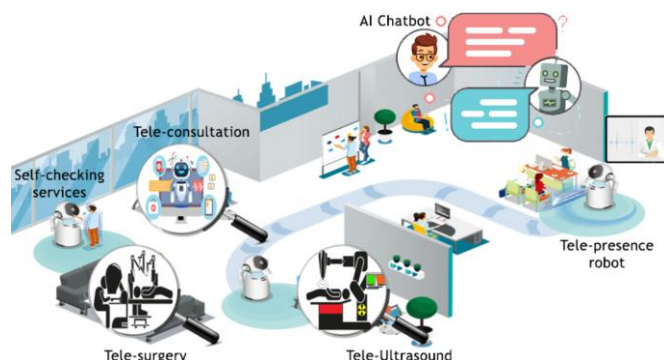


Fig. 2 Different available telehealthcare devices [18]

The future of neurosurgery holds immense promise for AI integration. AI has the potential to revolutionize this field not only by enhancing surgical accuracy but also by optimizing pre-operative care and improving peri-operative care. AI-powered navigation systems and robotic assistants can improve precision during surgery. Complex data analysis powered by AI can help identify patients who are most likely to benefit from surgery, leading to more targeted treatment plans. AI can contribute to more efficient and cost-effective peri-operative care, potentially even paving the way for new treatment strategies. However, significant obstacles remain before widespread adoption. Further validation studies are needed to solidify the efficacy and safety of AI-driven approaches in neurosurgery. Ethical concerns surrounding AI use in medicine, such as bias and transparency, need to be carefully addressed. The high cost of developing and implementing AI technologies presents a practical challenge [18]. Despite these challenges, the potential benefits of AI in neurosurgery are undeniable. Continued research and development are pivotal in overcoming these obstacles and enhancing a new era of AI-powered neurosurgery.

6. Discussion

The field of medical robotics has seen explosive growth over the past few decades, with research papers on the topic increasing exponentially since 1990 [21]. While initially focused on surgery, robotic systems, and even AI are now utilized across various medical specialties. This integration offers significant advantages for patients, surgeons, and the entire healthcare team. Despite the lack of comprehensive clinical trials definitively demonstrating improved surgical outcomes, reduced costs, or better patient results compared to traditional techniques, robotic surgery offers several potential advantages for both patients and surgeons. Patients may experience faster recovery times, fewer re-operations, and reduced blood loss, leading to shorter hospital stays. For surgeons, robotic-assisted surgery can minimize physical and mental strain, reduce back pain, and significantly lower radiation exposure during procedures employing intraoperative imaging. Capsule robots hold immense promise for revolutionizing GI tract diagnosis. These miniaturized robots could significantly reduce the invasiveness of diagnostic procedures, minimizing patient discomfort and potentially eliminating the need for open bowel surgery in some cases. Robotic-powered rehabilitation prostheses and rehabilitation robots significantly enhance post-stroke, spinal cord injury, and neurological disease rehabilitation, leading to improved patient outcomes such as increased mobility, greater independence, and reduced recovery times. The future of interventional radiology and cardiology holds immense promise for robotic assistance systems. These advancements have the potential to revolutionize intervention techniques, dramatically reducing the need for open-

heart and neurosurgical procedures. Soft robotic development can improve the quality of life of cardiac patients in the future. The growing integration of AI with preoperative and intraoperative imaging and sensing technologies is empowering robotic systems to perform tasks with increasing autonomy. This allows surgeons to intervene less frequently, paving the way for a future of more automated robotic surgery.

7. Conclusion

The field of medical robotics has undergone tremendous progress in recent decades. Its applications have expanded far beyond surgery, reaching various medical fields thanks to advancements in medical science. This evolution has resulted in benefits like greater precision and minimally invasive procedures for patients, along with enhanced safety for surgeons. Additionally, the integration of AI with these modern technologies holds immense promise for further refinement of existing procedures in the future.

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Possibilities of joining metals and CFRP/GFRP composites

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Abstract: The paper discusses the possibilities of joining thin-walled metals and composites reinforced with bidirectional carbon/glass fibres. The experimental part of the paper contains metallographic sections and results of load-bearing capacity testing of pilot metal-composite joints with thermoplastic matrix and glass and carbon fiber reinforcement, formed by thermal drilling technology. As a result, a sequential joining method is proposed which can achieve the optimum joint geometry with a hem to keep the joint from opening under tensile stress.

Keywords: METAL – COMPOSITE JOINING, MECHANICAL JOINING, CFRP, GFRP, THERMAL DRILLING

1. Introduction

The need for joining dissimilar materials is a response to the demands of creating ultra-lightweight structures, usually custom-made, where different materials are used in different zones of the product to fully exploit their potential [1-8].

In many applications where the weight and load capacity of the structure is a critical factor, the material design takes into account "specific strength", which is the strength-to-weight ratio of the material, rather than simple mechanical strength. Al, Mg, Ti alloys, as well as epoxy matrix composites reinforced with various types of continuous bidirectional fibres (glass, carbon, aramid) are excellent for use in the design of ultralight materials according to this characteristic. These materials, together with different grades of progressive steels, need to be combined into functional units, which brings new challenges due to the different material nature.

The possibilities of joining metals and composites can be divided into two main categories, Fig. 1.

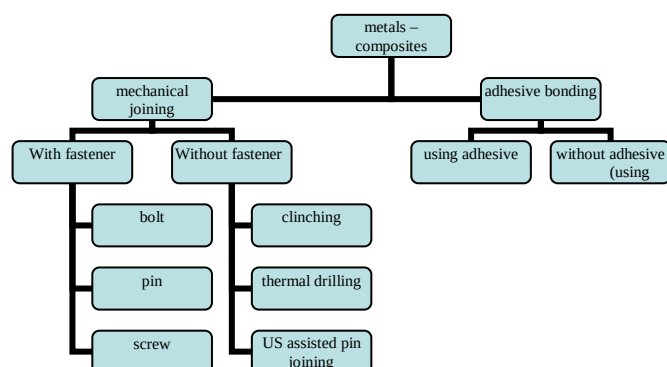


Fig. 1 Metals – composites joining methods overview [8]

Either mechanical fasteners or adhesives, or a combination of both, are used to join composites to metals. Mechanical fasteners may be rivets, pins, bolts, etc. When adhesive bonding of composites and metals, various physical treatments of the surface of the composites are used to improve adhesion, or the metal and composite are bonded together without the use of an adhesive, only through the heated thermoplastic matrix of the composite.

The paper focuses on the verification of the possibility of making joints of aluminium alloy and composites with thermoplastic matrix reinforced with continuous fibres in two directions by thermal drilling technology. The joint is to be made without the use of a screw (bolt), only by means of a metal bushing made of aluminium alloy, without disruption of the fibres in the composite material. The process of thermal drilling and joint formation will be carried out at temperatures above the melting temperature of the thermosoftening matrix of the composite to allow the fibres to deflect from their position and allow penetration of the tool without breaking the integrity of the fibres, Fig. 2. The joints geometry was investigated metallographically, and the load-

bearing capacity was determined by tensile shear testing of single lap joints.

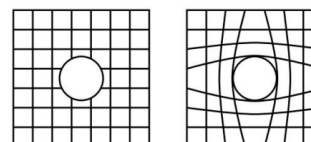


Fig. 2 Making holes by cutting or drilling (left) and by deflecting the fibres without breaking (right) [21]

2. Materials and methods

The following materials were used for the research:

Metal:

- Aluminium alloy EN AW 6082 T6 (AlSi1MgMn), 1 mm thick sheet (hereafter Al).

Composites:

- polypropylene matrix composite reinforced with glass fibre, 1.5 mm thick organosheet (hereafter PP-GF)
- polypropylene matrix composite reinforced with carbon fibre, 1.5 mm thick organosheet (hereinafter PP-CF)

A bench drill machine and a Flowdrill long Ø 5.3 mm tool were used for joining the selected materials. The shape and dimensions of the test joints were determined based on the diameter of the Flowdrill tool according to ISO 12996:2013 and are shown in Fig. 3.

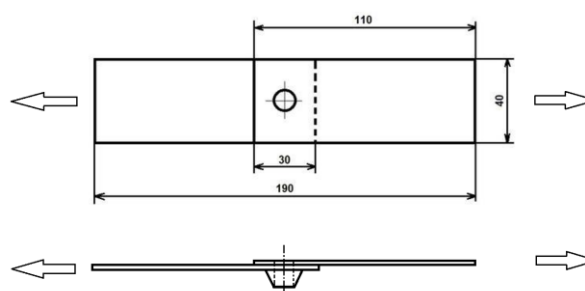


Fig. 3 Shape and dimensions of the test joints

The procedure for making the joints was as follows: heating the fixture and the materials to be joined in the furnace to 170°C, transferring the fixture and materials to the drilling machine (the temperature after removal from the furnace is maintained locally with a heat gun), fixing, drilling of the overlapped materials, with the Al sheet in the upper position of the joint.

After the joints formation, the geometry of the joints was investigated metallographically and the load-bearing capacity of the joints was tested on a universal tensile testing machine at a loading rate of 10 mm.min⁻¹.

2. Results

The metallographic section of the Al - PP GF joint is shown in Fig. 4.

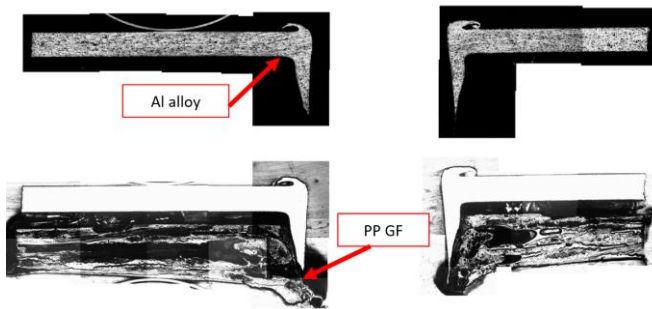


Fig. 4 Metallographic section of the Al - PP GF joint

Fig. 4 shows that the thermal drilling perforated both the metal and the composite, the Al bushing went through the entire thickness of the glass fiber composite. However, the underside of the composite was delaminated when the bushing and tool penetrated, which caused the bushing, although of sufficient length, not to be visible on the underside of the joint. A solution could be to turn the joint over in next step and use the same tool to create a hem on the formed bushing, Fig. 5.

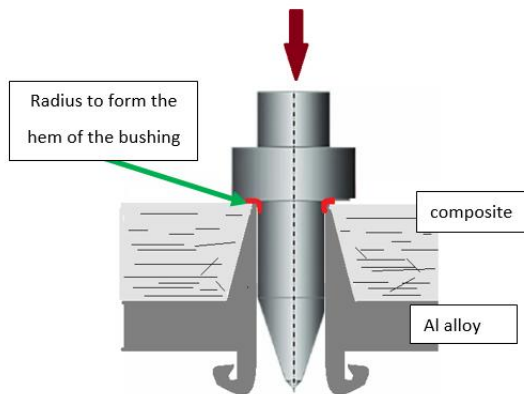


Fig. 5 Method of hemming and closing the joint

The Al - PP GF joint was formed by the above procedure with a hemming and is shown in Fig. 6.

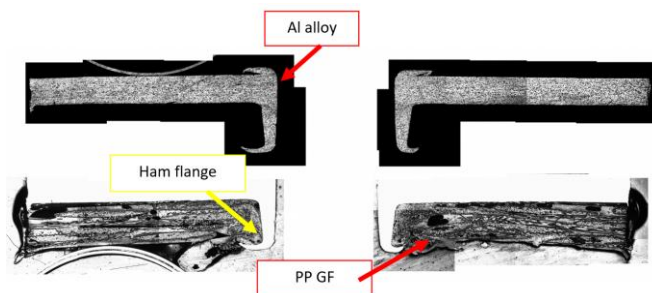


Fig. 6 Metallographic section of the Al - PP GF with hem

On the metallographic section, the hem of the Al bushing is visible, which encloses the composite material. The hemming on the opposite side of the joint has fulfilled its purpose and closed the joint, thus insuring it against opening due to the forces applied during tensile loading.

Fig. 7 shows a metallographic section of an Al - PP CF joint with a hem.

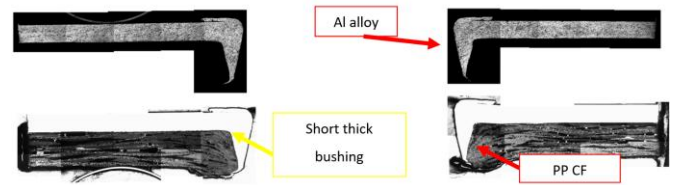


Fig. 7 Metallographic section of the Al - PP CF with hem

The figure shows that the joining of Al with the carbon fibre composite did not produce a long enough bushing. This resulted in the formed hem also not being sufficient, so we decided to try the sequential drilling and joining method.

To create a longer bushing, long enough to form a hem, the sequential joining method was tested, which consists of the following steps:

- creating a hole in the heated composite with a drill tool,
- covering the composite with Al sheet,
- forming the hole and bushing in the Al with a drill tool,
- turning the assembly,
- forming the hem - closing the joint.

The joints formed by the sequential method are shown in Figs. 8 and 9.

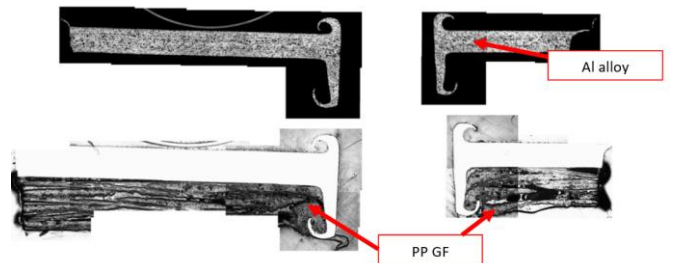


Fig. 8 Metallographic section of the Al - PP GF joint formed by the sequential method

The picture shows a formed bushing of sufficient thickness and length, the end of which, thanks to the reverse hemming, forms a tight bond with the composite and prevents delamination.

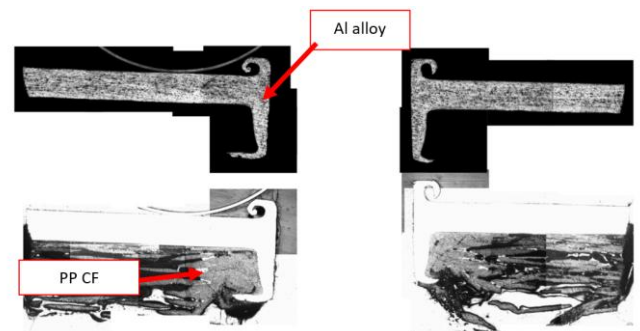


Fig. 9 Metallographic section of the Al - PP CF joint formed by the sequential method

Perfectly formed bushing can be seen again in this metallographic section. The hem is fulfilling its purpose, preventing delamination of the composite and closing the joint.

The results of the joints load-bearing capacity testing are shown in Figs. 10 and 11.

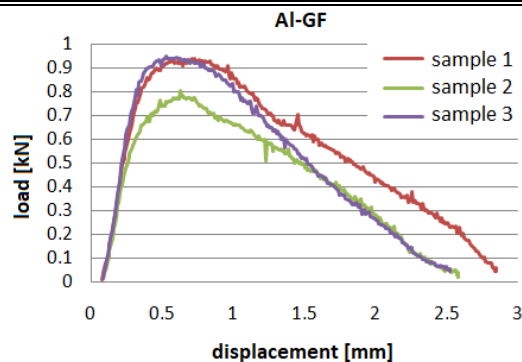


Fig. 10 Load-displacement curves of Al – PP GF joints

The curves show a linear increase in force up to F_{max} , followed by a short stagnation of force around F_{max} , which corresponds to the beginning of the failure of the joint - sliding of the composite out of the hem, and the curve continues with a gradual decrease, which also includes the failure of the adhesive bond of the composite to the metal over the entire surface of the overlap. The appearance of the joint surfaces after failure is shown in Fig. 11.

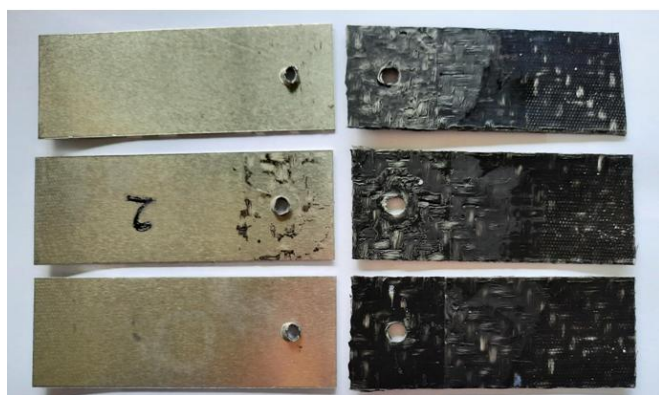


Fig. 11 Appearance of Al - PP GF substrates after load capacity test

The joints failed in the bushing area after static tensile load testing without major damage of the involved materials. The GF composite adhered to the Al alloy at a given temperature ($>T_{tav}$ PP) at the overlapped area and contributed to the load-bearing capacity of the joints.

Fig. 12 shows the loading history of the Al - PP CF joints.

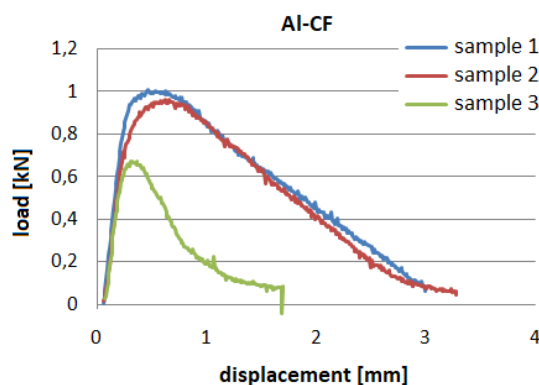


Fig. 12 Load-displacement curves of Al – PP CF joints

Again, the curves show a linear increase in force up to F_{max} . Subsequently, the onset of failure of the joint is visible - sliding of the composite out of the hem. The curve continues with a gradual decrease, which includes the failure of the adhesive bond of the composite to the metal over the entire area of the overlap.

The appearance of the joint areas after failure is shown in Fig. 13.



Fig. 13 Appearance of Al - PP CF substrates after load capacity test

During tensile testing of Al alloy and PP CF joints, the joint failed at the thermal drilling point. Some bushings were deformed and pressed. Carbon fibre damage - fibre pull-out - is also visible on the composite in the middle sample.

Conclusions

Based on the results obtained, the following information was found:

- The formed joints of the aluminium alloy and the two tested composites had approximately the same load-bearing capacity, about 1 kN, which includes not only the mechanical connection by the bushing, but also the adhesive forces between the softened PP matrix and the Al alloy over the entire overlap area, while the contribution of the mechanical and adhesive forces to the total load-bearing capacity of the joint is not easy to estimate.
- No fibre breakage was visible on the glass fibre composite specimen, but for the carbon fibre composite there were broken fibres around the hole. However, the failure occurred during the load capacity testing of the joints, not at the joint formation stage.
- The size and shape of the hem, which fixes the composite plate in the joint, appears to be a significant limiting factor affecting the load capacity of the joint. When the joint is subjected to tensile stress, the hem straightens, the Al alloy bushing deforms in the direction of the stress, in some cases leaving part of the separated hem in the hole of the composite.
- Metallographic sections of the formed joints showed that the sequential joining method has a positive effect on the geometry of the formed bushing and hem and contributes to the load carrying capacity of the joints.

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Behavior of steel, Al and Mg alloys when thermal drilling

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Abstract: The article deals with determinatin the optimum parameters for thermal drilling of selected Al, Mg and steel alloys to be subsequently used for joining with thermoplastic matrix composites reinforced with bidirectional continuous fibers. The optimum thermal drilling parameters will be considered to be those which produce a bushing of sufficient length and thickness to penetrate the composite material to a thickness of 1.5 mm.

Keywords: THERMAL DRILLING, MECHANICAL JOINING, COMPOSITES

1. Introduction

Thermal drilling is a specialized drilling technique that involves the use of heat to create holes in a variety of materials, including metals, plastics and composites, without cutting, just forming the material. Instead of conventional drilling methods, thermal drilling uses friction-generated heat to warm, form and penetrate the workpiece. [1]

The thermal drilling method gives the possibility to produce a smooth cylindrical or conical bushing in materials such as sheet metal, tubes or hollow profiles, to form threads in it and to use a fastener. The quality of the hole is influenced by the power of the machine and its technical condition, the number of revolutions, the axial force and the appropriate choice of tool. [2]

The process usually involves three phases, Fig. 1:

- Phase 1: Friction heating: a specially designed heat drill is brought into contact with the workpiece. As the drill turns, it generates heat through friction at the point of contact.
- Phase 2: Material softening: The heat generated raises the temperature of the workpiece, causing the material to soften locally.
- Phase 3: Hole Formation: As the drill advances into the softened material, it creates a hole by moving the soften material and forming a bushing into which threads can then be formed and a fastener can be placed. [1]

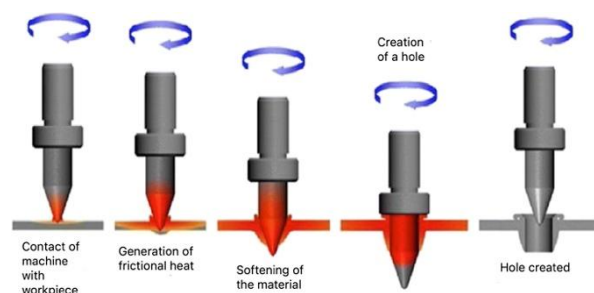


Fig. 1 Thermal drilling procedure [3]

In the production of tailored parts in automotive production, or in the aerospace industry, or in the production of parts for sports equipment, the challenge is to combine materials of different chemical composition, different internal structure, or different thicknesses. In this respect, the joining of metals and composites has a special position, as these are materials of completely different nature and internal structure, which can only be joined in two ways - adhesive bonding and mechanical joining. [4-8]

For fiber and polymer matrix composites, the fibers must absorb the load of the component. This requires high stiffness and strength and the lowest possible density. Experience shows that most

materials exhibit much better mechanical properties in fiber form than in compact form. Glass and carbon, although not really considered conventional structural materials, have found their unique application just in the form of fibers reinforcing polymer matrices.

If the matrix is thermoplastic, this is very advantageous in terms of processing (moulding) the composite into the final component. Thermoplastic matrices require short production cycle times. They can be combined with other thermoplastics and processing methods. A wide range of component designs can be achieved in this way. The resulting properties of the composite are strongly determined by the properties and arrangement of the fibers. [9-10]

The matrix (most commonly PA 6, PA 6.6, PA 12, PP, thermoplastic polyurethane, PPS, PC) performs the following key functions:

- provides force transfer to the fibers
- provides force transfer from fiber to fiber
- protects the fibers from environmental influences
- keeps the fibers in the desired geometric arrangement
- absorbs mechanical loads acting mainly perpendicular to the direction of the fibers and shear loads

The most commonly used reinforcing fibers are glass and carbon continuous fibers oriented in one or two perpendicular directions simply or in the form of a fabric.

The composite has optimum properties only if the applied forces are efficiently transferred from the matrix to the fibers, and from fiber to fiber. This requires a good bond between the fiber and the matrix by a targeted choice of surface treatment tailored to each polymer and applied to the fibers after manufacture, or by the addition of a coupling agent to the thermoplastic.

If these conditions are met, the composite can operate efficiently, with the mechanical properties - toughness, strength and impact resistance - mainly provided by the fibers, while the matrix mainly determines the electrical properties, thermal and chemical resistance, corrosion behaviour and workability of the resulting composite.

Joining metals and composites to a thermoplastic matrix using thermal drilling technology is advantageous for several reasons:

- no chipping - waste-free technology
- heating the composite at the drilling point reduces the viscosity of the matrix and allows the fibers sufficient freedom of movement to deflect out of the future hole location without compromising their integrity, Fig. 2. The fibers can thus continue to perform their reinforcing function.

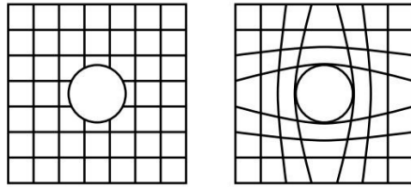


Fig. 2 Disruption of fiber continuity in conventional drilling (left) and fiber deflection in thermal drilling (right)

The aim of this article is to determine the optimum parameters for thermal drilling of selected Al, Mg and steel alloys to be subsequently used for joining with thermoplastic matrix composites reinforced with bidirectional continuous fibers. The optimum thermal drilling parameters will be considered to be those which produce a bushing of sufficient length and thickness to penetrate the composite material to a thickness of 1.5 mm.

2. Used materials

Optimal thermal drilling parameters were determined for 3 basic materials:

- Material No. 1 - aluminium alloy AlSi1MgMn (EN AW 6082 T6), thickness: 1 mm, next designation: Al
- Material No. 2 - magnesium alloy AZ91, thickness: 2 mm, next designation: Mg
- Material No 3 - Uncoated low carbon deep drawing steel DC04, thickness: 0.8 mm, next designation: DC

The chemical composition of the materials is given in Table 1.

Table 1: Chemical composition [%] of Al, Mg and DC materials

Elem.	Si	Fe	Cu	Mn	Mg	Zn	Al	C	P	S	Fe
Al	1.0	0.4	0.06	0.44	0.7	0.08	Bal.				
Mg	0.09	0.004	0.02	0.14	Bal.	0.93	8.9				
DC				0.25				0.04	0.009	0.008	Bal.

The mechanical properties of the individual materials were determined by static tensile testing in the rolling direction.

3. Technique of thermal drilling of materials

Because of the need to heat the composite materials (and the fixture) during drilling, we chose a TOS V 10 A bench drill and a Flowdrill long Ø5.3 mm tool for the experiments, Fig. 3. The tool speed was constant and the feed rate was achieved manually. The tool was lubricated with FDKS 100 grease during drilling. The drilling machine parameters are given in Table 2.

Table 2: Technical parameters of the drill TOS V 10 A

Number of spindles	1
Drilling depth	100 mm
Diameter of drilling spindle	18/20 mm
Base plate clamping surface	250 x 300 mm
Spindle speed	number of stages 10
Range RPM	500 – 6000
Feed	Manual
Total power input of the machine	0,65 kW

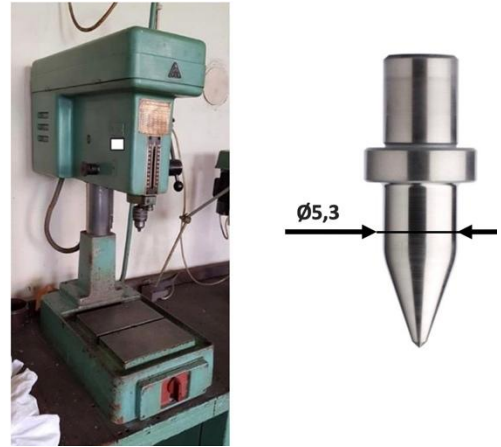


Fig. 3 Bench drill machine TOS V 10 A and tool Flowdrill long Ø5.3 mm

In order to investigate the behaviour of the selected materials during thermal drilling in terms of the shape and size of the resulting bushing, thermal drilling was carried out at two significantly different rotational tool speeds and two significantly different tool feed rates. Ideally, the optimum parameters would have been sought with the help of CNC process control, however, due to the heating of the materials and the need to maintain the temperature at the desired value, it was not possible to carry out the drilling on CNC machines at this stage. The tool speed of a Ø5.3 mm diameter tool can range from 1800-3300 min⁻¹ according to the tool manufacturer's recommendation, with 2400 min⁻¹ being considered the optimum speed when drilling steel. When drilling non-ferrous alloys, the manufacturer recommends using a speed 50% higher than the optimum speed for drilling Fe alloys.

For the experimental drilling of Al, DC and Mg, the tool speeds of 2400 and 4800 min⁻¹ were chosen. The feed rate was manual - slow (approx. 60 mm.min⁻¹) and fast (approx. 240 mm.min⁻¹).

The aim of drilling only metal sheets of Al, DC and Mg alloys is to investigate the effect of the selected tool speed and feed rate on the shape of the resulting bushing. The shape will be assessed metallographically by cutting through the axis of the hole. It is necessary to determine the drilling parameters at which a sufficiently long bushing with sufficient thickness is produced, suitable for subsequent joining with composite materials.

4. Static tensile test of base materials

Fig. 4 shows the stress-strain diagrams of the tested materials and Table 3 shows the mechanical properties of the Al and Mg alloys in the rolling direction found by this test as an average of five measurements.

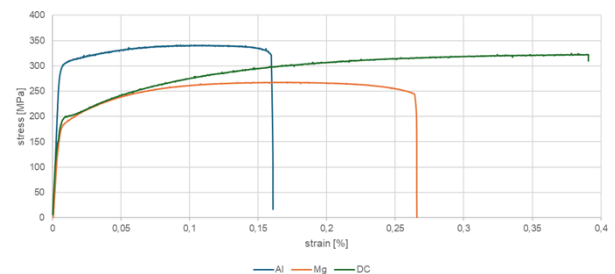


Fig. 4 Tensile diagram of tested materials Al, Mg, DC

Table 3: Mechanical properties of the tested materials in the rolling direction

Material	Rp _{0.2} [MPa]	Rm [MPa]	Ag [%]	At [%]	A80 [%]
Al	290.3	338.5	10.1	16.6	16.5
Mg	197.2	270.6	14.8	24.3	24.1
DC	197.3	322.1	24.0	26.2	26.2

The results of the static tensile test show that the Mg and DC materials have the same yield strength, but with further loading the DC steel strengthen more significantly and also exhibits the highest ductility of all the materials. Precipitation hardened Al alloy has a higher yield strength and tensile strength compared to DC and MG and the lowest ductility of the materials tested, but still sufficient to form the bushing properly.

5. Geometry of hole bushings prepared by thermal drilling

Table 4-5 shows the metallographic sections of holes made in metal sheets by thermal drilling at selected parameters.

Table 4: Metallographic cuts through the axis of holes created at 2400 min^{-1}

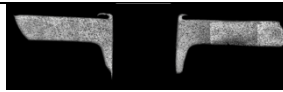
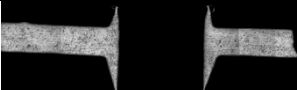
	RPM [min^{-1}] / feed rate [$\text{mm} \cdot \text{min}^{-1}$]	
	2400/60	2400/240
Al		
Mg		
DC		

Table 5: Metallographic cuts through the axis of holes formed at 4800 min^{-1}

	RPM [min^{-1}] / feed rate [$\text{mm} \cdot \text{min}^{-1}$]	
	4800/60	4800/240
Al		
Mg		
DC		

From the metallographic sections, the lengths and thicknesses of the individual bushings were measured; the results are shown in Table 6.

From the above results, it can be concluded that the shape of the resulting bushings varies for different materials as well as within a single material at different thermal drilling parameters. For the purpose of future bonding, it is advisable that the resulting bushing should be as long as possible (to penetrate through the composite in its entire thickness) at a sufficient thickness. The thermal drilling parameters and the thickness of the base material will influence the proportion of material that is displaced from the plane of the sheet into the bushing area and against the direction of tool movement - into the rim.

6. Calculation of the proportion of material displaced into the bushing area

In thermal drilling, the material originally placed in the plane of the sheet metal, at the location of the future hole, is displaced to form the rim and bushing. The volume of the material forming the bushing can be calculated using the relationship for the volume of the rotating elementary region M around the y-axis:

$$V = 2\pi \int_a^b x[f(x) - g(x)]$$

The equations of the functions $f(x)$ and $g(x)$ are determined by measuring metallographic sections and simplified by approximation. The curves of $f(x)$ and $g(x)$ were described using constant and linear functions, Fig. 5. In case the described region was not elementary, it was divided into several elementary regions, Fig. 6.

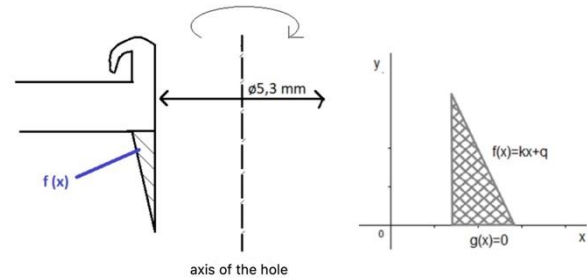


Fig. 5 Elementary region determined by the approximation of the shape of the bushing

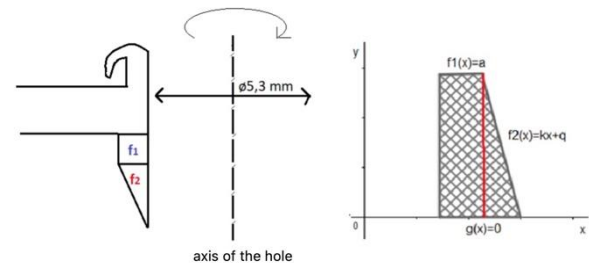


Fig. 6 Non-elementary region determined by the approximation of the shape of the bushing

Table 6 shows the % of material that contributed to the bushing formation for the applied tool speed and feed rate.

Table 6: Length and thickness of bushing formed and proportion of material displaced into the bushing area for the thermal drilling parameters tested

Material	RPM [min^{-1}] and feed rate [$\text{mm} \cdot \text{min}^{-1}$]	Bushing length [mm]	Bushing thickness [mm]	Percentage of material displaced to the bushing area [%]
Al	2400 / 60	1.0	0.3	47.83
	2400 / 240	2.5	0.63	97.83
	4800 / 60	3.2	0.61	69.90
	4800 / 240	2.46	0.54	81.76
Mg	2400 / 60	2.96	0.96	53.53
	2400 / 240	2.8	0.96	68.65
	4800 / 60	3.2	0.8	70.34
	4800 / 240	2.8	1.0	70.32
DC	2400 / 60	2.86	0.5	93.12
	2400 / 240	2.56	0.56	74.09
	4800 / 60	2.86	0.43	70.49
	4800 / 240	2.7	0.43	71.05

From Table 6, taking into account the proportion of material forming the bushing and at the same time taking into account the thickness and length of the formed bushing, it is possible to recommend a speed of 4800 min^{-1} and a slow manual feed rate, at which the proportion of material forming the casing is about 70%

and at the same time the highest bushing length is achieved at a relatively sufficient thickness.

The metallography of the resulting joints of metals with the PP-GF composite material is shown in Fig. 7.

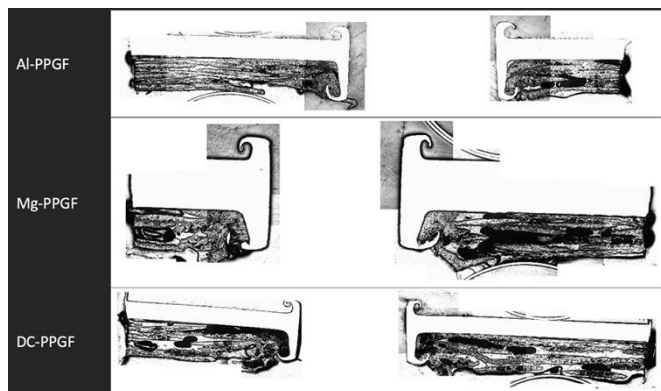


Fig. 7 Metallography of the resulting joints of metals with PP-GF composite material

7. Conclusions

The above study brought a new perspective on the use of thermal drilling for joining thin-walled lightweight metal-based materials with composites. By studying the shape of the formed holes in metallic materials by thermal drilling, the recommended parameters for joining with a composite with a thermoplastic polypropylene matrix and bidirectional glass fiber reinforcement were determined. For joining without CNC support, a speed of 4800 min⁻¹ and a slow manual feed rate are recommended. At these parameters, joints with sufficient bushing length were formed which, after hemming, formed a closed joint with the composite without delamination.

8. Acknowledgement

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The impact of particle size on mechanical-acoustic properties of cenosphere powders

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Abstract: Cenospheres are used in a variety of applications, including as fillers in building, construction, plastic, and composite materials. The aim of this paper is to evaluate the effect of particle size on the mechanical-acoustic properties of cenosphere powders, which were produced in two different sizes. The mechanical-acoustic properties of the studied powders were experimentally determined based on the frequency dependencies of the sound absorption coefficient, using the transfer function method. It can be concluded that not only particle size, but also powder bed height and the excitation frequency of acoustic waves, significantly influenced the mechanical-acoustic properties of the studied cenospheres.

Keywords: CENOSPHERES, PARTICLE SIZE, TRANSFER FUNCTION METHOD, SOUND ABSORPTION COEFFICIENT, LONGITUDINAL ELASTIC COEFFICIENT, EXCITATION FREQUENCY, POWDER BED HEIGHT, BULK DENSITY

1. Introduction

The term "cenosphere" is derived from two Greek words: "kenos" (meaning hollow) and "sphaira" (meaning sphere) [1]. The concentration of cenospheres in fly ash varies widely, ranging from 0.01 to 4.80 wt.%, but it typically falls between 0.3 and 1.5 wt.% [2]. The thickness of the cenospheres' shells is about 3–11% of their diameter [3]. Cenospheres are one of the major types of waste generated by coal power plants, along with fly ash. These lightweight, inert, and hollow spheres are primarily composed of silica and alumina and are filled with air or gases [4]. Cenospheres are utilized in a variety of applications, including as fillers in building and construction materials, plastics, biomedical products, ceramics, rubber, aeronautics, and composites [3, 5, 6]. The incorporation of cenospheres into composite materials can result in reductions in weight, thermal conductivity, cost, and environmental footprint. Moreover, the incorporation of cenospheres can enhance mechanical, sound insulation, and electrical properties [3]. The key parameters affecting the properties of cenosphere-based materials are particle size, shell thickness, volume concentration, and the presence of impurities [5].

The purpose of this paper is to evaluate the influence of particle size on the mechanical and acoustic properties of cenospheres. These properties were determined using the transfer function method with an acoustic impedance tube.

2. Materials and Methods

In this study, cenosphere powders were obtained from Ekibastuz GRES-2 Power Station (Kazakhstan). They were tested across two different particle size ranges to investigate their mechanical-acoustic properties. Table 1 lists the designations, particle size diameters, and bulk densities of these powders.

Table 1: Designations and parameters of the investigated cenosphere powders.

	Sample designation	
	C_40_80	C_80_125
Particle size diameter [μm]	40 ÷ 80	80 ÷ 125
Bulk density [g/cm ³]	1.0224 ± 0.0002	0.6118 ± 0.0001

The sound insulation properties of the investigated cenosphere powder beds are characterized by the sound absorption coefficient α (–), which is defined by the following ratio [7]:

$$\alpha = \frac{P_d}{P_i} \quad (1)$$

where P_d (W) is the dissipated acoustic power, and P_i (W) is the incident acoustic power. The frequency dependencies of the sound

absorption coefficient were determined using transfer function method according to ISO 10534-2 standard. Using this method, the sound absorption coefficient is defined by the equation [8]:

$$\alpha = 1 - |r|^2 \quad (2)$$

where r (–) is the normal incidence reflection factor.

The material's ability to absorb sound depends on various factors, including the type of material, its thickness, structure, and the excitation frequency. The effect of the excitation frequency on the sound absorption is quantified by the noise reduction coefficient NRC (–), which is defined as the arithmetic average of the sound absorption coefficients at the excitation frequencies of 250, 500, 1000, and 2000 Hz [9, 10]:

$$NRC = \frac{\alpha_{250} + \alpha_{500} + \alpha_{1000} + \alpha_{2000}}{4} \quad (3)$$

Moreover, to compare the sound absorption properties of the investigated powder samples, the arithmetic means of the sound absorption coefficient (α_m) over the measured frequency range (i.e., from 250 to 6400 Hz) were determined.

Based on the sound absorption measurements of the investigated powders, it is possible to determine the longitudinal elastic coefficient K (Pa), which is analogous to Young's modulus of elasticity for solids. This coefficient characterizes the mechanical stiffness of the powders and is expressed by the formula [11, 12]:

$$K = c^2 \cdot \rho_b = (4 \cdot h \cdot f_{p1})^2 \cdot \rho_b \quad (4)$$

where c (m·s^{–1}) is the speed of sound of elastic waves through the powder bed, ρ_b (kg·m^{–3}) is the bulk density of the powder bed, h (m) is the powder bed height, and f_{p1} (Hz) is the primary sound absorption peak frequency.

The frequency dependencies of the normal incidence sound absorption coefficient were experimentally measured using a two-microphone impedance tube (BK 4206) in combination with three-channel signal PULSE multi-analyser (BK 3560-B-030) and power amplifier (BK 2706) in the frequency range of 250–6400 Hz (Brüel & Kjær, Denmark). The schematic diagram of the experimental setup for measuring the sound absorption coefficient is depicted in Figure 1a. The view of this experimental setup is shown in Figure 1b.

The normal incidence sound absorption coefficient of the tested cenosphere loose powder samples of defined layer thickness (ranging from 5 to 25 mm) was determined. All experiments were performed under ambient laboratory conditions of 40% relative humidity and at 23 °C.

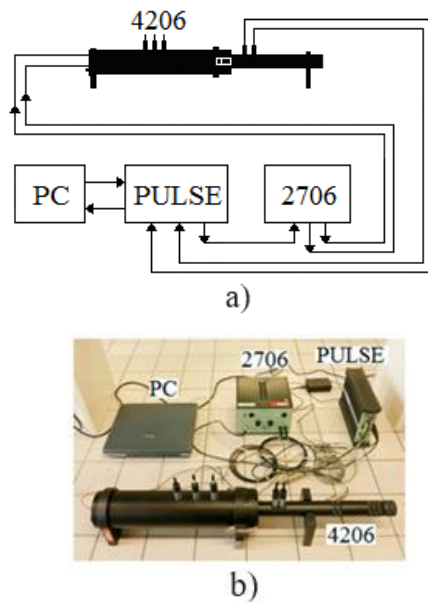


Fig. 1 Circuit diagram (a) and view (b) of the experimental equipment for measuring frequency dependencies of the normal incidence sound absorption coefficient.

3. Results and Discussion

Figures 2 and 3 show examples of the experimentally measured frequency dependencies of the sound absorption coefficient α for the investigated cenosphere loose powders of selected bed heights. It is evident from Figures 2 and 3 that the sound absorption properties of the tested loose powders generally increase with increasing excitation frequency. Furthermore, the increasing powder bed height leads to a higher ability to damp sound at lower excitation frequencies.

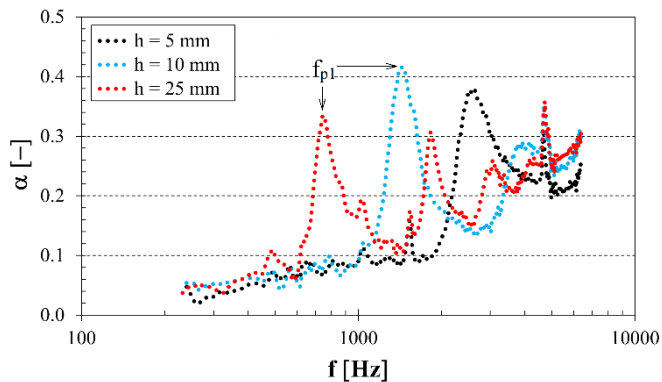


Fig. 2 Frequency dependencies of the sound absorption coefficient across various bed heights (h) of the C_40_80 powder sample.

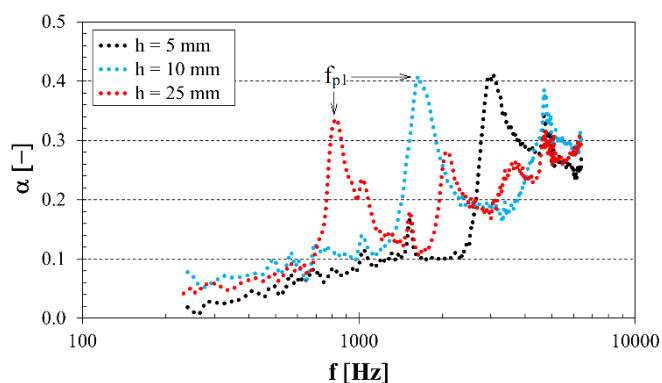


Fig. 3 Frequency dependencies of the sound absorption coefficient across various bed heights (h) of the C_80_125 powder sample.

The particle size effect on the sound absorption properties of the studied cenospheres for two different powder bed heights (i.e., 7.5 and 20 mm) is demonstrated in Figure 4. It is evident that the effect of the particle size on sound damping is significant mainly for smaller powder bed heights. In the case of higher powder bed heights, the influence of the particle size on the frequency dependencies of the sound absorption coefficient is negligible, as shown in Figure 4.

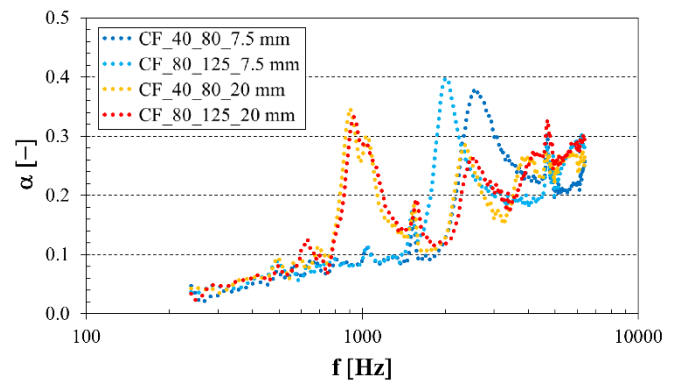


Fig. 4 Frequency dependencies of the sound absorption coefficient across various bed heights (h) of the studied cenosphere powders.

As stated above, the ability of the studied powders to absorb sound can be compared based on the arithmetic mean of the sound absorption coefficient (α_m) over the measured frequency range (i.e., from 250 to 6400 Hz) and the noise reduction coefficient (NRC), which was calculated from the experimentally measured frequency dependencies of the sound absorption coefficient according to equation (3). Their values, depending on the powder bed height and particle size diameter, are given in Tables 2 and 3.

Table 2: Arithmetic mean of the sound absorption coefficient α_m (–) of the investigated cenosphere powders for different powder bed heights h (mm).

h [mm]	Sample designation	
	C_40_80	C_80_125
5	0.2033	0.2175
7.5	0.2064	0.2063
10	0.2178	0.2326
12.5	0.2170	0.2092
15	0.2122	0.2231
20	0.2094	0.2185
25	0.2192	0.2196

Table 3: Noise reduction coefficient NRC (–) of the investigated cenosphere powders for different powder bed heights h (mm).

h [mm]	Sample designation	
	C_40_80	C_80_125
5	0.0838	0.0633
7.5	0.1383	0.1607
10	0.0879	0.1300
12.5	0.1026	0.1026
15	0.1215	0.1267
20	0.1411	0.1351
25	0.1361	0.1579

Tables 2 and 3 demonstrate that the sound absorption properties of the tested loose powders are relatively low (i.e., $\alpha_{mmax} = 0.2326$ and $NRC_{max} = 0.1607$). It is also evident that the influence of particle size diameter and powder bed height on sound absorption is negligible.

Based on the experimentally measured frequency dependencies of the sound absorption coefficient, it was possible to evaluate the speed of sound (c) and longitudinal elastic coefficient (K) of the investigated cenosphere powders according to equation (4). For this reason, it was necessary to determine the primary sound absorption peak frequencies (f_{p1}) at the maximum values of the sound absorption coefficient (α_{max}), as shown in Figure 2. The values of the primary sound absorption peak frequency for various powder bed heights and two particle size diameters are given in Table 4.

Table 4: Primary sound absorption peak frequency f_{p1} (Hz) of the investigated cenosphere powders for different powder bed heights h (mm).

h [mm]	Sample designation	
	C_40_80	C_80_125
5	2520	3080
7.5	1616	2008
10	1400	1608
12.5	1376	1392
15	1168	1176
20	872	904
25	736	816

It is visible from Table 4 that higher values of the primary sound absorption peak frequency were found for powders containing larger particle size diameters, independently of the powder bed height. Additionally, it is evident that the primary sound absorption peak frequency generally decreased with increasing powder bed height.

Based on the values of the primary sound absorption peak frequency (f_{p1}) and the bulk density (ρ_b), the speed of sound (c) of elastic waves through the investigated loose powder beds was firstly calculated according to equation (4). Graphical dependencies of the speed of sound vs. powder bed height are shown in Figure 5. It is evident that the speed of sound is significantly influenced by both the powder bed height and the particle size diameter. It was found that the speed of sound generally increases with increasing powder bed height. Moreover, higher speeds of sound through the loose powders were found for the cenosphere powders consisting of larger particle size diameters (i.e., from 80 to 125 μm).

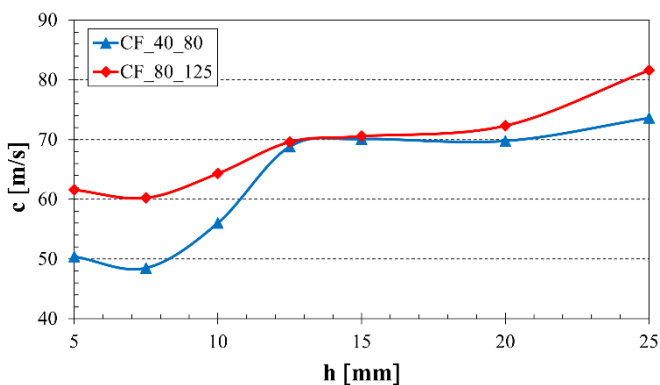


Fig. 5 Dependencies of the speed of sound (c) vs. powder bed heights (h) of the studied cenosphere powders.

Finally, the mechanical properties of the investigated loose cenosphere powders were evaluated by means of the longitudinal elastic coefficient (K), which was also calculated according to equation (4). It is visible, as in the case of the speed of sound, the longitudinal elastic coefficient generally increases with increasing powder bed height. On the contrary, higher mechanical stiffness (or higher longitudinal elastic coefficient) was found for the powder samples consisting of smaller particle size diameters (i.e., from 40 to 80 μm) independently of the powder bed height. This phenomenon results from the fact that smaller particle sizes more

effectively fill the gaps between individual particles, thereby enhancing the overall mechanical stability of the powder layer and consequently its mechanical stiffness. Therefore, a decrease in particle size diameter generally leads to an increase in the longitudinal elastic modulus [13]. Furthermore, cenosphere powders containing larger particles exhibited a lower powder bulk density (approximately 40%) compared to powders containing smaller particle diameters, as shown in Table 1. This lower bulk density was also accompanied by lower mechanical stiffness of the cenosphere powders containing larger particle sizes (i.e., from 80 to 125 μm).

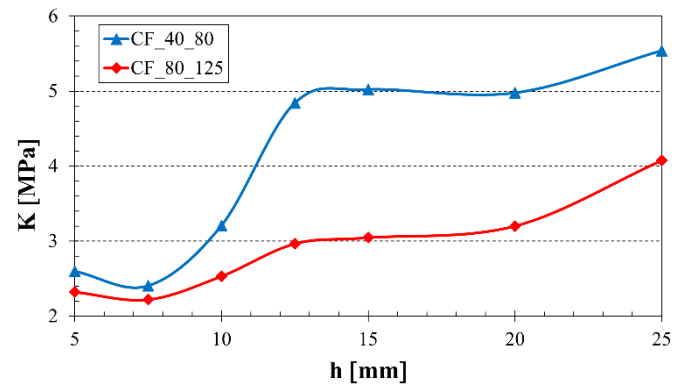


Fig. 6 Dependencies of the longitudinal elastic coefficient (K) vs. powder bed heights (h) of the studied cenosphere powders.

4. Conclusions

The aim of this paper was to investigate the sound absorption and mechanical properties of cenosphere loose powders with two different particle size ranges. These properties were experimentally obtained from the frequency dependencies of the normal incidence sound absorption coefficient in the frequency range from 250 to 6400 Hz using an acoustic impedance tube.

It can be concluded that the sound absorption ability of the tested cenosphere powders was relatively low, with the maximum value of the arithmetic mean of the sound absorption coefficient being less than 0.24. Therefore, the investigated loose cenosphere powders are more suitable for sound reflection. It was also found that the influence of particle size diameter and powder bed height on sound absorption properties is negligible.

The mechanical stiffness of the studied powders was determined based on the primary sound absorption peak frequency and the powder's bulk density. It can be stated that the mechanical stiffness of the powders was significantly influenced by their particle size diameter and bed height. It was found that the longitudinal elastic coefficient generally increased with a decrease in particle size diameter and an increase in powder bed height.

Cenospheres can be applied in a variety of applications, including as fillers in building, construction, and composite materials. Their incorporation in these materials can improve properties such as mechanical stiffness and sound absorption. Therefore, it is necessary to consider their particle size diameter, as it can significantly influence the properties of different cenosphere-based materials.

5. Acknowledgements

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ИССЛЕДОВАНИЕ ТЕМПЕРАТУРНОГО ПОЛЯ В ОБЪЕМЕ МЕДНОЙ ЗАГОТОВКИ ПРИ РАДИАЛЬНО-СДВИГОВОЙ ПРОКАТКЕ

INVESTIGATION OF THE TEMPERATURE FIELD IN THE VOLUME OF A COPPER BILLET DURING RADIAL-SHEAR ROLLING

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Abstract: Radial-shear rolling is one of the most promising methods of metal forming, allowing to develop a level of strain in the rolled bar sufficient to obtain an ultrafine-grained structure. At the same time, it has already been theoretically and experimentally confirmed that after metal processing by this method, a gradient distribution of grain size is observed in the cross section of the rod, which is a consequence of the laminar-turbulent flow of metal in the deformation zone. This work is devoted to the study of the temperature field during radial-shear rolling of M1 technical copper at an initial workpiece temperature of 20°C. To study the temperature distribution over the bar cross section, finite element modeling of radial-shear rolling of M1 technical copper was performed in the Deform program. A rod with a diameter of 30 mm and a length of 150 mm was set as the initial workpiece. It was decided to conduct three passes of radial-shear rolling with compression of 3 mm per pass. In addition to studying the temperature fields on the workpiece, the temperature distribution on the rolls was also considered. Analysis of the simulation results showed that the temperature distribution over the cross-section of the rod has a gradient character.

Keywords: RADIAL-SHEAR ROLLING, GRADIENT DISTRIBUTION, SIMULATION, TEMPERATURE, ROD.

Введение

Научные работы по получению высококачественного металла при различных методах интенсивной пластической деформации (ИПД) являются одними из наиболее цитируемых публикаций в мире [1-3]. Реализация ИПД за счет интенсификации сдвиговых и знакопеременных деформаций позволяет добиться измельчения исходной структуры до ультрамелкозернистого состояния и получения уникальных механических характеристик, которые иногда являются парадоксальными [4-5]. При этом наиболее известные способы ИПД - кручение под высоким давлением (КВД) и равноканальное угловое прессование (РКУП) – позволяют деформировать образцы ограниченных геометрических размеров, что существенно снижает возможность применения данных способов в промышленных масштабах.

Для возможности деформирования длинномерных образцов были разработаны ряд совмещенных процессов на основе равноканального углового прессования, которые также обеспечивают непрерывность процесса [6-7]. Однако для их реализации необходима модернизация существующего прокатного или волочильного оборудования. С этой точки зрения наиболее перспективным способом ИПД для деформирования длинных заготовок является радиально-сдвиговая прокатка, изучению которой посвящено немало работ, в том числе за последние годы [8-10]. Основное содержание данных исследований – это влияние данного способа на структуру и свойства обрабатываемого материала и изучение напряженно-деформированного состояния. При этом крайне малое внимание уделяется такому фактору, как распределение температурных полей в заготовке при различных геометрических и технологических параметрах процесса. Исследованию этой проблемы посвящена данная работа.

Материалы и методы

Изучение распределения температурных полей в заготовке при радиально-сдвиговой прокатке было проведено с использованием МКЭ моделирования в программе Deform. В качестве геометрии валков были использованы параметры стана СВП-08, установленного в Рудненском индустриальном университете. Медный сплав М1 был выбран как материал заготовки при температуре 20°C. Для изучения влияния геометрических и технологических параметров процесса целесообразно проводить варьирование их значениями. Моделировались следующие условия:

1) Диаметр заготовки 30 мм, скорость вращения валков 100 об/мин, обжатие 1 мм;

2) Диаметр заготовки 30 мм, скорость вращения валков 100 об/мин, обжатие 1,5 мм;

3) Диаметр заготовки 30 мм, скорость вращения валков 50 об/мин, обжатие 1,5 мм;

4) Диаметр заготовки 20 мм, скорость вращения валков 100 об/мин, обжатие 1,5 мм.

Длина заготовки во всех моделях была равна 100 мм, коэффициент трения на контакте заготовки и валков был равен 0,5. Коэффициент теплообмена заготовки с инструментом составлял 5000 Вт/(м²•°C); коэффициент теплообмена заготовки с окружающей средой составлял 0,002 Вт/(м²•°C).

Результаты и обсуждение

Для анализа распределения температуры в заготовке было сделано поперечное сечение на расстоянии 50 мм от переднего конца. Измерение температуры проводилось в момент деформирования данного сечения в очаге деформации прокатных валков. При этом использовался инструмент «отслеживание точек», измеряющий температуру от центра заготовки до зоны контакта металла с валком.

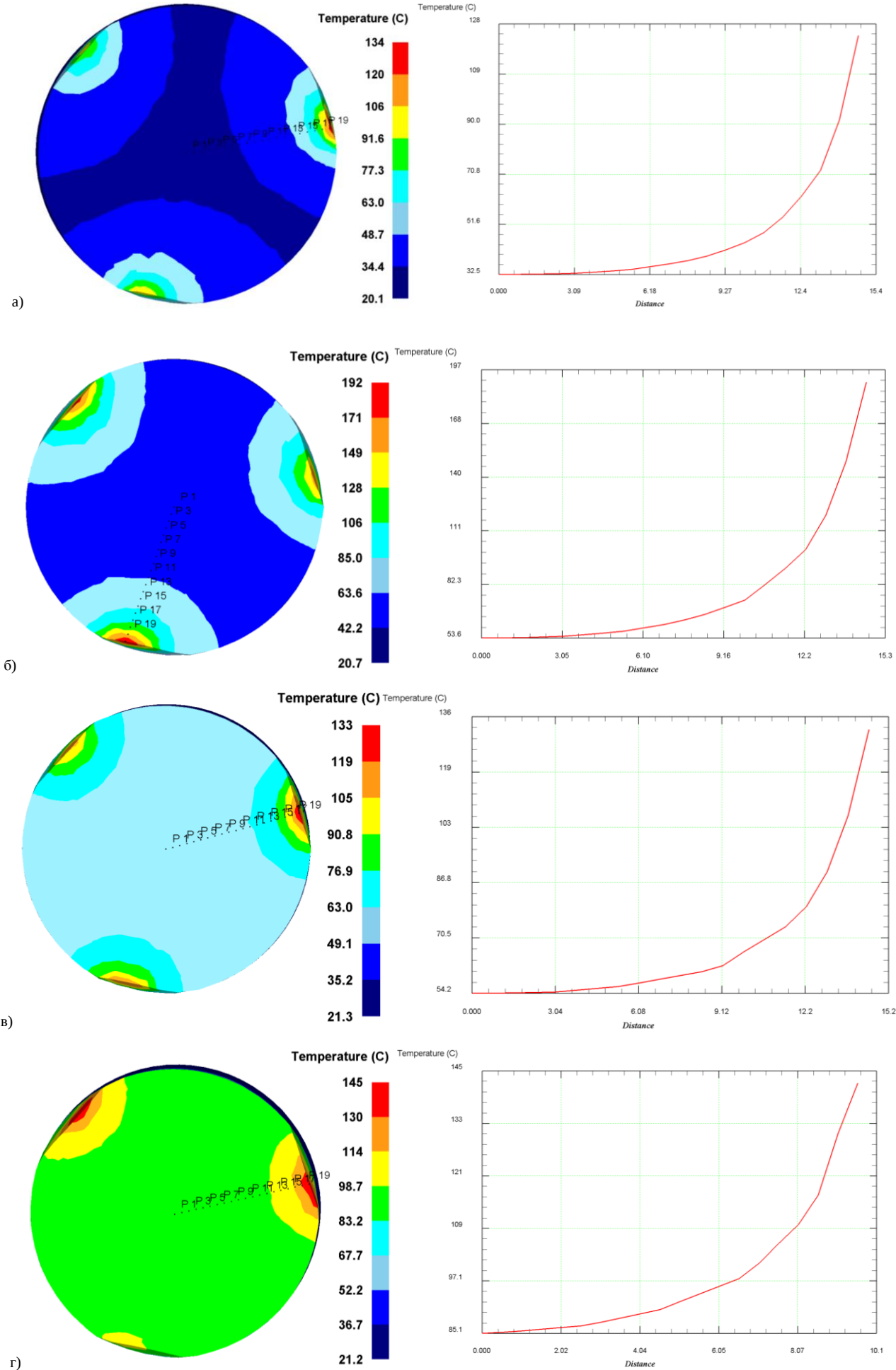


Рис. 1. Распределение температуры в сечении заготовки: а – модель 1; б – модель 2; в – модель 3; г – модель 4

При рассмотрении полученной модели 1 с диаметром заготовки 30 мм, скоростью вращения валков 100 об/мин и обжатием (по диаметру) 1 мм было отмечено крайне неравномерное распределение температуры по всему сечению заготовки (Рисунок 1а). Центр прокатываемой заготовки разогревается до 32°C, тогда как поверхностная зона заготовки разогревается до 124°C, т.е. перепад температур при данных условиях составляет 92°C. Для сравнительного анализа данная модель была принята как базовая.

В полученной модели 2 при увеличении обжатия в валках до 1,5 мм (Рисунок 1б) зафиксирован общий рост температуры во всем сечении заготовки. Центральная зона прутка разогревается до 54°C, тогда как поверхностная зона разогревается до 191°C, т.е. перепад температур при данных условиях составляет 137°C. Общее повышение температуры по всему сечению заготовки является прямым следствием увеличения абсолютного обжатия. Однако рост разницы температуры между центром и поверхностью обусловлен изменением кинематических параметров на контакте заготовки и инструмента. Ввиду того, что валки имеют грибовидную форму, при увеличении обжатия длина очага деформации также увеличивается, при этом металл получает более высокую линейную скорость.

Все последующие модели имели увеличенное значение обжатия в валках 1,5 мм. При снижении скорости вращения валков до 50 об/мин (модель 3 – Рисунок 1в) было отмечено значительное снижение разницы температуры между центром и поверхностью. При почти идентичном разогреве центральной области заготовки до 55°C, поверхность заготовки в области контакта с валками разогрелась до 133°C, т.е. перепад температур при данных условиях составляет 78°C. Таким образом, можно сказать о том, что изменение обжатия влияет на изменение температуры по всему сечению заготовки, а изменение скорости вращения валков влияет на изменение температуры преимущественно в поверхностных слоях. Также данные различия могут являться результатом того, что при изменении обжатия происходит изменение конфигурации очага деформации в валках.

Для проверки данного утверждения была рассмотрена модель 4, где для изменения параметра очага деформации была использована заготовка меньшего диаметра 20 мм (Рисунок 1г). В данной модели центр заготовки разогревается до 85°C, тогда как поверхностная зона разогревается до 143°C, т.е. перепад температур при данных условиях составляет 58°C. Более равномерное распределение температуры при повышенных обжатиях и скорости вращения валков стана радиально-сдвиговой прокатки стало возможным благодаря тому, что из-за снижения начального диаметра валков расположение очага деформации на данном стане смещается в более пологую область валков, где кинематические условия более однородные. Именно этот фактор позволяет получать достаточно ровную поверхность заготовки без винтовых ребер даже при высоких обжатиях.

Заключение

Проведенное исследование распределения температуры в заготовке при радиально-сдвиговой прокатке показало, что общий уровень температуры и характер ее распределения по сечению зависят как от геометрических параметров процесса, так и от технологических параметров. При этом было отмечено, что изменение параметров, влияющих на изменение конфигурации очага деформации, приводит к изменению градиента распределения температуры между центром и поверхностью. Информация о данных закономерностях позволит контролировать изменение температуры в требуемых условиях.

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РАЗРАБОТКА КОНСТРУКЦИИ ПЕРЕГРУЗОЧНОГО УЗЛА ДЛЯ УКЛАДКИ ГОРНОЙ ПОРОДЫ ВО ВНЕШНИЕ ОТВАЛЫ НА ОТКРЫТЫХ ГОРНЫХ РАБОТАХ

DEVELOPMENT OF THE DESIGN OF A RELOADING UNIT FOR LAYING ROCK IN EXTERNAL DUMPS IN OPEN-PIT MINING

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Abstract: The developed new energy-saving container technology for lifting rock mass on quarry dumps by mobile complexes reduces lifting costs, reduces atmospheric pollution and improves mining operations. Container delivery of rock mass allows performing a single excavation of the container and lifting it with lifting machines with a minimum tare coefficient. All the equipment of the transshipment point is placed on self-propelled trolleys, which will make it possible to quickly move to a new location. The equipment of the transshipment unit includes a screen and a jaw crusher, where the rock is prepared for loading into containers. They are placed on a conveyor belt and, after loading, are picked up by a lifting machine and transported to the unloading site. Unloading of the rock mass occurs automatically due to the hydraulic system of the container. The developed equipment is characterized by simplicity of design, which allows it to be manufactured at the mining enterprise itself.

Keywords: LIFTING MACHINE, PRODUCTIVITY, DUMP, RELOADING UNIT, EFFICIENCY, CONTAINER, GRIPPER, CONVEYOR.

Введение

При разработке рудной залежи с помощью карьера, приходится вынимать большое количество вскрыши, объём которой во много раз превосходит объём вынимаемой руды. Добытая из карьера горная масса складывается во внешние отвалы, которые занимают большие площади и сильно ухудшают экологию региона. Технологии отвалообразования в настоящий момент не уделяется большого внимания, и они отстают по производительности и себестоимости от технологий в карьере [1].

В настоящее время известны несколько технологий отвалообразования, зависящие от средств транспортирования горной массы и физико-механических свойств горных пород.

Отвалообразование хорошо дробленых скальных пород при доставке их на отвалы железнодорожным транспортом может производиться отвальными плугами. Отвальный плуг представляет собой самоходный или прицепной вагон специальной конструкции, оборудованный с одной или с двух сторон отвальными лемехами. Технология отвалообразования заключается в перемещении во время своего движения по путям разгруженной из думпкаров породы отвальными лемехами в сторону откоса отвала. При этом отвалообразование осуществляется по всей длине отвального тупика. Укладка крепких горных пород в отвалы при доставке автомобильным транспортом производится мощными бульдозерами. Автосамосвалы разгружаются на некотором расстоянии от бровки по периферии отвала. Бульдозеры перемещают ее под откос, оставляя на бровке предохранительный вал [2].

При разработке месторождений с крепкими горными породами и перевозке железнодорожным транспортом применяется отвалообразование механическими лопатами. Технология отвалообразования заключается в экскавации разгружаемой из думпкаров породы и укладке ее в отвал одноковшовым экскаватором. Экскаватор располагается ниже уровня железнодорожных путей на высоту разгрузки экскаватора. Порода из думпкаров разгружается в приямок, сооружаемый самим экскаватором. После разгрузки породы экскаватор производит укладку ее сначала в нижний подступ, а затем в верхний. Для хорошо раздробленных пород и при применении в карьере конвейерного транспорта возможна организация отвалообразования с помощью транспортно-отвальных мостов [3].

Для всех известных технологий отвалообразования необходимо организовать движение транспортных средств по поверхности отвала, поэтому необходимо создать хорошие

дороги, так как отсыпанная порода имеет низкую устойчивость и за автомобильными и железнодорожными дорогами надо осуществлять постоянный контроль. Работа горнотранспортного оборудования на отвалах при существующих технологиях вызывает ряд проблем, главной из которых является движение техники возле призмы возможного обрушения породы. Необходимо разрабатывать специальные мероприятия, способствующие предотвратить обрушение горных пород [4].

Технология укладки пустой породы во внешний отвал тесно связана со способом ее транспортирования. автомобильный, железнодорожный, конвейерный транспорт обусловили создание и развитие бульдозерного, экскаваторного и конвейерного способов отвалообразования. Основной операцией в этих способах является подъем породы автосамосвалами, поездами или конвейером на верхнюю площадку отвального яруса и разгрузка непосредственно под откос или в приямок отвального экскаватора, который укладывает породу в отвал. Поэтому эффективность отвалообразования определяется в основном затратами на подъем породы. С этой точки зрения автомобильный и железнодорожный транспорт не оптимальны в качестве подъемных средств из-за высокого коэффициента тары (до 0,8-0,9). Это магистральные виды транспорта. Иными словами, автосамосвал массой 80 т и полезной грузоподъемностью 85-87 т поднимает за каждый рейс 62-63 т балласта по сравнению со скиповым подъемником с коэффициентом тары скипа 0,2 [5]. Серьезным недостатком использования колесных видов транспорта на отвалах является трудность эксплуатации автодорог и железнодорожных путей в связи с низкой несущей способностью поверхности отвала.

Прием породы на железнодорожных отвалах выполняется с дополнительной энергоемкой экскавацией породы, на бульдозерных отвалах – с дополнительным перемещением породы бульдозером. Кроме того, работа транспортного и отвального оборудования вблизи призмы возможного обрушения снижает безопасность ведения работ.

Материалы и методы

Существенно повысить эффективность и безопасность отвалообразования возможно при контейнерной технологии доставки пород на отвалы.

Для решения всех обозначенных вопросов предлагается для транспортировки укладки пород в отвал применить контейнерную технологию. Главным элементом технологии является мобильная подъемная машина, при этом не возникает

необходимость в строительстве автомобильных дорог или железнодорожных путей на борту и поверхности отвала (рисунок 1).

Доставленная из карьера руда загружается в контейнеры, которые подъемными машинами доставляются сразу к месту разгрузки. Контейнеры оборудованы возможностью саморазгрузки, в результате чего горная масса высыпается непосредственно в место укладки на отвале.

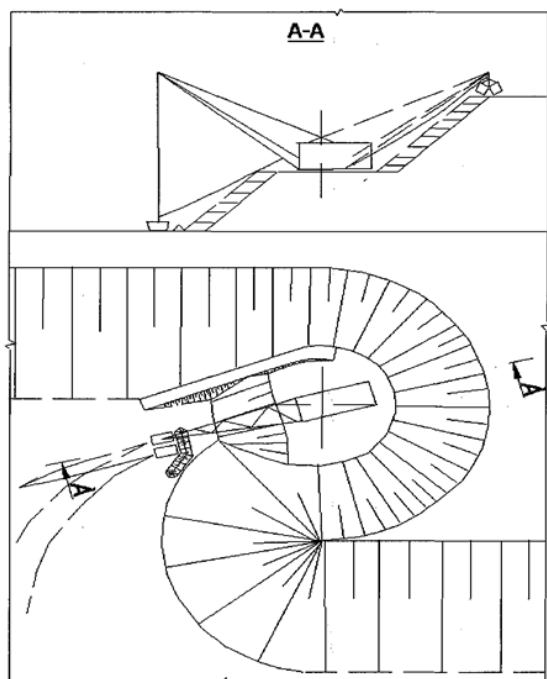


Рис. 1. Схема отвалообразования при контейнерной технологии с послойной укладкой породы

При необходимости перемещения контейнера возможно использование автопогрузчика-контейнеровоза. Контейнеры с породой устанавливаются перед фронтом отвальной заходки, а подъемная машина размещается на специальной площадке предотвала.

При использовании контейнерной технологии происходит снижение себестоимости транспортирования из-за уменьшения времени разгрузки транспортных средств, следовательно, растет производительность всего комплекса оборудования подъема горной массы.

Технологическая схема контейнерного подъема на отвалах обладает достаточной надежностью и гибкостью. Она позволяет постепенно наращивать высоту подъема, распределить оборудование подъема по всему отвалу, распределить горную породу по разным видам, что даст возможность дальнейшего её использования.

Контейнерный подъем позволяет решить некоторые проблемы отвалообразования горных пород:

во-первых, подъем горной массы выполняется с использованием подъемных машин, что снижает энергозатраты, по сравнению с транспортированием автотранспортом;

во-вторых, в отличие от железнодорожного транспорта при укладке породы в отвал не выполняется процесс перевалки горной массы из прицепа;

в-третьих, большая длина стрелы подъемной машины позволяет значительно увеличить высоту отвального яруса и ширину заходки.

За счет применения нового комплекса оборудования может быть увеличена высота отвала, что приведет к сокращению его площади. Это позволит получить значительный экологический и экономический эффект.

Контейнерная технология изменит порядок работы, при этом снижается высота подъема горной массы за счет ее послойной горизонтальной укладки. Большие размеры стрелы

подъемной машины позволят увеличить количество укладываемой горной массы в пределах отвальной заходки.

Безопасность горных работ будет достигнута отсутствием транспортных коммуникаций на поверхности отвала. На земной поверхности рядом с отвалом будет создан мобильный перегрузочный пункт, где будет осуществляться перецепка контейнеров. Порода будет автоматически выгружаться в необходимой точке на поверхности отвала, после чего пустой контейнер доставляется назад в зону загрузки подъемной машиной.

Заполнение контейнеров горной массой на отвалах карьера возможно по различным схемам. Среди основных можно выделить следующие:

1 схема – ковшовыми погрузчиками;

2 схема – непосредственной перегрузкой из автосамосвалов с эстакады;

3 схема – через промежуточный бункер пластинчатым или ленточным питателем.

Выбор схемы в конкретных условиях может быть сделан на основе технико-экономического анализа.

Использование ковшовых погрузчиков выгодно при небольших расстояниях от забоев до места подъема контейнеров и доставке только по горизонтальным участкам трассы. Ограничением области применения этой схемы может стать и трудность экскавации горной массы.

Перегрузка горной массы в контейнер из автосамосвала по второй схеме обеспечит высокую производительность работ, но сопряжена с большими ударными нагрузками на контейнер и строго ограничивает грузоподъемность автосамосвалов. Использование этой схемы возможно при грузоподъемности автосамосвала, равной грузоподъемности контейнера, и при мелкокусковой горной массе.

Наиболее универсальной является третья схема, представленная на рисунке 2.

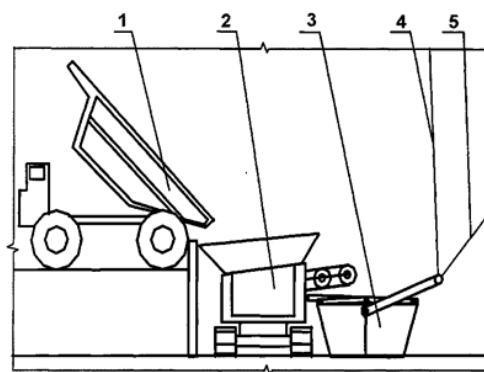


Рис. 2. Канатный экскаватор HS-8300 с грейфером: 1 – автосамосвал, 2 – питатель с бункером, 3 – контейнер, 4 – подъемный канат драглайна, 5 – тяговый канат драглайна.

Результаты и обсуждение

По этой схеме горную массу доставляют от забоев автосамосвалами любой грузоподъемности и выгружают в бункер пластинчатого или ленточного питателя, который заполняет контейнеры по мере их подачи карьерной подъемной машиной. Недостатком такой схемы является пониженная скорость заполнения контейнера в сравнении, допустим, со схемой № 1 или № 2. Например, питатель типа 1-24-150, имеющий ширину полотна 2400 мм, мощность привода 37,5 кВт и собственную массу 108 т при высоте рабочего слоя 0,8 м с насыпной плотностью материала 1,5 т/м³, обеспечивает производительность 2000 м³/час или 0,83 т/с. При такой производительности на заполнение контейнера грузоподъемностью 70 т потребуется 66 секунд, что значительно удлинит рабочий цикл карьерной подъемной машины и снизит ее производительность. Для обеспечения

времени загрузки контейнера в пределах 35 с необходимо подобрать питатель с подачей не менее 1,6 т/с или 3800 м³/ч.

Комплексная сравнительная оценка предлагаемой схемы перегрузочного пункта и существующего внутрикарьерного склада штабельного типа выполнена по следующим показателям: стоимость комплекта оборудования; годовые эксплуатационные затраты; объем и стоимость горно-капитальных работ, необходимых для размещения в карьере перегрузочного пункта и подъездных коммуникаций.

Для совершенствования третьей схемы предлагается внедрить промежуточный конвейер, который будет устанавливаться на базе экскаватора ЭКГ-10. На нем будут перемещаться пустые контейнеры, которые будут подаваться под погрузку щековой дробилки. Груженные контейнеры с другого конца конвейера будут захватываться подъемной машиной и транспортироваться в отвал, тем самым повысится производительность перегрузочного узла. Установка конвейера на гусеничный ход позволит перемещать весь перегрузочный узел при необходимости (рисунок 3).

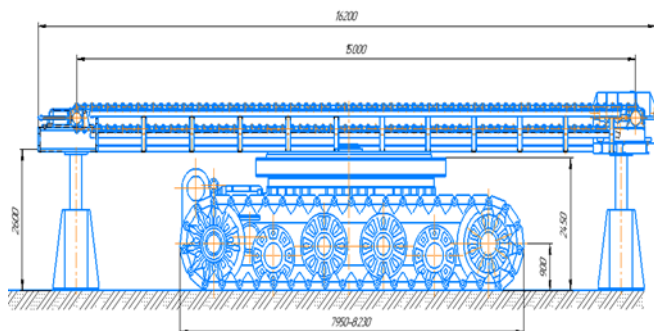


Рис. 3. Схема передвижного конвейера

Объем массы материала в контейнере, м³:

$$V = \frac{m}{\rho},$$

где m – масса контейнера, кг;
 ρ – насыпная плотность породы, т/м³.

$$V = \frac{70000}{2800} = 25.$$

Конструктивно принимаются размеры контейнера 3х3х3 м.

Ширина настила для штучного груза определяется по его размерам, м:

$$B = B_r + (0,1 \div 0,15) = 3 + 0,15 = 3,15.$$

Погонная нагрузка от транспортируемого штучного груза, кг/м, определяется по формуле:

$$q_{sp} = \frac{m}{l},$$

где l – шаг установки равный 15 м.

$$q_{sp} = \frac{70000}{15} = 4666,67.$$

Погонная нагрузка от собственного веса движущихся частей (полотна с цепями), Н/и, определяется по формуле:

$$q_n = (60 \cdot B + A),$$

где A – коэффициент, принимаемый в зависимости от ширины полотна, $A=150$.

$$q_n = 60 \cdot 3 + 150 = 330.$$

Методом обхода выявляется максимальная и минимальная нагрузка на приводные звездочки.

Величина тягового усилия F_0 , Н, на приводной звездочке:

$$F_0 = \xi_{36} \cdot F_4 - F_1,$$

$$F_0 = 1,06 \cdot 95997,97 - 1500 = 100257,85.$$

Мощность электродвигателя для привода конвейера, кВт, определяется по формуле:

$$N = \frac{F_0 \cdot v}{1000 \cdot \eta_{пр}} = \frac{100257,85 \cdot 0,25}{1000 \cdot 0,9} = 27,85.$$

где $\eta_{пр}$ – КПД привода, принимается равным 0,9;

v – скорость движения полотна. $v=0,25$ м/с.

Принимается электродвигатель с повышенным пусковым моментом серии 4А: тип двигателя – 4AP200L6Y3; мощность $N=30$ кВт; частота вращения 975 об/мин.

Для предотвращения опрокидывания передвижного конвейера предлагается устанавливать по краям гидравлические домкраты, удерживающие снизу раму.

Выводы

Внедрение контейнерной технологии на отвалах приведет к улучшению всех технологических показателей. Произойдет сокращение парка экскаваторов на отвале, что приведет к экономии энергоресурсов. Из-за отсутствия необходимости перемещаться по поверхности отвала сократится расстояние откатки автосамосвалами, что приведет к уменьшению расхода дизельного топлива. Уменьшение площади отвалов улучшит экологическую обстановку в регионе. При контейнерной технологии будут применяться оптимальные виды горной техники и все перегрузочные операции будут выполняться с высокой производительностью, что обеспечит высокий коэффициент использования оборудования.

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Numerical modeling and determination of tensile properties of 3D printed composite specimens

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Abstract: In this paper, the tensile strength of the composite material made of onyx and carbon fibers was investigated. Onyx is a material manufactured by the company Mark Forged, which is used for 3D printing of composite materials. It is a thermoplastic filled with carbon fibers used for printing solid and rigid parts. The tensile test according to the standard ISO 527 was carried out experimentally and the numerical results were obtained by numerically modelling the test specimen and simulating the test in Ansys, after which the results obtained experimentally and numerically were compared.

Keywords: TENSILE PROPERTIES, COMPOSITE, NUMERICAL MODELING, 3D PRINTING

1. Introduction

Nowadays, 3D printing technology is becoming more and more common. FDM (Fused Deposition Modelling) is one of the most popular additive manufacturing techniques used to investigate the elastic properties of 3D printed polymer composite structures. [1] Polymer materials are most commonly used in FDM printing. Polymers are very large molecules or macromolecules that are formed by the chemical bonding of a large number of smaller molecules or repeating units called monomers. [2]

In FDM printing, a polymer thread (filament) is unwound from a spool and fed to a nozzle, which is then heated to melt the filament and can be moved horizontally and vertically to form layers, while the filament solidifies immediately after exiting the nozzle, thus creating the final product. [3] In continuous fiber fabrication (CFF), the fibers are softened (not melted) and captured by the thermopolymer matrix, similar to how thermopolymer adhesives such as epoxy capture the fibers in traditional fiber fabrication processes. [3]

The Markforged Two 3D printer is the first commercial FDM-based composite printer, developed by Markforged in 2014, and features a print head with two separate extrusion nozzles for polymer and continuous fiber reinforcement. [1] It is therefore suitable for printing composites with a polymer matrix and continuous fiber reinforcements. Composites are materials made by combining two or more different materials (selected fillers or reinforced with a compatible matrix as a binder) with the aim of achieving specific characteristics and properties that a single component does not have alone. [4]

Carbon fiber composites are used where low mass with high stiffness and strength is required. They are therefore particularly suitable for use in the aerospace industry, then in the manufacture of wind turbines, shipbuilding, construction, the telecommunication industry, the manufacture of orthopaedic aids, the automotive industry, electrical engineering, the chemical industry, the nuclear industry and nanotechnology. [5]

2. Problem description

Additive manufacturing (3D printing) technology is becoming more and more prevalent in rapid prototyping these days. However, in order to use it for industrial purposes, it is important to verify the mechanical properties of the printed samples. Therefore, this work investigates the tensile properties of a 3D-printed polymer composite in which continuous carbon fibers are added to the onyx polymer matrix as reinforcement.

Onyx is a material produced by the company Mark Forged and used for 3D printing of composite materials. It is a thermopolymer filled with carbon fibers used for printing solid and rigid parts. [2]

The standard ISO 527 – 1:1993 - Determination of tensile properties prescribes the shape and standard dimensions of test specimens. For polymer specimens reinforced with continuous

fibers, the standard specimen 5A is used. [6] The shape of sample 5A is shown in Figure 1, while the dimensions are listed in Table 1.

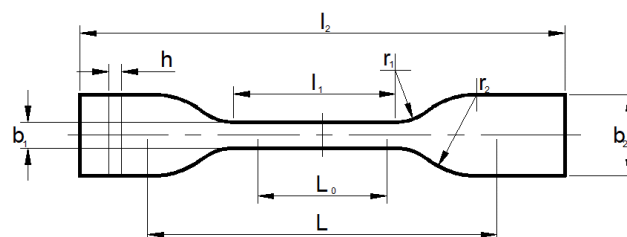


Fig. 1 Shape of tensile sample 5A [6]

Table 1 Dimensions of tensile sample 5A [6]

	Dimensions, mm	
Shape of tensile sample	5A	5B
l_2 – total length	≥ 75	≥ 35
b_2 – width at the end	$12,5 \pm 1$	$6 \pm 0,5$
l_1 – length of the narrow parallel part	25 ± 1	$12 \pm 0,5$
b_1 – width of the narrow part	$4 \pm 0,1$	$2 \pm 0,1$
r_1 – small radius	$8 \pm 0,5$	$3 \pm 0,1$
r_2 – large radius	$12,5 \pm 1$	$3 \pm 0,1$
L – initial distance	50 ± 2	20 ± 2
L_0 – measuring length	$20 \pm 0,5$	$10 \pm 0,2$
h – thickness	≥ 2	≥ 1

The selected sample consisted of 16 layers, with layers 1 – 4, 8–9, 13–16 consisting of onyx only (layer stacks with $+45^\circ$, -45° fiber orientation), while the other layers had a carbon fiber in the layer and a triangular filling of onyx inside. The specimen was made with 41% filling and contained a total of 6 carbon fibers.

During the work, an experiment was conducted to test the specimen on a tensile testing machine. A numerical analysis was also carried out using the finite element method in Ansys Workbench, after which the experimental and numerical results were compared.

3. Experimental analysis

In order to carry out the experiment, it was necessary to produce test specimens. The specimens were produced using 3D printing technology. The 3D printing process consists of the following steps:

1. Creation of the geometry of the specimen (specimen with dimensions according to ISO 527 – 1:1993) in the software CAD (Siemens NX 12.0)
2. The CAD model was exported as an STL file, as a universal input file type for 3D printers.

3. After exporting the model, the STL file was uploaded to the slicing software. Markforged printers use the Eiger software. In the slicing software, the parameters required for 3D printing the specimen had to be defined (filling percentage, number of reinforcing fibers, layer thickness, type of filling elements,...). Figure 2 shows the layers in the slicing software.

4. Printing the specimen on a 3D printer (Markforged Mark Two). The Markforged Mark Two printer, as previously mentioned, contains two nozzles, one of which is used for 3D printing of onyx, while the other provides continuous carbon fiber reinforcement.

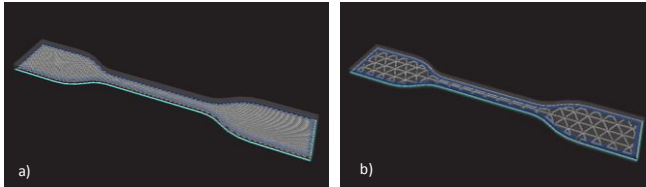


Fig. 2 Appearance of specimen layers: a) top, bottom and middle layer, b) fiber reinforced layers

When the specimens were 3D printed, they had to be separated from the base and were ready for testing after finishing. The tensile test was performed on a Shimadzu AGS-x 10 kN tensile testing machine to determine the tensile properties. The tensile testing machine consists of a housing, a force transmission mechanism, clamps, and a device to record the force-strain results. During the test, the specimen was clamped into the testing machine and continuously loaded until failure. During the test, the force at which yielding occurred and the maximum force were recorded. The force-strain curve was recorded. The standard defines the dimensions of the test specimen, the speed, the temperature of the environment and the performance of the test, as well as the calculation of the results. In this work, three test specimens with 41% fill and 6 carbon fibers were tested. Figure 3 shows three test specimens that broke during the test, and it is obvious that all three failed in the same way.

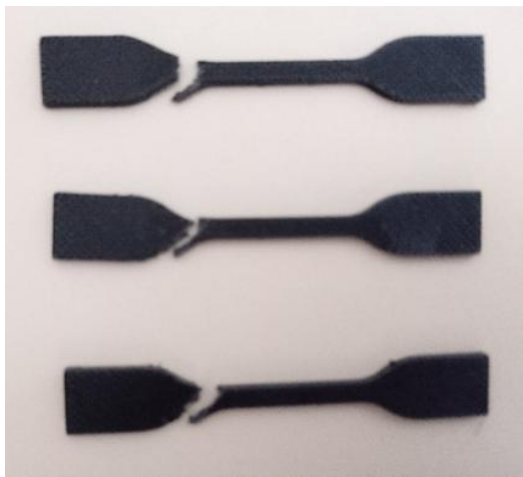


Fig. 3 Specimens after the experiment

4. Numerical analysis

After the experiment was performed, it was necessary to perform a numerical analysis. The software used for the numerical analysis with the finite element method is Ansys Workbench. To perform the analysis, the following steps were necessary:

1. To define the material (Engineering Data) - it was necessary to define the material properties for onyx and carbon fiber. For onyx and carbon fiber, the material properties were taken from the table provided by the manufacturer Markforged. Certain properties that were not defined in the table were taken in accordance with the investigation made in the paper F. Ghebretinsae et. al [7]. The

material properties defined for carbon fiber are: $\rho=1400 \text{ kg/m}^3$, $E_x=60 \text{ GPa}$, $E_y=E_z=8,5 \text{ GPa}$, $\nu_{xy}=\nu_{xz}=0,1$, $\nu_{yz}=0,12$, $G_{xy}=G_{xz}=8,5 \text{ GPa}$, $G_{yz}=3,4 \text{ GPa}$. The material properties defined for onyx are: $\rho=1200 \text{ kg/m}^3$, $E=2,4 \text{ GPa}$, $\nu=0,39$

2. Creating the geometry of the specimen in 3D modeling software (Siemens NX 12.0) and importing the geometry into Ansys and setting up the surface models in the SpaceClaim module required to define the orientation of the fibers

3. Starting the Model module - it was necessary to define the thickness of the surface model and associate the material with them. After that, the mesh was set up. The meshing method was set to Quadrilateral and the element type is Quad/Tri. The size of the elements was set to 1 mm for the top (13-16 layer), middle (8-9 layer) and bottom layer (1-4 layer), while 0,042 mm was set for the other elements. After meshing of the model, it was necessary to make a Named Selection in order to import them into ACP as Element Sets and Edge Sets. In the Named Selection, it was necessary to select the faces or lines to be placed in ACP as Element Sets or Edge Sets and confirm them. Also, the Named Selection had to be defined for all surfaces and fibers of the specimen and for the edges of the carbon fiber paths

4. Starting the ACP (Pre) module – in this module the layers are placed and the fiber orientation is defined. When defining the layers and fiber orientation, it is important to follow the steps below:

a) Defining data under Material Data – it was necessary to define Fibers (fiber material and layer thickness), Stackup (materials used in stackup and their orientation)

b) Defining the rosette - for the top, bottom and middle layer Type: Parallel, where the x-axis of the rosette was set in the direction of the fibers, while for the other layers (fibers) Type: Edge Wise and the path of the carbon fiber was selected as Edge Set

c) Defining an Oriented Selection Set – it was necessary to select an Element Set, select a point on the surface of the Element Set, select the direction of adding the layer and select a rosette

d) Defining Modeling Group and Ply – it was necessary to create a Modeling Group and add a Ply to this Modeling Group. When defining the Ply, it was necessary to select the Oriented Selection Set, the fiber used and the number of layers

e) Defining the Solid Model

5. Transferring Solid Composite Data into Static Structural and starting the Static Structural Module

The boundary conditions have been defined in the Static Structural module. Since the pressure obtained by the experiment had a value of approximately 120 MPa and occurred in the middle of the specimen where the area $A_1=4 \times 2=8 \text{ mm}^2$, a load of $F=\sigma_1 \times A_1=120 \times 8=960 \text{ N}$ was applied on the specimen. At the ends of the specimen, the pressure (stress) was determined by dividing the force obtained from the stress at the center by the area at the end of the specimen, which was $A_2=12,5 \times 2=25 \text{ mm}^2$, and thus it was $\sigma_2=F/A_2=960/25=38,4 \text{ MPa}$. Thus, as boundary conditions, a fixed support was placed at one end (Fig. 4), while a pressure of 38,4 MPa prevailed at the other end (Fig. 5).

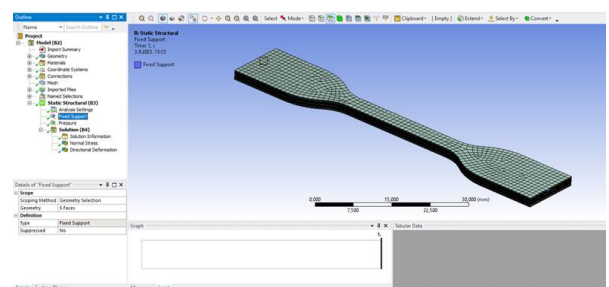


Fig. 4 Fixed support on one side of the specimen

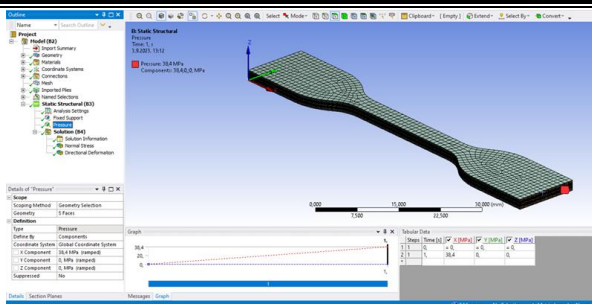


Fig. 5 Pressure on other side of the specimen

6. Starting the solver and getting the analysis results

5. Results and discussion

After the experiment and numerical analysis were performed, obtained results were compared. The experiment showed that the maximum stress was approximately 120 MPa, the deformation was approximately 0,06%, and the average modulus of elasticity was about 2800 MPa. These results are shown in Table 2.

Since the stress on the whole surface was calculated in the experiment and the filling ratio was 41%, it was assumed that the actual surface area was 41% of the whole surface. When the stress obtained by the experiment was divided by the real surface (41% of A), the stress acting on the real surface was 292,68 MPa.

Table 1 Results obtained by the experiment

Specimen label	Max. stress, MPa	Deformation, %	Elastic modulus, MPa
9 (41-6)	117,65	0,05950	2909,6
10 (41-6)	117,15	0,05960	2847,78
11 (41-6)	120,31	0,06359	2768,24

It is also possible to display diagrams of the test results. Figure 6 shows diagrams for all three test specimens made with 41% filling and 6 layers reinforced with fibers obtained from the test results. It can be seen that all three diagrams are similar.

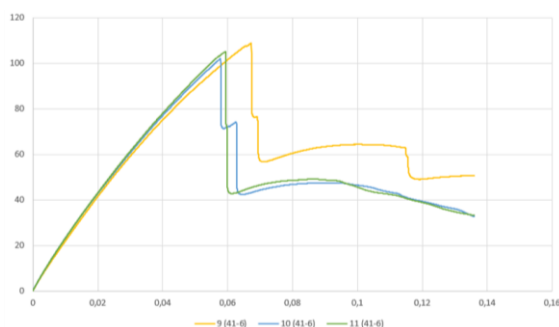


Fig. 6 Diagrams obtained from the test results

Once the material, geometry, mesh, fiber orientation and boundary conditions have been specified in Ansys, it was possible to start the process of solution. The results showed the stress in the x-axis direction and the displacement in the same direction, and they are compared with the results obtained in the experiment. The experiment showed that the average value of the deformation is 0,0609%. From the deformation, it was possible to calculate the displacement according to the expression:

$$\Delta l = \frac{\varepsilon \cdot l}{100} = \frac{0,0609 \cdot 75}{100} = 0,045 \text{ mm}$$

Figure 7 shows the displacements obtained by numerical analysis. It can be seen that the largest displacement is 0,042 mm. By comparing the numerical and experimental results, it is obtained that the deformation deviation is 6,7%.

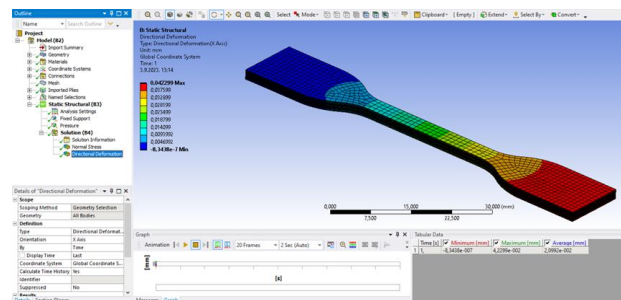


Fig. 7 Displacements obtained by numerical analysis

After comparing the results for the displacements, the comparison was extended to the stress results. Figure 8 shows the stresses obtained by numerical analysis. It can be seen that the highest stress is 240,03 MPa. The comparison of the numerical and experimental results showed that the stress deviation is 18%.

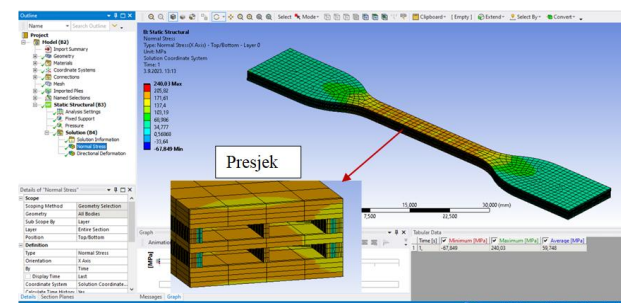


Fig. 8 Stresses obtained by numerical analysis

Table 3 shows a comparison of the deformation and stress results of the numerical analysis and the experiment with the calculated associated deviations.

Table 1 Comparison of experimental and numerical results

	Experiment	Numerical analysis	Deviation, %
Stress, MPa	292,68	240,03	18
Displacement, mm	0,045	0,042	6,7

6. Conclusion

The aim of this work was to numerically model the tensile behavior of 3D printed composite polymer specimens, and then compare it with the experimentally obtained tensile behavior. First of all, an experimental tensile test was performed according to the ISO 527 standard, and the numerical results of the tensile strength were obtained by numerical modeling of the test specimen and simulation of the test in Ansys.

In the experiment, where the force was applied to the actual surface of the specimen, a tensile strength with a value of about 293 MPa and a displacement of 0,045 mm was obtained. The numerical analysis, in which the force was applied to the entire surface, showed that the stresses were about 240 MPa and the displacements were 0,042 mm.

The comparison of the experimental and numerical results showed that the deviation in the stress results is 18%, while the deviation in the displacement results is 6,7%. The deviations in the results are due to the approximation of circular fibers by square fibers due to limitations in the software. Further investigation will

include modeling of circular geometries of fibers once this option is available in a future version of the software. This would greatly improve the accuracy of the simulation results.

In addition, the software restricts the import of the model modeled in layers into the Explicit Dynamics module. Therefore, it was not possible to actually model the final failure of the specimen, but only load it with the experimentally determined pressure and then obtain the stress and displacement results. This could also be resolved in future versions of the software.

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Method for Estimating a Residual Service Life of Fibre-reinforced Industrial Concrete Floorings and Pavements

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Abstract: Current construction practice often implies the need to carry out specific actions related to the specification of current operating characteristics of existing and operated in different periods in different ways fibre-reinforced industrial concrete internal floorings and external pavements. Such problems are most often related to a planned change in the operating load, or to estimate their service life in the future. In this regard, specific parameters of a system approach proposed by the author are specified below, including the necessary preliminary field, laboratory and analytical activities related to establishing the current strength-deformation and other essential characteristics of existing industrial concrete floorings and pavements, as follows: concrete cross-section thickness, concrete strength-deformation characteristics, type and amount of reinforcement used (including fibres), deformation characteristics of the crushed-stone base - according to the dynamic penetration in number of test points, static calculations for the new load conditions, restoring their integrity after sampling, etc. Given the lack of any normative documents on the subject, the proposed systematic approach to the assessment of the residual operational resource of existing fibre-reinforced industrial concrete floorings/pavements is of important methodological importance and fully corresponds to the needs of real construction practice. Its practical use has been approved by the author through a number of successfully conducted systematic expert procedures at a number of sites in the country and abroad.

Keywords: FIBRE-REINFORCED CONCRETE, STRENGTH, DEFORMATION, CONCRETE FLOORINGS, SERVICE-LIFE

1. Introduction

Initially, it should be noted the existing relative ambiguity in the definition and in the methods of construction and sizing of fibre-reinforced industrial concrete floorings/pavements, which are contributed to by the fact that they are not defined separately, precisely and unambiguous - as in the still valid Bulgarian rules for the design of concrete and reinforced concrete structures as well as in Eurocode 2 [1].

In this sense, and in the aspect of the present exposition, is the definition proposed by the author for industrial concrete floors: cast-in-place specific type of concrete structure with geometric dimensions in plan many times exceeding the dimensions in height, designed as a slab on an elastic base and executed by surface machine power-floating, for long-term bearing of specific operating loads with ensured resistance to environmental [2].

Current construction practice often implies the need to carry out specific actions related to the specification of current operating characteristics of existing and used in different periods in different ways fibre-reinforced industrial concrete floorings and pavements. Such problems are most often related to a planned change in the operating loads, or to establish current damages, which calls into question the continued service life of construction.

In this case, it is obviously not possible to offer an optimal technical solution without obtaining the necessary information in two important aspects - the actual current state of the floorings/pavements in general and the potential future operating loads predicted.

Regarding the first mentioned aspect, the practice shows that there are serious problems related to the adequate assessment of the applicability and usability of the industrial concrete floor/pavement after certain time of operating. It can be seen that this current state is a complex characteristic, the individual components of which by themselves cannot be considered as mutually independent. For example, if the established compressive strength of the concrete corresponds to the design characteristics, this does not provide guarantees of future flawless operation, if the parameters of the located below compacted crushed stone base are compromised.

Examples similar to that one is too many - given the multifactorial interdependencies of the individual key characteristics of the floorings/pavements as a whole, which cannot be established only on the basis of existing standards.

In this connection, there is a need to develop a complex systematic approach to the problem, through which to propose and

unify a series of in-situ, laboratory and analytical activities, through which to evaluate the overall actual state of the finished and operated concrete flooring/pavement over time. The formatter will need to create these components, incorporating the applicable criteria that follow.

2. Method proposed

The statement below specifies specific components of a system approach proposed by the author, including the necessary preliminary, field, laboratory and analytical activities related to establishing the current strength-deformation and other essential characteristics of existing industrial concrete floorings/pavements on the site, namely:

- Review of the existing project documentation, if any;
- Detailed visual technical inspection of the flooring and specification of visible defects;
- General condition of the executed crushed stone embankment under the pavement;
- Basic concrete physical-mechanical characteristics;
- Flooring/pavement concrete cross-section thickness;
- Type and amount of reinforcement used;
- Assessment of the depth and width of possible presence of cracks with different genesis of manifestation;
- Adhesive bonding of the applied dry shake surface hardener to the main concrete section as part of the finishing treatment, etc.

2.1. Visual Technical Inspection

As a first and mandatory step, a specialized technical visual inspection has to be planned and carried out to establish the actual general state of the flooring/pavement. The type of flooring (jointed, or joint-less), location of the different types of joints (insulation, expansion and saw-cut one), characteristic sizes of one-day casting fields, type and state of the finish surface (with or without surface hardener, presence of impregnating systems and products), noticeable defects (various types of cracking, delamination, unregulated opening and defecting of various types of joints, collapse of the base, deplaning of individual fields, dusting, etc.) – Photos 1-6.

As a result of the visual inspection, an initial assessment of the general serviceability of the flooring/pavement can be made, specifying the individual types of visible defects and the way to assess their significance for the operational condition.

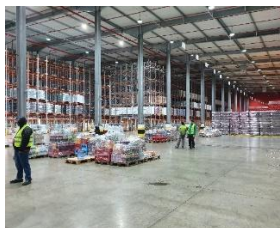


Photo 1



Photo 2



Photo 3



Photo 4



Photo 5



Photo 6

2.2. General State of the Completed Crush-stone base under the Flooring

The different test procedures described in Eurocode 7 [3,4] should be applied.

Initially, the entire flooring area has to be scanned with a specialized device – geo-radar, to establish the presence of voluminous caverns under the flooring/pavement, due to the collapse of the crushed stone base, or sub-base - Photos 7-8.



Photo 7



Photo 8



Photo 9



Photo 10

These specialized studies are able to provide an answer for the presence of local defects in the completed bases, the location of which has to be mapped on a separate drawing - flooring plan.

A good example is the use of the **Radarteam Cobra GPR** system, consisting of a GPR and antenna, an on-board computer with a screen and a moving cart. The multi-frequency spectrum of operation is from 100 to 900 Mhz, which allows scanning depths of up to 10 m, and obtaining a real-time signal diagram is possible.

In cases where there is doubt about problems with the soil layers at depth, it is also possible to apply deep drilling with sampling through mobile drilling rigs. A lithological description of the different types of soil layers passed is made, determining the physical and mechanical characteristics of the different types passed, including the possible presence of water-bearing layers, too - Photos 9-10.

In the boreholes, it is possible and desirable to conduct base compaction investigations with penetration tests (SPT) to establish the deformation characteristics of the "bottom edge of flooring/pavement" elevation. In this way, the nodal index of the base-compaction can be determined - the so-called bed coefficient (Winkler's constant, MN/m^3). This coefficient is directly involved in the static dimensioning of floorings/pavements as a base-supporting structure - a slab on an elastic ground [5,6,7].

Field tests with a dynamic penetrometer allow the determination of important technical characteristics of construction soils (embankments) - bulk density, bulk density in a water-saturated state, modulus of total deformation, speed of propagation of transverse waves (V_s), dynamic shear modulus (G), modulus of total deformation (E_v), Poisson's ratio, modulus of elasticity, indicators of undrained strength (cohesion or angle of internal friction ϕ_0), peak resistance of the cone, Winkler's constant, etc. The last parameter is directly related to the subsequent calculation procedures for dimensioning the flooring/pavement with the new load.

This type of field research can be carried out using a (super heavy) penetrometer, for example of the type DPSH-B. The results can be perceived as sufficiently informative, and with a good correlation with archival ones, obtained by loading with a round plate according to BDS 15130-80 at the level "lower edge of flooring/pavement" during the implementation of embankment works [8].

Everything said above makes it possible to assess the general condition of the completed crushed stone base, as a part of as part of the operational load bearing system.

2.3. Steel Bars Reinforcement Identification

HILTI "PS 200" Ferrosan device is designed for the operational control of the placement, thickness of the concrete cover and the diameter of the reinforcing steel in concrete elements, structures and products by the method of magnetic induction. It works according to the requirements of BS 1881-204:1988 [9].



Photo 11



Photo 12

The use of this device can identify the potential presence of upper steel reinforcement in the form of single bars or welded mesh, their distribution in plan and single bars diameter, as well as the actual thickness of the concrete cover - Photos 11-12.

The identification of the reinforcement system used also has an arbitrage value - it shows whether the developed design has been correctly laid out in the building stage.

2.4. Concrete Basic Physics and Mechanical Characteristics

The drilling test concrete samples (cores), after standard processing, make it possible to determine the thickness of the flooring/pavement, visually directly establish the presence of steel-bars reinforcement and/or fibers with structural purpose, the volume density, compressive strength and splitting tensile strength, as well as modulus of elastic deformations by direct loading and by using of the ultrasonic method.

In agreement with the contractor, a scheme for sampling by drilling and extracting drill cores has to be drawn up, based on which a number of strength-deformation and special characteristics of the existing flooring/pavement have to be determined - volume density and class of concrete in terms of compressive strength, splitting tensile strength, modulus of elasticity of concrete, concrete cross-section thickness, type and amount of fiber-reinforcement.

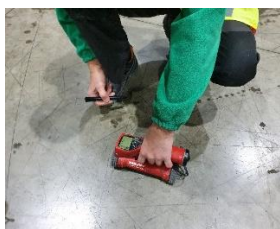


Photo 13

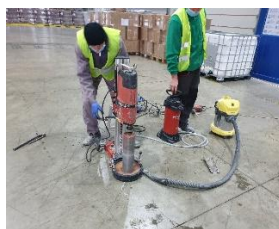


Photo 14



Photo 15



Photo 16



Photo 17



Photo 18

The core cutting, preparation and testing are carried out according to the requirements of the current national and European standards. The test procedures should be in accordance with the requirements of the following several current standards [9,10,11,12,13].

After drilling concrete cores are cut with a diamond cutting disc to produce cylindrical samples (Photo 17). The cutting direction is parallel to the vertical axis of the core. The mass has to be measured to determine the volume density of the concrete (Photo 18). Surfaces intended for loading are processed by grinding or by coating (Photo 19).



Photo 19



Photo 20

Initially, it is possible to determine the dynamic elastic modulus of concrete by a non-destructive method (Photo 19) according to BDS EN 12504-4:2005 [12]. The relationship between ultrasonic speed velocity and dynamic modulus of elasticity of concrete is expressed by the formula:

$$V = \sqrt{\frac{k E_d}{\rho}} \quad (1)$$

Where:

V - ultrasonic speed velocity, km/s;
 E_d - dynamic modulus of elasticity of concrete, MPa;
 ρ - concrete volume density, kg/m³;
 k - correction coefficient.

$$k = \frac{1 - \mu}{(1 + \mu)(1 - 2\mu)} \quad (2)$$

Where:

μ - Poisson's ratio of concrete equal to 0,2 (according to Eurocode 2

The functional relationship between static and dynamic modulus of elasticity is as follows:

$$E_c = 0,83 \cdot E_d \quad (3)$$

Given the impossibility of directly determining the flexural strength of the concrete (necessary for the static calculations) from the cores a specialized test, a method [13] is applied, admissible acc. the requirements of Eurocode 2 - namely by determining the concrete tensile strength by splitting - Photo 21.



Photo 21



Photo 22



Photo 23

The test sample is loaded using a compression (Photo 22), and the splitting tensile strength is calculated using the formula:

$$f_{ct} = \frac{2F}{\pi Ld} \quad (4)$$

Where:

f_{ct} – concrete splitting tensile strength, MPa;

F – max load, N;

L – liner core dimension, mm;

d – cross-section diameter, mm.

From the total number of unit results obtained, the arithmetic mean value of the splitting tensile strength $f_{ct,sp}$ is determined.

In accordance with the requirements of Eurocode 2, on this basis, the average axial tensile strength f_{ctm} can be determined by the formula:

$$f_{ctm} = 0,9 f_{ct,sp} \quad (5)$$

Looking for the average flexural strength $f_{ctm,fl}$ of the concrete, needed for flooring static calculation, we can use formula 3.24 (p.37 - Eurocode 2), namely:

$$f_{ctm,fl} = \max \left\{ \left(1,6 - \frac{h}{100} \right) f_{ctm} \right. \\ \left. \text{or } f_{ctm} \right\} \quad (6)$$

Where:

h - average concrete structure thickness (in our case the determined average thickness of the flooring, obtained by direct cores measurement).

The actual concrete compressive strength can be determined by direct compression testing of the specimens (Photo 21).

Concrete compression strength is calculated by formula:

$$f_c = \frac{F}{A_c} \quad (7)$$

Where:

f_c - concrete compression strength, MPa (N/mm²);

F - max fracture load, N;

A_c - the cross-sectional area of the test specimen on which the compressive force acts, mm².

The processing of the results is carried out according to the requirements of the current European standards [14,15,16,17].

The average characteristic compressive strength f_{ck} can be calculated according to the requirements of the standard:

$$f_{ck} = f_{cm} - 1,64s \quad (8)$$

Where:

f_{ck} - characteristic concrete compressive strength;

f_{cm} - average concrete compressive strength;

s - mean standard deviation

After reading the maximum compressive fracture force, the core is disintegrated until the steel fibers are completely separated (Photo 24), and the amount contained in each core is weighed to the nearest 1 g (Photo 25). The obtained result is recalculated for 1 m³, which represents an experimental assessment of the fibre-reinforcement embedded in the concrete. The type, diameter and length of exposed fibers are determined (Photo 26).

On the basis of the core samples, the modulus of elastic deformation of the concrete can be determined, which is also necessary for conducting the corresponding static calculations (Photo 23).

In the manner described above, up-to-date values of all necessary actual strength-deformation characteristics of the

concrete in the flooring/pavements are already available for additional analytical considerations.



Photo 24



Photo 25



Photo 26

2.5. Depth and Width of Visible Cracks Evaluation

In most cases, given the possibility of the large-scale presence of multiple cracks visible on the flooring/pavement surface, it is of particular importance to identify the causes of their appearance, and, above all, to assess their behavior in the near future. Hence the need for their in-depth study - especially for their width and the depth presence in the concrete section.

It should be taken into account that cracks with a width of less than 0,4 mm (or less than 0,3 mm when operating in an aggressive environment), Eurocode 2, qualifies them as permissible (Б/ДС EN 1992-1-1:2005, Table 7.1 N, page 124).

Another issue is that the comments included in the mentioned Eurocode 2 refer to conventional steel-reinforced concrete structures - slabs, beams, columns, walls, etc. In most of them, the admissibility of cracks with a limited width does not negatively affect their operational condition, as long as they would not become a bridge for the corrosion effect of the conventional steel reinforcement.

This is not the case with the impact of cracks on the operational condition of industrial concrete floorings/pavements - given the usual heavy moving traffic on the finished surface. So, the presence of cracking, even just superficial micro-cracking, could seriously escalate over time, leading to severe consequences for surface quality. From a moment on, even "cosmetic" micro-cracks can lead to time-increasing defecting of the finish surface, reflected in the initiation of delamination, local collapse of the edges of the cracks, etc., with the possibility of avalanche-like growth of defects in the depth of the concrete section.

In such a context, and in order to fully clarify the flooring actual condition, the studies to establish the depth of crack formation, especially those cracks with a visibly larger surface width, become of particular importance.



Photo 27



Photo 28

Initially, within the framework of the expert actions, research on the width of the cracks can be carried out by two complementary methods - by using a template card and by optical measurement.

A professional **Metzger-MacCure** template (www.metzgermacquire.com) can be used with a measurement step of 0,2 to 2,5 mm (Photo 27), including by using an optical magnifier (Photo 28). Measurements are carried out at visually selected characteristic test points - preferably near the core drilling points.

Non-destructive ultrasonic method can be used to determine the approximate depth of cracks without intervening in the depth of the concrete cross-section – by using of ultrasound device **Proceq TICO** for unilateral sounding, for example (Photos 28-31).

Each individual measurement is carried out at an acoustic base of 60 cm, determining the depth of the crack from the expression:

$$d_{cr} = \frac{L}{2} \sqrt{\frac{t_{cr}^2}{t_{0m}^2} - 1} \quad (9)$$

Where:

$L (= 2x)$ - size of the unilaterally sounded acoustic base in mm, located perpendicular to the direction of the crack and symmetrically on both sides;

t_{cr} - measured time for the passage of the ultrasonic pulse along the corresponding acoustic base across the crack, μs ;

t_0 - measured time for the passage of the ultrasonic pulse along the uncracked concrete at the same acoustic base, μs

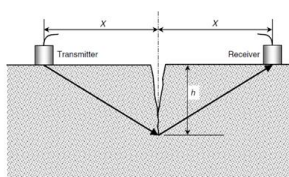


Photo 27



Photo 28



Photo 29



Photo 30

2.6. Surface Hardener Adhesion to the mail Concrete Section

For an objective assessment of the quality of the applied surface hardener (topping) during the execution of the flooring, specialized adhesion tests have to be conducted in accordance with the requirements of BDS EN 1542:1999 [18] using equipment in accordance with the requirements of EN 24624:1993 [19].

The obtained results provide information on the adhesion stress at the point of failure and specification of the area of adhesion failure, through which an analysis can be made of the quality of the applied powder surface hardener and its ability to provide the required flooring surface finish (Photo 31).

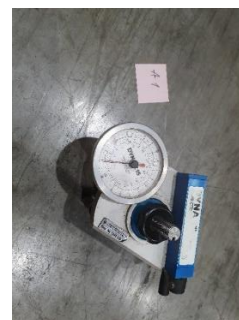


Photo 31

3. Practical Significance of Method Proposed

The field (in-situ), laboratory and analytical activities described above provide all the necessary information to assess the actual current state of the industrial concrete flooring/pavement as a whole, with which to assess its future operational behavior and durability, including if it is necessary to take on some additional new loads.

After collecting all the necessary input data for flooring with a set load (rack systems, dynamic loads, specialized equipment, uniform distributed load, etc.), the corresponding static calculations can be carried out easily with specialized software - preferably with one developed by the manufacturer of the fibers found to have been used in construction.

The static calculations for each of the specified loads are presented in an expanded form as an appendix to every study performed. An analysis of the obtained results can be made by comparing the obtained values of the safety factors with the minimum necessary ones for a certain type of load.

The real bearing capacity of the existing flooring/pavement can be evaluated, as a result of which a conclusion could be made about the admissibility or not of the new operating loads.

Within the framework of the relevant expert actions, some additional arguments related to the real state of the flooring/pavement can be usually presented. Regardless of whether an additional potential for taking on the new dominant load is approved, specific recommendations should be specified – for example, for new arrangement of racking system, its supports (legs) position at a certain minimum distance from any existing expansion or saw-cut joints, permissible depth of new anchoring (given the established current thickness of the flooring), technological options for repair and reparations of existing structural defects, maintenance measures during operation, etc.

4. Conclusion

Given the lack of any normative documents on the subject, the proposed systematic approach to the assessment of the residual operational resource of existing fibre-reinforced industrial concrete flooring/pavements has methodological importance and fully corresponds to the needs of real construction practice. Its practical use has been approved by the author through a number of successfully conducted systematic expert procedures at a number of sites in the country.

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ФОРМОИЗМЕНЕНИЕ МЕТАЛЛА ПРИ ПРОКАТКЕ В РЕЛЬЕФНЫХ ВАЛКАХ С ФАКТОРОМ АСИММЕТРИИ

METAL SHAPING DURING ROLLING IN RELIEF ROLLS WITH AN ASYMMETRY FACTOR

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Abstract: A preliminary laboratory experiment was conducted on a lead billet in order to test the technology being developed, as well as to verify the data on the shape change obtained by computer simulation. A comparison of the geometric parameters of the workpiece after rolling in relief rolls and two subsequent alignment passes in smooth rolls showed that the results of computer simulation have a high level of convergence. At each deformation stage, the difference in the geometric parameters of the workpiece between the model and the experiment did not exceed 3-5%. When deforming a copper billet, the maximum difference level was 8%, which is the result of the low rigidity of the rolling cage with smooth rolls. The theoretical results obtained in the article will be useful as a basis for creating an industrial installation of this deformation process, or for upgrading an existing rolling mill.

Keywords: ROLLING, RELIEF ROLLS, ASYMMETRY, EXPERIMENT, METAL SHAPE.

Разрабатываемый процесс интенсивной пластической деформации, представляющий собой комбинацию прокатки в рельефных валках с наложением фактора асимметрии, хорошо зарекомендовал себя на теоретическом этапе исследований. Так, в работах [1-2] были изучены различные параметры процесса при использовании кинематической и геометрической асимметрии. Также в работе [3] были рассмотрены энергосиловые параметры данной схемы деформирования. С целью апробации разработанной технологии, а также проверки данных об изменении формы, полученных с помощью компьютерного моделирования, был проведен лабораторный эксперимент на свинцовой заготовке. Для корректного сравнения результатов эксперимента с моделированием была рассчитана дополнительная модель асимметричной прокатки в рельефных валках для свинцовой заготовки с идентичными геометрическими параметрами, где проводилось только исследование изменения формы. Геометрические параметры заготовки и валков были полностью идентичны в ходе моделирования и эксперимента, была выбрана заготовка толщиной 10 мм и шириной 150 мм (рис. 1). Скорость вращения валков и зазоры между гладкими валками также соответствовали значениям, принятым при моделировании медной заготовки.



Рисунок 1 – Исходная заготовка

Лабораторный эксперимент проводился в соответствии с разработанной технологией деформирования – после прокатки в рельефных валках (рис. 2) заготовка выравнивалась в гладких валках. Для тех же условий была построена соответствующая конечно-элементная модель.



Рисунок 2 – Прокатка заготовки в рельефных валках

При этом зазор на втором этапе выравнивания (3-й проход) был равен толщине заготовки, а на первом этапе выравнивания зазор был установлен равным половине разницы в высоте заготовки до и после прокатки в рельефных валках. Ранее было выявлено, что высота заготовки после первого прохода увеличивается на 75-80% [3]. Согласно этому принципу зазор во втором проходе был равен 14 мм. После прокатки в рельефных валках и последующих двух этапов выравнивания заготовка приобрела форму, показанную на рисунке 3. Для сравнения высота и ширина заготовки при моделировании показаны слева. Принимая во внимание тот факт, что материал при конечно-элементном моделировании полностью однороден, при рассмотрении ширины в перпендикулярном направлении обзора очень трудно увидеть выступы и впадины. Поэтому, для наглядности, ширина заготовки модели показана в изометрии.

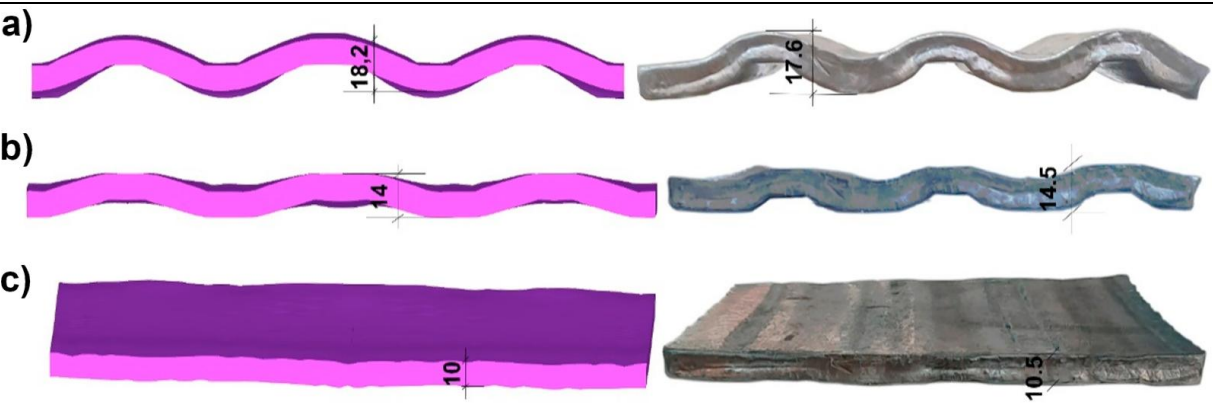


Рисунок 3 – Сравнение формы свинцовой заготовки при моделировании и эксперименте:
а – после прокатки в рельефных валках; b - после 1-го этапа выравнивания; c - после 2-го этапа выравнивания

В таблице 1 приведены значения амплитуды высоты для каждого прохода. Также показаны различия полученных значений в процентах.

Таблица 1 – Значения амплитуды высоты свинцовой заготовки

	Проход 1, мм	Разница, %	Проход 2, мм	Разница, %	Проход 3, мм	Разница, %
Моделирование	18.2	3.29	14	3.57	10	5
Эксперимент	17.6		14.5		10.5	

Сравнение геометрических параметров заготовки после прокатки в рельефных валках и двух последующих проходов выравнивания в гладких валках показало, что результаты

компьютерного моделирования имеют высокий уровень сходимости. На каждом этапе деформации разница в геометрических параметрах заготовки между моделью и экспериментом не превышала 3-5%.

После предварительной асимметричной прокатки свинцовой заготовки в рельефных валках был проведен аналогичный эксперимент по деформированию заготовки из медного сплава М1 толщиной 10 мм и шириной 150 мм. На рисунке 4 показаны результаты сравнения формы заготовки во время моделирования и эксперимента на всех стадиях деформации.

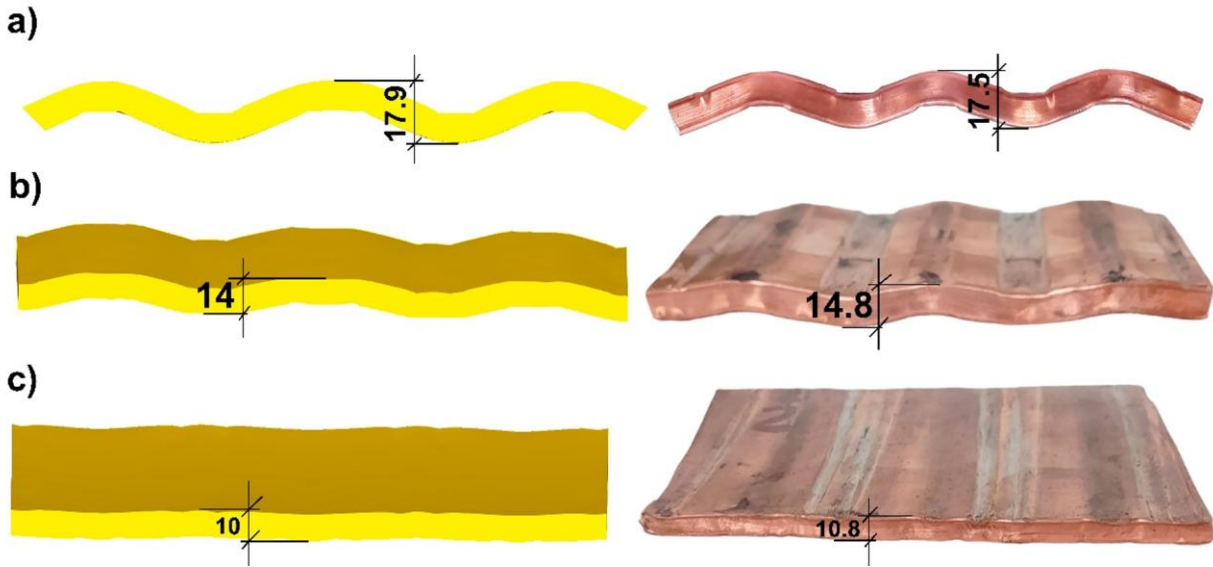


Рисунок 4 – Сравнение формы медной заготовки при моделировании и эксперименте:
а – после прокатки в рельефных валках; b - после 1-го этапа выравнивания; c - после 2-го этапа выравнивания

Таблица 2 – Значения амплитуды высоты медной заготовки

	Проход 1, мм	Разница, %	Проход 2, мм	Разница, %	Проход 3, мм	Разница, %
Моделирование	17.9	2.28	14	5.7	10	8
Эксперимент	17.5		14.8		10.8	

В таблице 2 приведены значения амплитуды высоты для каждого прохода. Увеличенные значения разности на этапах выравнивания являются результатом того факта, что прокатная клеть лабораторного стана с гладкими валками имеет меньшие размеры и, как следствие, меньшую жесткость конструкции. Следовательно, при прокатке более твердого материала увеличивается зазор между валками. В реальных условиях все прокатные клетки имеют более высокий уровень жесткости, а также специальные механизмы для создания эффекта предотвращения изгиба валков.

Выводы

Был проведен предварительный лабораторный эксперимент на свинцовой заготовке с целью тестирования разрабатываемой технологии, а также проверки данных об изменении формы, полученных с помощью компьютерного моделирования. Сравнение геометрических параметров заготовки после прокатки в рельефных валках и двух последующих проходов выравнивания в гладких валках показало, что результаты компьютерного моделирования имеют высокий уровень сходимости. На каждом этапе деформации разница в геометрических параметрах заготовки между моделью и экспериментом не превышала 3-5%. При деформировании медной заготовки максимальный уровень разницы составил 8%, что является результатом низкой жесткости прокатной

клетки с гладкими валками. Теоретические результаты, полученные в статье, будут полезны в качестве основы для создания промышленной установки этого процесса деформации или для модернизации существующего прокатного стана.

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The effect of applying a conversion layer by phosphating on the roughness relief of the steel surface

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Abstract: The contribution is focused on the analysis of the surface roughness after applying the conversion layer using phosphating. In the experiment, uncoated deep-drawn steel DC 04 was used as the base material. During the application of the conversion layer, changes in surface roughness were studied with respect to the phosphating time, which was 3, 5 and 10 minutes. The achieved results provide information for other technological operations such as creating joints by gluing, where the correct anchoring of the glue is important for sufficient adhesion to the surface.

Keywords: STEEL SURFACE, PHOSPHATING, ROUGHNESS, CONVERSION LAYER

1. Introduction

The protection of metal products against environmental influences can be ensured in various ways, from the most common of which are material selection, corrosive environment treatment and the use of protective coatings.

Material selection is the simplest method. However, this requires a deep, comprehensive knowledge of materials and the relationship between the material and the specific corrosive environment. In addition to technical suitability, the proposed material should also demonstrate the economic viability of the choice.

Corrosive environment treatment is often used in the field of temporary protection of products in storage and transport. Protective coatings are mainly used in the protection of carbon steels against atmospheric influences. These include organic coatings (coatings), metal coatings (zinc, aluminium and alloy) and combination coatings (metal coating combined with coating). In the field of corrosion protection of surfaces of engineering products, bridges and steel structures, the application of coatings and coatings is the dominant method of surface treatment. [1-7]

In anti-corrosion protection of cars, the method of protection with metal coatings is very widespread. An important criterion for these coatings is the thickness of the film and its porosity. The service life of the coating increases with its thickness and at the same time the number of corrosion-significant pores decreases. If we achieve a non-porous coating, the anti-corrosion protection of the coating is then equal to the resistance of the metal that was used for the coating.

The work deals with surface treatment of metal materials by conversion coatings, more precisely by phosphating. This is a widespread method in technical practice, mainly in the automotive industry, due to its wide applicability given the current availability and reliability of coatings. Phosphate layers are applied to metals to improve corrosion resistance due to their relatively high electrical resistance. Their other role is to support the adhesion of organic coatings or other adhesives. The conversion coating has the ability to adhere excellently to the treated metal and resists solubility in water or other solvents. Subsequently applied coatings are characterized by excellent adhesion to the material.

In general, three types of phosphating can be applied, iron, zinc and manganese. The uniqueness of these species is characterized by the crystals that form in each of them. Manganese phosphating is generally considered to be highly resistant in corrosion protection. Iron phosphating is more stable than zinc phosphating at higher pressures and temperatures. [8-12]

The paper deals with zinc phosphating applied to uncoated deep-drawn steel with different applied phosphating times. The latter causes changes on the surface of the material, which are also manifested by changes in roughness.

2. Materials and methods

2.1 Used basic material

DC04 steel (designation of samples DC) is an uncoated deep-drawn steel, particularly suitable for demanding external and internal parts in car bodies, or for other extrusions. The chemical composition of the materials is in Table 1.

Table 1: Chemical composition of used steel DC

Material	C	Mn	P	S
DC	0,04%	0,25%	0,01%	0,01%

2.2 Pre-treatment of the surface

The surface of the test samples of DC steels was without any surface treatments. The tested samples of both materials were classified into two categories:

- Surfaces without further treatment – a steel sample is used for testing in the state in which it was delivered from the manufacturer. The sheet surface was preserved by electrostatic oiling with an intensity of 0,5 – 2,5 g.m⁻², which protects it from corrosion.
- Surfaces with the addition of a conversion layer of zinc phosphate - during the phosphating process, small crystals form on the surface of the material, creating a phosphate layer that serves as protection against corrosion or as a base layer to improve adhesion when applying additional layers and when gluing.

A total of 4 types of samples were used for the experiment. Samples DC 0 were samples, the surface of which was not treated with a zinc phosphate conversion layer. The other samples used in the experiment were treated with a layer of zinc phosphate with different immersion times of the sample in the phosphating bath, namely 3, 5 and 10 minutes.

For the phosphating of the samples, the technology of phosphating with Pragofos, manufactured by Pragochema s.r.o., applied by immersion, was used. Before applying the phosphate layer after the application of the degreaser Pragolod 57 N, the rinse in the bath was diluted with the activating rinse Pragofos 1007 at a concentration of 0,3% at room temperature with a mixing time of 3 minutes. DC type steel samples were subsequently phosphated in a Pragofos 1501 bath at a temperature of 60°C for 3, 5 and 10 minutes.

2.3 Roughness measurement methodology

Surface roughness of the produced samples was evaluated according to ISO 21920 by the contact method using a stylus profilometer SurfTest SJ-201, Mitutoyo, Tokyo, Japan. This standard defines roughness parameters based on the deviation from

the mean line for the primary profile. The measurement parameters used were as follows:

- a measured profile: R,
- a filter: GAUSS,
- a sampling length $\lambda_c = 0,8$ mm,
- a number of sampling lengths $N = 5$,
- an evaluation length $l_n = 4$ mm,

In order to obtain as much information as possible about the produced surfaces in individual positions, the surface roughness was evaluated using a set of several parameters:

- the arithmetical mean deviation of the assessed profile (Ra),
- the maximum height of profile on the basic length (Rz),
- the mean width of the profile element on the sampling length (RSm),
- the mean number of peaks per centimeter (R_{Pc}),

2.4 Methodology of statistical analysis of surface microgeometry

The measured data were subjected to the statistical analysis using Statistica software using a non-parametric Kruskal - Wallis test. The Kruskal - Wallis nonparametric test was used to compare positions on the building platform for each roughness parameter evaluated. The test that compares more than two groups, whether population comes from the same distribution.

3. Results

By measuring the selected roughness parameters on the DC material, the values shown in Table 2 were achieved.

Table 2. The mean and standard deviation of roughness parameters

Sample	Measured values of roughness parameters			
	Ra [μ m]	Rz [μ m]	R _{Pc} [1/mm]	RSm [μ m]
DC 0	1,04 ± 0,10	5,43 ± 0,49	44,78 ± 7,80	230 ± 39
DC 3	1,05 ± 0,11	5,28 ± 0,37	47,17 ± 6,72	216 ± 34
DC 5	1,00 ± 0,12	5,35 ± 0,47	47,54 ± 9,87	218 ± 41
DC 10	0,96 ± 0,10	5,21 ± 0,57	56,57 ± 12,85	186 ± 46

In the attached profilograms of individual surfaces of materials Fig. 1a – Fig. 1d we recorded a change in the surface roughness of tested materials.

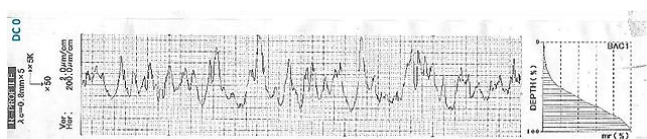


Fig. 1a Profilogram + Firest-Abbot curve for the sample DC 0

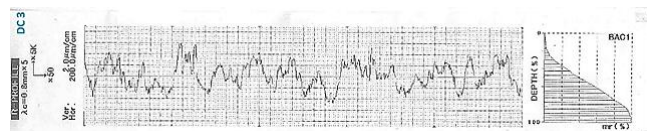


Fig. 1b Profilogram + Firest-Abbot curve for the sample DC 3



Fig. 1c Profilogram + Firest-Abbot curve for the sample DC 5

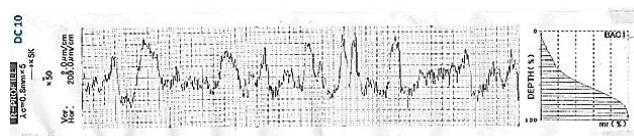


Fig. 1d Profilogram + Firest-Abbot curve for the sample DC 10

From the measured values of the roughness parameter Ra, it can be concluded that it is relatively stable on the base material as well as on the applied pretreatments.

Differences were noted in R_{Sm} and R_{Pc} parameters. Zinc phosphate consists of multiple crystals of insoluble phosphates, which gained their size on the surface during the application of the phosphating process, thereby achieving an increase in the density of the projections. If there is an increase in the density of protrusions per cm of length, it means that there is a prerequisite for an increase in the contact area between the treated surfaces, which is advantageous in the case of using such surfaces to create adhesive joints.

The average density of protrusions of the R_{Pc} surface increased the most in the DC material pretreated with zinc phosphate compared to the original surface of the material at a phosphating time of 10 min. Compared to a process lasting 5 min. this difference is relatively small (9 protrusions per cm⁻¹) and therefore it is possible to recommend the application of a phosphate layer on the surface for 5 minutes with the DC material. Applying this conversion layer for a period of 10 (with a minimal difference in the number of protrusions compared to 5 min.) is neither suitable (higher operating costs) nor efficient from the point of view of the economy of the process.

SEM appearance of the base material and pretreatment samples are in Fig. 2.

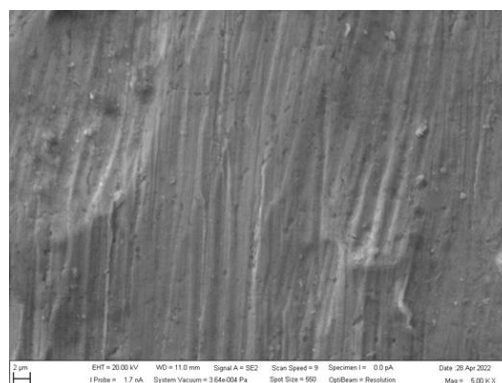


Fig. 2a DC 0 sample surface

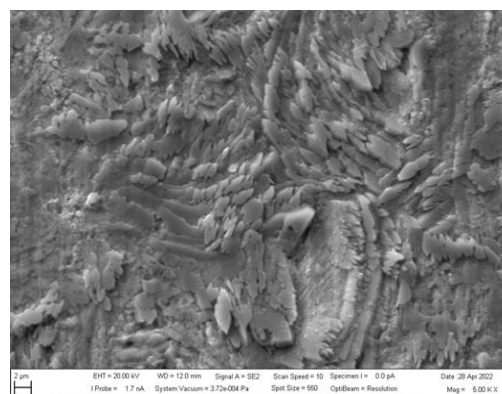


Fig. 2b DC 3 sample surface

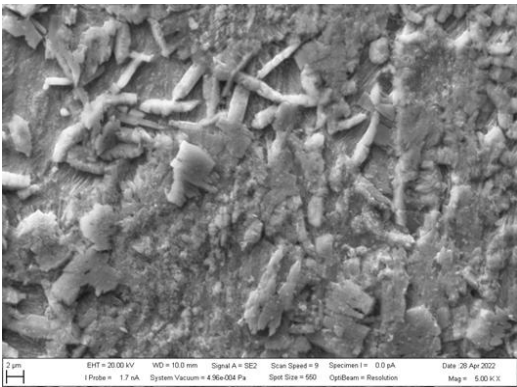


Fig. 2c DC 5 sample surface

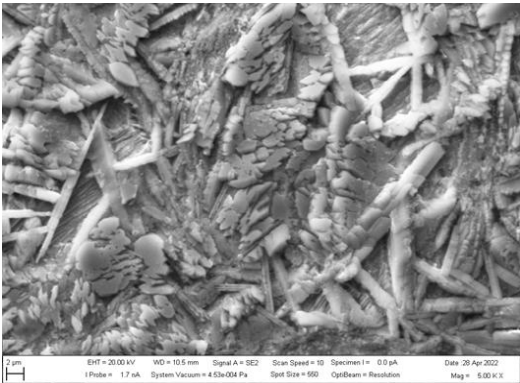


Fig. 2d DC 10 sample surface

Results of statistical evaluation for parameter Ra

The homogeneity condition for the Ra parameter values at different phosphating application times was verified by Levene's test. The value of p was as follows: DC (p = 0.5682 > 0.05) and this means that the null hypothesis of equality of variances is not rejected at the significance level of 0.05. The condition of homogeneity is fulfilled. A graphical comparison of the phosphating time for the parameter Ra is in Fig. 2.

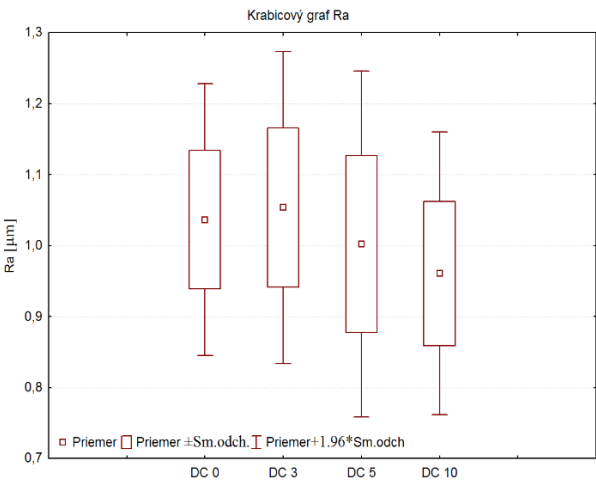


Fig. 2 Comparison of phosphating time for parameter Ra

The result of the one-factor variance analysis is $0.0011 < 0.05$, i.e. the null hypothesis is rejected at the level of significance, i.e. there is a statistically significant difference between the individual mean values of the Ra parameter at different phosphating times.

This means that the time of phosphating has an influence on the value of the Ra parameter.

Given that the null hypothesis of equality of means was rejected at the 0.05 significance level, post-hoc analysis subsequently identified pairs with a statistically significant difference (Table 3). Statistically significant differences were noted between groups DC 0 - DC 10, DC 3 - DC 10.

Table 3. Post-hoc analysis – parameter Ra

Ra - DC	Tukey HSD test			
	DC 0	DC 3	DC 5	DC 10
DC 0	-	0,8936	0,4991	0,0106
DC 3	0,8936	-	0,1501	0,0008
DC 5	0,4991	0,1501	-	0,326
DC 10	0,0106	0,0008	0,326	-

4. Conclusions

Based on the experimental measurements, it can be concluded that:

- using different application times when applying a phosphate conversion layer on uncoated deep-drawn steel creates a surface with a different appearance and different roughness values
- measurements of the roughness parameters at all applied times showed that the value of the parameters Ra and Rz after surface treatment by phosphating does not change significantly, the differences were manifested in the parameters RSm and R_{Pc}.
- the statistical evaluation showed that the phosphating time has a slight effect on the value of the Ra parameter.

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The influence of galvanic coatings as a chemical pretreatment of the surface on the microgeometry of steel materials

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Abstract: In the contribution, the surface quality of the steel substrate is analyzed from the point of view of its microgeometry as a set of quantities capturing the differences of individual surface changes. The subject of investigation are the surfaces of steel substrates, i.e. the base material, degreased surface, standard galvanized surface, surface after galvanizing and subsequent chromating, surface after phosphating and surface after phosphating and application of RAL coating.

Keywords: GALVANIZING, PHOSPHATING, STEEL, SURFACE QUALITY, ROUGHNESS

1. Introduction

The development of other technologies, such as mechanical pretreatment of the surface, degreasing and other preparatory operations as well as intermediate and finishing operations - rinsing, chromating, phosphating and others - is closely related to the development of electroplating. [1 - 5]

It is generally known that even with the best and most effective coating system, it is not possible to achieve satisfactory results (adhesion, durability, etc.) if this protective coating is not applied to a suitably pre-treated and cleaned surface. The surface layer is decisive in terms of the strength of the entire component under cyclic stress. From a physical point of view, the properties on the surface are significantly different from those in the volume - this transition is smooth, the properties do not change abruptly. The significance of the change is conditioned by the chemical composition, relief and structure of the material. Technological and functional conditions of material processing significantly affect the physical and chemical properties of the metal surface. [6 - 9]

From the point of view of the component's function, in many cases the geometric properties of the surface are very important (e.g. in conditions of friction and wear). Therefore, it is necessary to place sufficient emphasis on the assessment of the geometry of the surfaces and the determination of deviations of the profile from the defined plane.

Among the whole range of surface properties, its microgeometry plays a very important role. In order to assess the microgeometric condition of the surface, a surface evaluation and measurement system is built. [10 - 15]

Measurement with touch profilometers is one of the most sophisticated methods of assessing surface roughness with a larger range of measured characteristics, which can be used in laboratory as well as operational conditions. The basic source of information is the surface profile.

Quantities standardized in STN EN ISO 21920 are used to assess the surface structure. The surface structure is characterized by the following geometric parameters in the mentioned standard:

- P parameter – parameter calculated from the primary profile,
- R parameter - parameter calculated from the roughness profile,
- W parameter - parameter calculated from the waviness profile.

The basic source of information is the surface profile, which is created by cutting the real surface with a defined area.

Primary profile (P – profile) – a profile that results from a section of the measured surface by a plane that is perpendicular to this surface. It represents the basis for the numerical processing of the profile using profile filters and for the calculation of profile parameters.

Roughness profile (R – profile) – a profile that is derived from a primary profile by suppressing long wavelength components with a

profile filter. It is the basis for determining the parameters of the roughness profile.

Wave profile (W – profile) - a profile that is derived from the primary profile using profile filters. It is the basis for determining the waviness parameters of the profile.

The calculation system for evaluating the parameters of the surface profile, which is used in the mentioned EN ISO, is based on the system of the middle line of the profile of roughness, waviness and the middle line of the primary profile.

From the point of view of worldwide technical practice, the most widespread evaluation parameter of roughness is the mean arithmetic deviation of the considered profile Ra - an integral quantity that is often confused with the general term roughness. It should be noted here that this parameter has only informative value. It does not allow the resolution of sharpness or roundness of protrusions of profile irregularities, is significantly distorted by cracks and other random surface defects. Therefore, when evaluating the microgeometry of various types of surfaces, it is necessary to use a selected set of roughness parameters from the ISO 21920 standard, which will sufficiently accurately capture the specifics of the assessed surface.

2. Materials and methods

2.1 Basic material

Unalloyed structural steel of usual quality S235JR was used as the basic material. It is used for fusion-welded, statically and dynamically stressed parts of constructions and machines of medium thickness. Furthermore, for components made from sheet metal, longitudinally welded hollow profiles and forged components for thermal power equipment and pressure vessels operating with limited excess pressure and temperature up to 300°C.

The chemical composition of the materials is in Table 1.

Table 1. Chemical composition of used steel S235JR

Material	C	P	S	N
S235JR	0,17%	0,045%	0,045%	0,009%

2.2 Pre-treatment of the surface

The surface of the test samples of S235JR steels was without any surface treatments. The tested samples of both materials were classified into following categories:

1. Surfaces without further treatment – a steel sample is used for testing in the state in which it was delivered from the manufacturer (designation: Sample no. 1).

- Surface after degreasing - used bath AKTIGAL FB 5-6%, immersion at temperature 65°C, pH11, immersion time 5min. (designation: Sample no. 2).
- The surface is galvanized - after degreasing, the sample was immersed in the HELIOSTAR zinc bath of the company ENTONE OMI at a temperature of 18°C, pH 4.9, immersion time 20 min. (designation: Sample no. 3).
- Surface galvanized and chromated - after degreasing, the sample was immersed in a zinc bath and subsequently chromated in an IMMUNOX 3K bath from ENTONE OMI at a temperature of 18°C, pH 2, immersion time 35 min. (designation: Sample no. 4).
- After degreasing, the surface was phosphated in a DURIDIN 3822 IT bath from the HENKEL company at a temperature of 40°C, pH 5.8, by spraying for 3 min. (designation: Sample no. 5).
- A RAL 9016.5020/0661 coating was electrostatically applied to the surface after degreasing and phosphating with a NORDSON type gun, 65 kV (designation: Sample no. 6).

2.3 Roughness measurement methodology

Surface roughness of the produced samples was evaluated according to ISO 21920 by the contact method using a stylus profilometer Surftest SJ-201, Mitutoyo, Tokyo, Japan. This standard defines roughness parameters based on the deviation from the mean line for the primary profile. The measurement parameters used were as follows:

- a measured profile: R, filter: GAUSS, a sampling length $\lambda_c = 0,8$ mm, a number of sampling lengths $N = 5$,
- an evaluation length $l_n = 4$ mm,

In order to obtain as much information as possible about the produced surfaces in individual positions, the surface roughness was evaluated using a set of several parameters:

- the arithmetical mean deviation of the assessed profile (R_a),
- the maximum height of profile on the basic length (R_z),
- the total height parameter (R_t),
- the mean width of the profile element on the length (R_{Sm}),
- the mean number of peaks per centimeter (RP_c),

3. Results

By measuring the selected roughness parameters on the basic and pre-treatment material, the values shown in Table 2 were achieved. For surface samples no. 5 and 6, it was not possible to measure the RP_c and R_{Sm} values, as they did not show the necessary number of protrusions for evaluation.

Table 2. The mean of roughness parameters

Sample	Measured values of roughness parameters				
	R_a [μm]	R_z [μm]	R_t [μm]	RP_c [1/mm]	R_{Sm} [μm]
1	0,96	5,17	6,22	148,1	67,75
2	0,79	4,81	6,09	197,8	52,06
3	0,79	4,42	5,47	186,2	54,53
4	0,67	4,13	5,52	221,0	45,70
5	0,83	4,63	5,64	153,2	66,03
6	0,13	2,29	3,62	-	-

Profilograms and Abbott Firestone curves of individual surfaces were also realized Fig. 1a-1f where we recorded a change in the surface roughness of the tested materials.

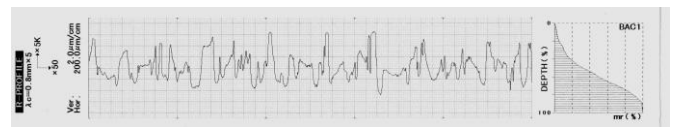


Fig. 1a Profilogram and Abbott Firestone curve for the sample no. 1

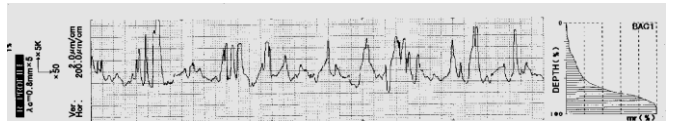


Fig. 1b Profilogram and Abbott Firestone curve for the sample no. 2

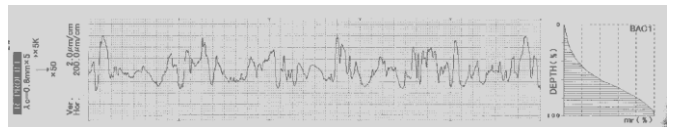


Fig. 1c Profilogram and Abbott Firestone curve for the sample no. 3

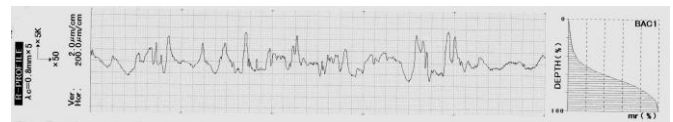


Fig. 1d Profilogram and Abbott Firestone curve for the sample no. 4

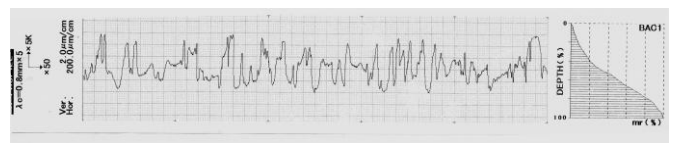


Fig. 1e Profilogram and Abbott Firestone curve for the sample no. 5

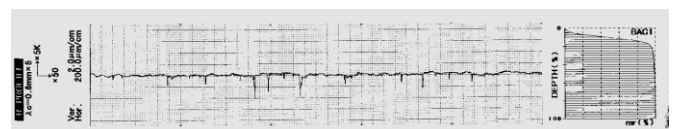


Fig. 1f Profilogram and Abbott Firestone curve for the sample no. 6

By comparing the measured values with each other, it can be concluded that the surface morphology in the process of pretreatment and subsequent surface treatment by galvanization remains basically the same. This fact is also confirmed by the profilograms of the surfaces shown in Fig. 1, which document the relief of the degreased surface and the surface after degreasing and subsequent galvanizing.

From a quantitative point of view, it can be stated that after galvanizing, or after galvanizing and chromating, there is a very slight decrease in the roughness characteristics, evaluating the surface in the vertical direction, Fig. 2a-2e, while at the same time the number of profile protrusions per unit length RP_c increases slightly, which logically results from a slight decrease in the spacing of protrusions R_{Sm} . This phenomenon occurs due to the in-house technology of surface formation by galvanization. This fact was most evident in surfaces after galvanizing and subsequent chromating.

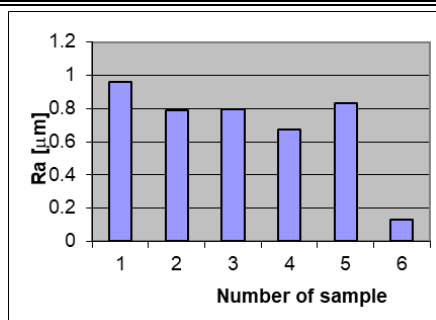


Fig. 2a Graph of measured Ra values

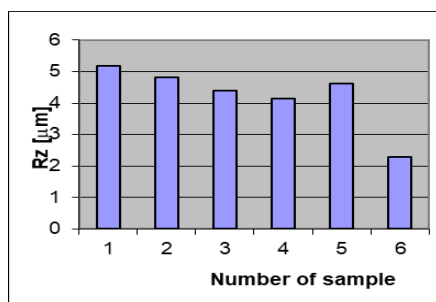


Fig. 2b Graph of measured Rz values

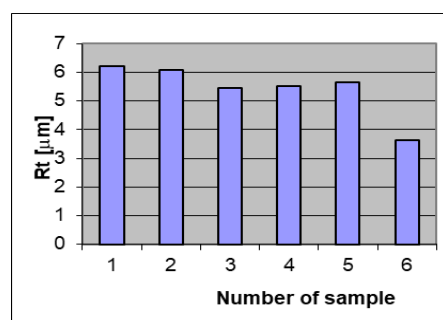


Fig. 2c Graph of measured Rt values

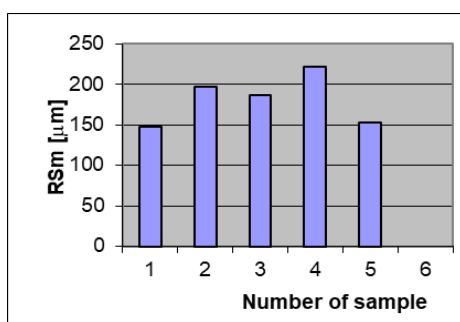


Fig. 2d Graph of measured RSm values

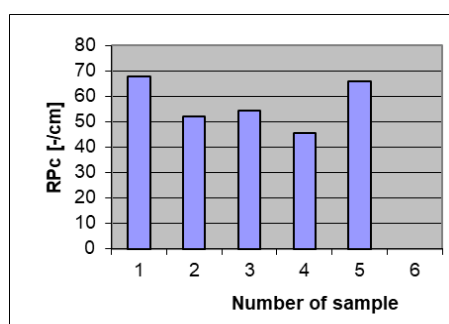


Fig. 2e Graph of measured RPC values

Due to the complexity of the assessment, a plastic surface (RAL) was also included in the evaluation, which was applied to the surface after degreasing and subsequent phosphating. The production technology as well as the hardening nature of the plastic material used ensured the creation of an almost smooth surface with a roughness Ra of approximately 0,13 μm, while the maximum height of irregularities on the evaluated relief Rz was 2,29 μm. From the point of view of the thickness of the applied coating, which was greater than 50 μm, it is clear that the original surface relief could not be copied.

4. Conclusions

Based on the experimental measurements, it can be concluded that:

- the morphology of the surface in the process of pre-treatment and subsequent surface treatment by galvanization remains basically the same,

- after galvanizing, or after galvanizing and chromating, there is a very slight decrease in the roughness characteristics, evaluating the surface in the vertical direction. This fact was most evident in surfaces after galvanizing and subsequent chromating,

- the production technology as well as the curing nature of the RAL coating ensured the creation of an almost smooth surface, and since the thickness of the applied coating was 50 μm, there was no copying of the original surface relief.

Acknowledgement

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Non-detonating chemical mixture for non-invasive methods of rock breaking

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Abstract: Within the Innovation Project of the Ministry of Science and Technological Development of the Republic of Serbia, researchers of Blasting Center at the University of Belgrade - Faculty of Mining and Geology have developed several different non-detonating chemical mixtures for non-invasive methods of rock breaking. Laboratory and polygon tests gave the satisfactory results and knowledge enough to start the practical experiments in the field. The basis of this innovation is a theoretical assumption that certain chemical mixtures release a large quantity of gases during combustion. If these gases are found in the enclosed space a growing pressure on the walls of the chamber in which combustion takes place will be resulted. If this space is a borehole with good stemming, the rising pressure should be sufficient to break the rock material in which the borehole was drilled. Chemical mixtures developed through the research do not detonate. They represent the generators of borehole pressure made up of oxidants and fuels and the modifiers to adjust the speed of combustion and ignition temperatures. Rock breaking occurs because of progressive increase in pressure. Non-detonating chemical mixtures can be applied in road and railroad construction, demolition works, secondary breaking, rock breaking for foundation, trenching and similar civil construction operations especially in urban areas as well as quarrying of dimension stones. In other words, for different methods of rock breaking where negative effects of blasting should be avoided.

Keywords: NON-DETONATING, CHEMICAL MIXTURE, ROCK BREAKING, BOREHOLE PRESSURE

1. Introduction

Regarding the method of decomposition, except for black powder, which is classified as deflagrating explosive, all commercial explosives are decomposed by detonation. Deflagrating explosives have a relatively low decomposition rate because the activation energy is transferred from layer to layer by heat transfer. Detonation is the process of explosive decomposition, where the energy required to activate the explosive molecules is transferred from layer to layer by means of a shock wave, which moves through the explosive material at supersonic speed. During the detonation of explosives, there is a sudden release of energy, which is partly spent on breakage the rock mass, moving the broken rock, heating the immediate rock environment and on other useless effects of explosive energy such as seismic waves. The energy of seismic waves induced by blasting manifests itself in the form of ground vibration. Another negative effect of every blast are: air blast, toxic fumes, and flyrock. For this reason, it is necessary to strictly define safety zones to protect the immediate surroundings of the blast field from these negative effects when planning blasting especially in urban areas [1].

During the construction of buildings in urban areas, in some cases there is a need to remove large quantities of solid rock mass that cannot be excavated by machinery. For smaller quantities, the problem can be solved by hydraulic jackhammers mounted on the excavator. However, when larger volumes of rock mass are involved, the use of explosives is necessary.

In cases where there are facilities declared as cultural heritage, industrial and other objects that are very sensitive to ground vibration, blasting using commercial explosives may be prohibited. Despite this, the need to remove a certain solid rock mass still exists.

During building demolition in urban areas, certain parts of the structures, which are usually concrete or reinforced concrete, are blasted. In that case, the problem of negative effects of blasting is even more pronounced, so the procedure and calculation are even more complex [2].

The use of explosives is limited during the extraction of dimension stone blocks. Contour blasting methods using small-diameter explosive charges or a detonating cord are most often used to cut off primary blocks from the remaining rock mass. The parameters of contour blasting must be strictly defined so that the explosive energy would be used only for cutting the block and not for crushing the rock mass. The procedure is similar when the primary block is split into commercial blocks.

During production blasting in surface mines, depending on the quality of the blasting, the blasted rock mass may contain a smaller

or larger percentage of oversized fragments of rock mass called boulders that must be subsequently crushed. A high percentage of boulders worsens the technical and economic indicators of surface mining, reduces the performance of loading and transport machinery, and increases the unit cost of the product.

The tendency in the world today is to find new solutions that can be applied to break solid rock masses, and which will be an adequate replacement for commercial explosives in sensitive areas. The reason for this is the problems related to blasting in urban areas, in road and railroad construction, demolition works, secondary breaking, rock breakage for foundation, trenching, stabilization of slopes and similar civil construction operations especially in urban areas as well as quarrying of dimension stones. In all the cases mentioned, there is a problem of removing solid rock mass or concrete structures in an efficient way, while protecting the environment. Except where prohibited or restricted, blasting remains the cheapest method of efficiently removing large volumes of solid rock mass. However, the problem of the negative effects of blasting remains.

The negative effects of blasting have influenced the researchers to work on improving new chemical mixtures that could be an adequate replacement for explosives. These are mainly different compositions that develop borehole pressure without the detonation process and which are placed in a previously drilled series of boreholes (in a case of the extraction of primary blocks of dimension stone, splitting the primary block of dimension stone into commercial blocks as well as cutting off a rock mass during slope stabilization as a substitute for contour blasting methods) or according to a pre-calculated pattern of bore holes (in a case of the building demolition, secondary breaking, rock breakage for foundation, trenching and similar civil construction operations especially in urban areas, etc.). When the stress overcomes the tensile strength of the rock, cracks appear along the predisposed direction and the rock is broken.

One of the mixtures that are used as a substitute for explosives for the generation of borehole pressure is expansive mortar. Expansive mortars do not detonate. Although there are several well-known manufacturers of expansive mortars, they are mostly chemical agents with similar characteristics. The expansive mortars are mixed with water in a certain ratio according to the recommendation of the manufacturer. When the mixture is obtained, it is poured into the boreholes. Expansive mortar in the boreholes expands, developing a pressure force in the range of 7-8 kN/cm², which is much more than the required force for splitting the rock mass. The speed of expansion directly depends on the temperature of the rock mass.

Expansive mortars have the following advantages: the rock mass splitting process takes place without detonation and

explosions. Rock splitting is done without noise, dust, and toxic fumes. Expansive mixtures do not cause ground vibration, flyrock and excessive damage to the surrounding rock mass. They are clean ecological products and very acceptable from an environmental point of view. Storage and transport are not dangerous for the environment.

One of the well-known expansive mortars on the market is DEXPAN [3]. DEXPAN is used for controlled demolition of buildings, especially in urban areas, minor construction works, such as trenching and the extraction of blocks of dimension stone: granite, marble, limestone, and onyx. DEXPAN [3] is a mixture of powdery consistency which, expanding inside the boreholes, develops a pressure of 1241 bar, enabling the cutting the dimension stone blocks safely, without noise, vibration, and dust. Handling the DEXPAN mixture does not require special permits and certificates, as is the case with explosives, does not require the employment of a specially trained operator, as well as special regulations for safe storage, transport, and maintenance, because it is not categorized like explosive.

Cardox [4] non-detonating expansive system is another alternative to classic explosives. The Cardox system [4] has several different tubes for specific applications. The tubes are filled with liquid carbon dioxide (the same as a fire extinguisher). After activating the chemical heater with a small electrical charge, liquid carbon dioxide is converted into gas. This conversion expands the volume of CO₂ and increases the pressure inside the tube until it causes the disc at the end of the tube to burst. Then the release of CO₂ occurs - now 660 times greater than the original volume - through a special discharge nozzle, which creates a force, at pressures of up to 3000 bar. The whole process takes place in milliseconds. Since it does not detonate, the Cardox system is suitable for use in sensitive areas, for controlled demolition of reinforced concrete, tunneling, shafts, and underwater demolition. It does not create air blast, vibrations, dust, or harmful gases, so it is suitable for use in urban areas and in populated areas where blasting by conventional methods is prohibited. The Cardox system is also widely used for the exploitation of ore, as well as dimension stone blocks [5].

Within the Innovation Project of the Ministry of Science and Technological Development of the Republic of Serbia [6], researchers of Blasting Center at the University of Belgrade - Faculty of Mining and Geology have developed several different non-detonating chemical mixtures for non-invasive methods of rock breaking. Chemical mixtures do not detonate. They represent the generators of borehole pressure made up of oxidants and fuels and the modifiers to adjust the speed of combustion and ignition temperatures. The gases increase the borehole pressure and cause stresses that should overcome the tensile strength of the rock and cause rock breaking. The laboratory and field tests were consistent with research of foreign Companies that dealing with this problem for several years.

2. The characteristics of developed non-detonating chemical mixtures

The basis of this innovation is a theoretical assumption that certain chemical mixtures release a large quantity of gases during combustion. If these gases are found in the enclosed space a growing pressure on the walls of the chamber in which combustion takes place will result. If this space is a borehole with good stemming, the rising pressure should be sufficient to break the rock material in which the borehole was drilled. Chemical mixtures developed through the research do not detonate. They represent the generators of borehole pressure made up of oxidants and fuels and the modifiers to adjust the speed of combustion and ignition temperatures. Rock breaking occurs because of a progressive increase in pressure [2,6].

Developed non-detonating chemical mixtures are pyrotechnic compositions whose energy potential is lower than that of black

powder. The process of developing the non-detonating chemical mixtures has started from the concept that new compositions should have the characteristics of „benumbed“ black powder in order to keep the rate of decomposition by deflagration even in the conditions of confined charging [2,6].

These generators of borehole pressure represent a wide range of mixtures made up of oxidants and fuels containing modifiers to adjust the speed of combustion and ignition temperatures. Compositions combust during the activation on the open with the speed of 2-5 cm/s, while in the closed space a significant acceleration of combustion is taking place, but still below the explosive one. Thereby it comes to a sudden jump in pressure, leading to an increase in combustion rate in such a way that there are at least two decomposition rates until the final decomposition of the mixture. All compositions have powdery consistency with the cartridge bulk density of 0.85 to 1.1 kg/dm³. Commercial explosives detonate at a speed of 2000-6000 m/s, while the decomposition velocity of these mixtures should be set at 180 - 300 m/s. Combustion rate is lower than of black powder and conventional fuels [2,6].

Gas pressure grows exponentially during the several tens of milliseconds until they overcome the rock tensile strength, which is 10-20% of the compressive strength of rocks. Depending on the composition of the mixture it is possible to achieve borehole pressures at the initial speed of decomposition of 34, 68, 102 and 136 MPa when it comes to jump of combustion rate in the function of lnP, which gives a new pressure jump before the final decomposition of the mixture. Thus, mixture achieves at least two speeds in the combustion process. Gas pressure of powdered redox mixtures is aimed primarily at the bottom part of the borehole. Powdered redox compositions for this purpose after ignition burn at the subsonic speed, even at higher pressure up to 276 bar, while with the use of explosives a supersonic shock wave is created at normal atmospheric pressure.

2.1 The modifiers

In these compositions a decomposition rate and pressures of released gases in the borehole can be controlled to achieve stresses in rock mass slightly greater than the rock tensile strength. All this can be achieved by modifying the basic redox composition.

These modifiers are combustion catalysts such as metal oxides and organometallic compounds. Compounds that promote the reaction rate and the amount of released gases are also in use, because they also participate in the creation of gaseous products and thus increase the gas volume of mixtures. Besides these compounds, substances that contribute to the release of heat may also be used, although they do not release gaseous products alone. The released heat helps the reaction rate at which emission of gases occurs and affects the increase in pressure because with the heat the volume of released gases increases, too. For this purpose, various metal powders can be used such as: Al, Mg, FeSi, paying special attention to safety in the work [2,6].

2.2 Charging the cartridges with non-detonating chemical mixtures

The best effects are achieved by direct loading of boreholes with non-detonating chemical mixtures but it is often impossible in real conditions of application, so it is provided that the mixture is transported in form of cartridges. The cartridge should be made of flexible plastic material in order not to relieve until the reactive mixture is completely deflagrated after initiation. The possibility of deformation of 10 - 20% of cartridge is preferred before it bursts, and the diameter of the cartridge should be as close to the diameter of drilled hole.

Elasticity of the cartridge is achieved by choosing the material that can withstand plastic deformation, at least until the expansion of the cartridge on the borehole wall. In the case that the diameter of the cartridge is 30 to 33 mm, plastic cartridge in the radial direction

should withstand the increase of the diameter on 35 to 38 mm before it expands.

During the research cartridges of high-density polyethylene, with the outer diameter of 25 mm, inner of 20 mm, wall thickness 2.5 mm and length 150 mm were used. Different types of mixtures were examined in terms of composition, powdered consistency, combustion time, the degree of coat deformation. For the initiation of the mixtures, various systems that were available were applied. At the same time, several redox compositions with increased density, using a natural binder for thickening the mixtures were also made and tested [2,6].

Stemming the bore holes was carried out with well compressed mixed clay - sandy material. It must be taken that stemming is not burden in the geometry but should be for a minimum of 50% higher than burden and the distance between bore holes. To determine the parameters of blasting the same amount of non-detonating chemical mixture per m^3 is recommended as in the case with conventional explosives 290-600 g/m^3 . Stemming must be well done to withstand the pressure of released gases and direct them to the walls of the bore holes, where there is a breaking of the rock material due to tension stresses. In this case, the detonation does not occur as well as the formation of shock waves as in case during the use of commercial explosives.



Fig. 1 Charging the cartridges with non-detonating chemical mixture [2,6]



Fig. 2 Cartridges charged with non-detonating chemical mixture [2,6]

2.3 Initiation of the non-detonating chemical mixtures

Initiation of non-detonating chemical mixtures was done with electrical fuse heads or NONEL shock tubes. Figure 3 shows preparing the initiation of cartridge with NONEL shock tube while Figure 4 shows preparing the initiation of cartridge with electrical fuse head.

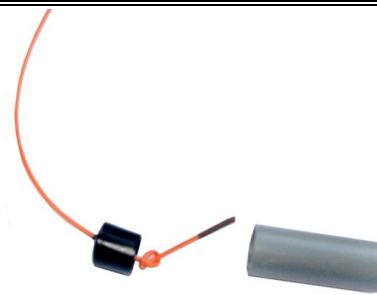


Fig. 3 The initiation of cartridge with NONEL shock tube [2,6]

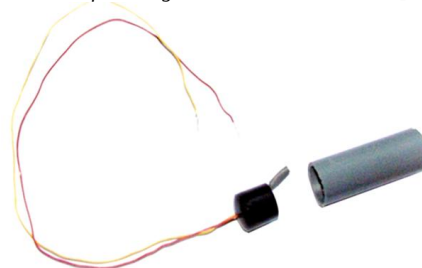


Fig. 4 The initiation of cartridge with electrical fuse head [2,6]

Non-detonating chemical mixture had different sensitivity to the initial impulse. Most sensitive are ignited with spark generated in standard NONEL shock tube (20 mg/m reactive mixture) while those less sensitive required a stronger initial impulse.

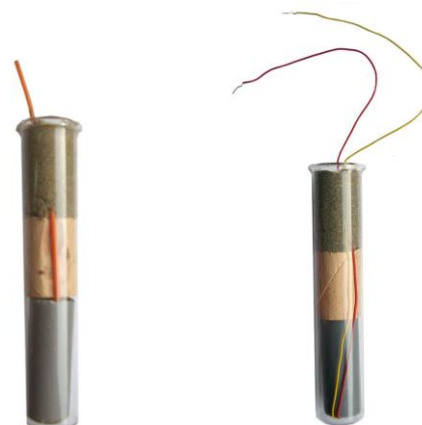


Fig. 5 Initiation of charges of non-detonating chemical mixtures with NONEL shock tube (left) and electrical fuse head (right) [2,6]

2.4 Polygon tests of non-detonating chemical mixture

Polygon tests of non-detonating chemical mixtures were carried out at the granite quarry. The tests consisted of cutting off a granite block using non-detonating chemical mixtures. A borehole with a diameter of 32 mm was drilled into the granite block, in which the cartridge with a diameter of 25 mm was placed. The cartridge was charged with a non-detonating chemical mixture. Initiation of the charge of non-detonating chemical mixture was done with an electrical fuse head [2,6].

The results of testing are satisfactory. As shown in Figure 6, cutting of the granite block was achieved by increasing the pressure of the gases produced by the combustion of non-detonating chemical mixture. The pressure of released gases in the borehole creates stresses in the rock mass slightly higher than the rock tensile strength, which is 10-20% of compressive strength and causes rock breaking without a shock wave.

After the fracture of rock mass, the stress decreases due to a sudden drop in the pressure of generated gases, thus avoiding excessive flyrock of rock pieces. As shown in Figure 6, after the fracture of rock mass, gaseous products of the combustion of non-

detonating chemical mixture exit through the newly formed cracks, which causes the pressure of gases to decrease intensely, and the gas mixture begins to decompose by burning. The results of polygon tests of non-detonating chemical mixture are shown in Figure 6.



Fig. 6 The results of polygon test of non-detonating chemical mixture [2,6]

3. Application of non-detonating chemical mixture

Non-detonating chemical mixture as borehole pressure generators, can be widely used as a replacement for commercial explosives when it is necessary to break the rock or concrete structures non-invasively, in sensitive and urban areas, such as:

- road and railroad construction,
- demolition works,
- secondary breaking,
- rock breakage for foundation,
- trenching,
- stabilization of slopes and similar civil construction operations especially in urban areas,
- quarrying of dimension stones block etc.

The main difference between the effects of explosives and non-detonating chemical mixtures is that in the case of non-detonating chemical mixture the energy is transferred to the rock mass by increasing the pressure of released gases without shock waves. In just a few milliseconds gas pressure exceeds the tension strength of rocks and splits or breaks the rock depending on the non-invasive method of rock braking. Stress waves rapidly decrease after rock breaking which is of great importance for the reduction of ground vibration, flyrock and possible damage of the surrounding rock mass.

Ground vibration is many times less than that caused by commercial explosives, and safety zone against flyrock does not exceed 30-35m. The air overpressure is 6-10 times lower than during blasting using explosives. An essential condition for successful application of non-detonating chemical mixture is that the cartridge must fit well with the wall of the borehole, because the smallest gap affects the reduction of the effect due to drop of the released gas pressure. Cartridge should have such a diameter that can be inserted into the bore hole without compression, and at the same time the gap between the cartridge and the borehole wall should be as small as possible.

4. Conclusion

After completion of laboratory and polygon testing, the basis for successful IN SITU implementation of non-detonating chemical mixture was created. The final adjustment of compositions remains, in terms of the optimization of charging and initiation pattern in specific types of rock regarding the type of non-invasive methods of rock breaking.

The best results are achieved if non-detonating chemical mixture is used in compact rock mass, because in bore holes with intensive system of joints, there are two reasons for the reduction of effect of non-detonating chemical mixture [2,6]:

1. expiration of products of decomposition through joints and thereby the inability of directing the released energy,
2. inability to create the optimal pressure and force necessary to break the rock because of conditions in which the reaction itself takes place.

For these reasons, the retention of the released gases in the cartridge is a necessary precondition for effective application of these mixtures until obtaining the optimum pressure.

Further research is moving towards finding adequate rates of decomposition of non-detonating chemical mixtures, achieving optimal bore hole pressures with the absence of detonation, controlling ground vibration, toxic fumes, flyrock, etc. A special problem is the precision of the initiation of non-detonating chemical mixtures, which is required, for example, when cutting the rock material.

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Modeling of roller leveling process

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Abstract: Roller leveling is a technological process of metal forming, used to minimize the flatness of sheet blanks and reduce the level of residual stresses. When leveling, the workpiece is subjected to cyclic alternating bending with decreasing amplitude. The report presents an experimental testing set-up designed and used to model the leveling process. The equipment is described and the first results are presented.

Keywords: LEVELLING PROCESS, LEVELLING FORCE, MODELING

1. Introduction

Sheet blanks are widely used in industrial production. For their cutting, laser and plasma cutting is often used. After that, sheet blanks often have insufficient geometric accuracy (flatness). To improve the geometric accuracy of sheet blanks various methods can be used, including roller levelling.

Roller levelling is a technological process of metal forming, used to minimize the flatness of sheet blanks and reduce the level of residual stresses. When levelling, the workpiece is subjected to cyclic alternating bending with decreasing amplitude. In this case, the penetration depth of deformation should be at least 0.7 of the thickness of the workpiece [1].

When levelling due to the presence of cyclic loading, there are conditions in the process that both hinder the levelling process (hardening) and facilitate it (the Bauschinger effect). All this can give rather large differences in the results of calculations performed by different methods. To obtain reliable results it is necessary to know the dependence of stress on the degree of deformation for a given material.

The existing experience of the world's leading manufacturers of process equipment (ARKU, KOHLER, etc.) shows the feasibility of using multi-roll levelers both for straightening piece sheet parts and for integrating levelers into existing and planned automated lines for the production of piece sheet blanks of a wide range for machine-building, petrochemical, aerospace and other branches of industrial production.

Multi-roll levelers are used for cold straightening of steel sheet blanks and blanks of non-ferrous alloys up to 50 mm thick and up to 5000 mm wide. Hot straightening of steel sheet blanks is carried out at temperatures of 500-700 °C, mainly immediately after leaving the working stand of the rolling mill. Sheets with a thickness of over 40 - 50 mm are usually straightened in a cold state under presses.

2. Experimental set-up

The experimental set-up is designed for modeling the leveling process of a sheet blank. Technological tests are designed to identify the ability of a metal to undergo deformations similar to those that the metal undergoes during its processing (leveling).

Physical modeling of the leveling process is carried out using up to 13 leveling rolls from the input side of the mill 1, where it is captured by rotating rolls. The workpiece moves to the output side of the mill; during the movement, the workpiece is subjected to successive alternating bends with decreasing amplitude (leveling). When leveling, force is recorded using strain gauges installed in the mill, and torque is recorded using strain gauges installed in the gearbox 2.

Modeling of leveling is carried out as follows. The workpiece is fed into the gap between the rolls from the input side of the mill 1, where it is captured by rotating rolls. The workpiece moves to the output side of the mill; during the movement, the workpiece is subjected to successive alternating bends with decreasing amplitude (leveling). When leveling, force is recorded using strain gauges installed in the mill, and torque is recorded using strain gauges installed in the gearbox 2.

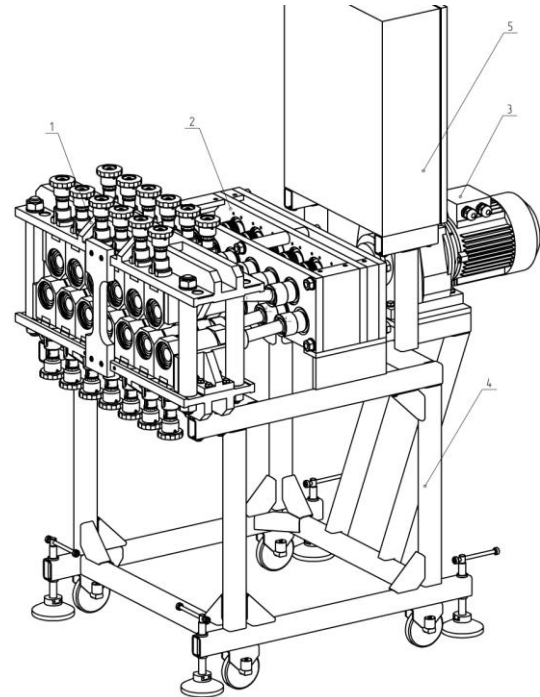
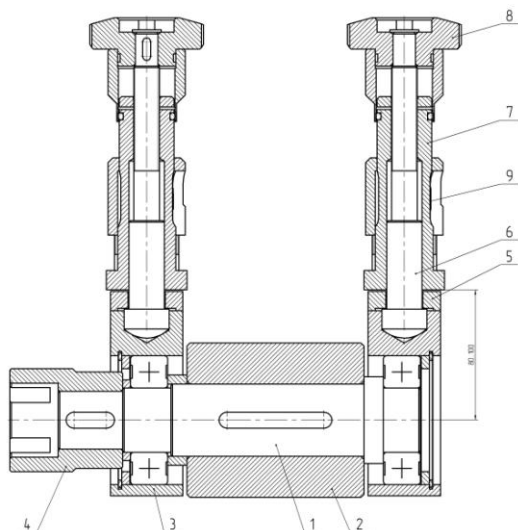


Fig. 1 Experimental set-up used in the modeling.

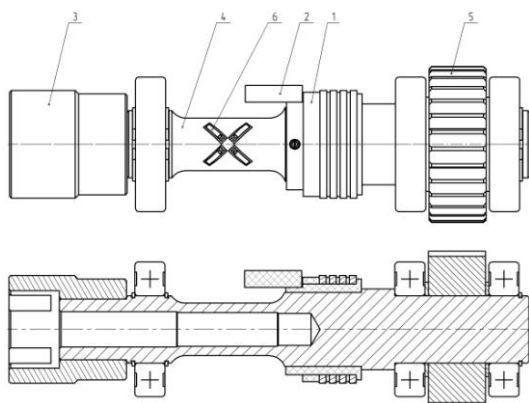
Table 1: Experimental equipment technical parameters.

Power supply	220 V, 50 Hz
Power of installed engines, kW	2,2
Maximum sample length, mm	1500
Minimum sample length, mm	200
Maximum sample width, mm	100
Minimum sample width, mm	50
Maximum sample thickness, mm	10
Minimum sample thickness, mm	1

Sketches of the leveling roll and gearbox shaft with strain gauges are shown in Fig. 2 and 3, respectively.

**Fig. 2** Sketch of the leveling roll.

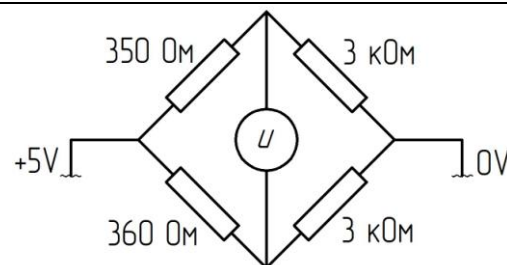
In the sketch shown, part 4 transmits torque to roll 2 mounted on shaft 1. Using screw 6, part 7 experiences tensile stresses in a specially prepared section where strain gauge 9 is installed.

**Fig. 3** Sketch of the gearbox shaft.

In the sketch shown, 1 – current collector; 2 – amplifier; 3 – part for connecting to the cardan shaft; 4 – shaft; 5 – gear; 6 – strain gauge.

Force measurements were carried out using a bridge circuit (Fig. 4).

Strain gauges BA350-100AA(11)-BX30 with a nominal resistance of $350 \pm 0.2 \text{ Ohm}$ and a gain of $2.11 \pm 1\%$ were used. Standard 360 Ohm and 3 kOhm resistors were used.

**Fig. 4** Bridge circuit.

To convert electrical quantities into force values, a preliminary calibration of the bridge circuit was carried out at two points. For calibration, an HBM RTNC3/15T sensor with a HBM WE2108M meter was used. The accuracy of the HBM RTNC3/15T sensor is within 17.5 N.

3. Conclusion

The article presents the design of an experimental set-up for modeling of the leveling process. The energy-power parameters obtained during modeling can be used to adjust calculations and computer models during computer simulations.

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Additive technologies applying in the design, development and filtering materials manufacturing

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Abstract: On the filter for fine air purification example the possibilities of additive technologies are shown, which allow to simplify and facilitate significantly the product development process, in particular, the filtering purpose. The results of 3-D modeling of the filter design, as well as 3-D modeling and 3-D printing of the tooling for studying the properties of filter elements to the filter and their structural elements (except for the filter layer) are given. The possibility of questions operative solution in case of adjustment necessity of tooling designs and filter elements at additive technologies application is noted.

Keywords: FILTER MATERIALS, WOVEN MESHES, 3D PRINTING, SAMPLES, INVESTIGATIONS, PROPERTIES

1. Introduction/Введение

The intensity of additive technologies development (AT) is unparalleled [1]. These technologies have fundamentally changed the design and construction processes and have found wide application in such industries as automotive and aircraft construction, electronics, medicine and others, due to their advantages: the ability to quickly change the shape and size of manufactured parts, to create products of complex geometry with high dimensional accuracy and the ability to minimize the consumption of the materials used [1-5]. The additive technologies application in the creation of permeable materials, which include the filtering materials considered in this work, has opened good prospects for developers. Give one example, in [6] additive technologies were used in the introduction of mesh structures into the volume of parts without additional supporting structures and boundary conditions, in [7] materials on experimental samples of filtering materials rapid prototyping with orthotropic structure assembled with tooling using 3D printing are presented, in [8] the possibility of using additive technologies for laboratory research and creation of in-plastic filter from cross-linked polyethylene has been investigated. The advantages of additive technologies are especially evident when it's necessary to promptly fulfill one-time orders from consumers for the filtering devices design, which in some cases can be executed in a complete cycle in laboratory conditions.

The work is aimed at sharing experience in the application of additive technology on the fine air purification filter example.

2. The results of experiment and their discussion

The main role in the purification of liquids and gases process, in particular, air, is played by filtering materials (FM), which provide the performance characteristics required by the consumer, from which filtering elements (FE) are made, in turn, on the basis of which a filtering device is constructed (in this case - filter for fine air purification (filter)). Accordingly, the algorithm for the development of a fine air purification filter included the following main operations:

- 1) designing a FM with a given filtration fineness;
- 2) calculation of the filtration area providing the required throughput capacity of the filtering device;
- 3) filter and FE design development and calculation of the number of filter elements;
- 4) tooling design development for properties research;
- 5) fabrication of FE blanks from FM and study of their properties;
- 6) fabrication of structural elements for FE assembly;
- 7) assembly of FE and filter.

The scheme of the filter development process agrees well with the four types of AT applications cited in [9], which were used for the main operations: 3-D modeling of the filter, FE and tooling to study their properties, manufacturing of the filter element components (except for the filter layer) and tooling. Methodology of creation of FEs and devices based on them does not depend on customer's requests, but for reference we note that in the considered case the fineness of filtration of the device was no more than 5 microns, throughput capacity not less than 70 m³/min, pressure drop not more than 500 mm Hg, temperature at operation not exceeding 50 °C, overall dimensions amounted to 640x640x150 mm, along the perimeter of the filter elements should be indented not less than 40 mm.

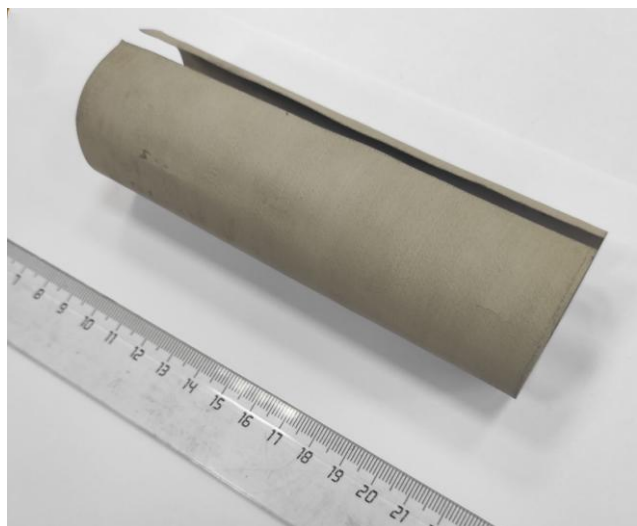
At the first stage, a composite thin sheet filtering material based on finely dispersed nickel powders of high flexibility was developed to produce sintered porous blanks of tubular FEs by rolling (at this stage of the work a preliminary conclusion was made about the use of tubular FEs). The choice of thin sheet material was made taking into account the trends analysis in this area of FM creation, which are mainly reduced to achieving a lower price for the product compared to competitors with its high consumer properties (low hydraulic resistance, high flow capacity and filtration fineness, good mechanical strength, long service life, etc.). The main ways to fulfill these requirements nowadays are creation of porous structures anisotropic in the filtration direction (providing reduction of filtering layer thickness to a minimum), filtration area increase (mainly by corrugation), FM porosity increase, introduction of innovative design solutions for specific filtration processes realization).

Then, based on the Darcy expression for laminar flow, knowing the value of the viscous permeability coefficient of the developed FM [10], the filtration area was calculated to provide the required filtering device capacity (it is also possible to determine the filter area by determining the capacity of the workpiece at a given pressure drop), digital 3D models of the filter, FE and tooling were developed to study their properties and the number of filter elements was calculated. When developing 3D models of the filter and FE, a flexible relationship was established between their dimensions, the total area of the filtering surface, the number of filter elements and the dimensional limitations of the consumer; when developing a 3D model of the tooling, the dimensions of the sheet blank before rolling were taken as a basis. Then the structural elements were fabricated and the FE and filter were assembled. The figures below illustrate some operations results of the described process.

Fig. 1 shows photographs of a composite thin-sheet blank of the filter layer after sintering and rolling for the manufacture of FE.



a)



b)

Fig. 1 Composite thin-sheet blank of the filter layer after sintering (a) and rolling (b) for the manufacture of FE.

The tooling appearance for controlling the properties of sintered filter layer blanks are shown in Fig. 2 and the process of determining the value of maximum pores are shown in the Fig. 3.

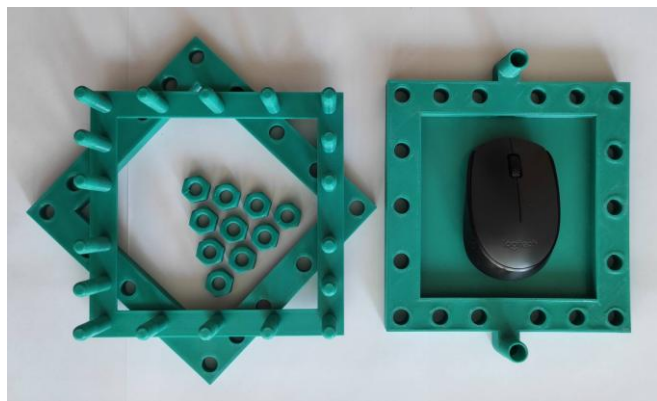


Fig. 2 The tooling appearance for controlling the properties of sintered filter layer blanks.



Fig.3 Determination of the maximum pore size by the bubble method.

The developed 3D models of the filter and FE are presented in Fig. 4 and 5.

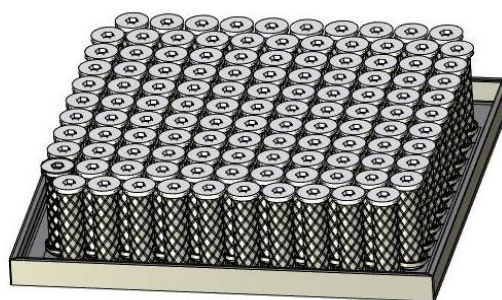


Fig.4 3D model of a filter for fine air purification.

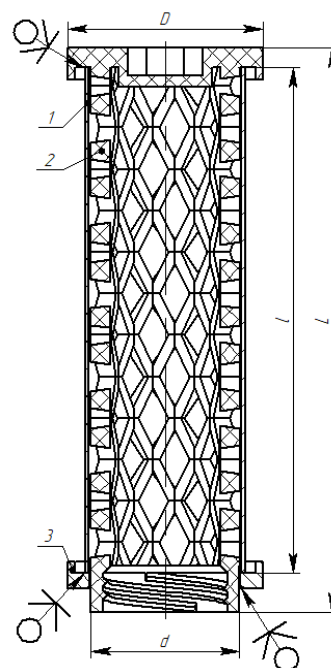
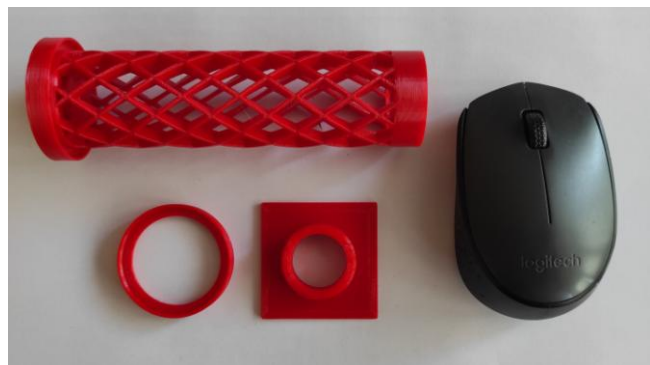
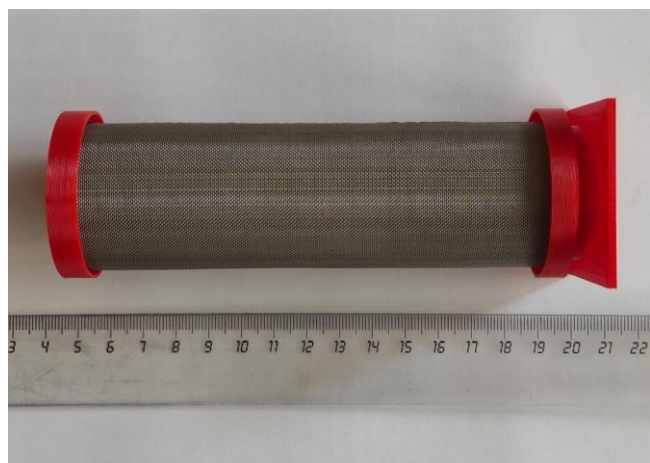


Fig. 5 3D filter elements model: 1 - composite filtering layer assembled with outer layers of woven metal mesh; 2 - support frame; 3 - snap ring.

The appearance of the components made on a 3D printer for the assembly and installation of the FE and filter element is shown in Figure 6.



a)



b)

Fig. 6 Accessories for assembly and installation FE (a) and filter element (b).

To manufacturing by 3D printing of components for assembly and PE mounting and tooling for controlling the sintered blanks properties of the PE filter layer 3D printer model Z - BOLT S300 (Belarus) and PET - G grade UMKA (Belarus).

The filter design is conditioned by the peculiarities of the production equipment and represents a plate with holes for PE installation, which by welding is hermetically connected to the frame formed by four elements in the form of bent channels. It's accepted as a typical one for solving similar technical problems. The peculiarity of the design is that the filter is placed directly in the air pipeline in a box-shaped casing with sealing tape seals on the channels side surfaces. It facilitates installation and dismantling of the filter, reduces labor and time of works. There are 119 filter elements in the filter under consideration (Fig.4).

The developed FE design is also a typical one (Fig.5). It includes 3 constructive elements: composite three-layer element (1), consisting of two support layers of woven mesh and a filtering layer of composite thin sheet filtering material based on finely dispersed nickel powders, frame (2) and a cap ring (3). In the upper flange of the frame (2) and the cap ring (3) there are grooves for hermetic adhesive connection of the frame (2) and the element (1). The presented filter element has a length of 145 mm and an outer diameter of the upper flange of 50 mm. The upper flange has a blind hole for a hexagonal wrench to create an axial force between the filter plate and the lower end of the frame by means of the internal thread located in the lower part of the frame in order to seal the interface. The square shape of the mating partbase (shown bottom right in Fig. 6a), which is located on the plate opposite side, prevents the FE from turning during installation.

In the filter design and manufacturing process, additive technologies were used in operations 3-6. As a result, based on our own experience, we can talk about the reduction of labor intensity of work by 30-40% (under conditions of single production). It should be noted that the work was performed in the conditions of one research unit, non-productive time expenditures for technological development and tooling for the study of properties and structural elements of PE production were eliminated. The developed designs are simple, reliable, allow to replace any filter element from the filter composition, are standard and can be flexibly and quickly reworked in accordance with the consumers' requests.

3. Conclusion

The algorithm of filter for fine air purification development with wide application of additive technologies is given. Filter 3D models, PE and tooling were developed to study their properties and the number of filter elements was calculated. The components for assembly (except for the composite three-layer element with a filter layer) and mounting of the PE and tooling for the study of their properties were produced by 3D printing method. It's noted that in conditions of single production the reduction of labor intensity can be up to 40%.

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Modeling of steady-state nonlinear transfer processes in enclosing structures taking into account convective flows, sources or sinks of heat

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Abstract: For various canonical forms (plane, cylinder, ball, etc.), a generalized mathematical model (MM) of a nonlinear steady-state process of molecular heat transfer (or moisture diffusion) through enclosing structures (ES) is proposed, taking into account infiltration or exfiltration of a vapor-air (gas) mixture and the presence of various internal or surface positive (moisture condensation) or negative (evaporation of moisture) of heat sources (HS). The mathematical formalization of the posed boundary value problem (BVP) of transfer and its general solution are given, on the basis of which, under various specified conditions of unambiguity, solutions of specific physical processes with constant or variable thermophysical characteristics and HS are constructed and analyzed. For large-scale transitions, the short-circuit problem is posed and solved under various boundary conditions (BVC), written in a criterion form as dependences of the dimensionless temperature $T(\bar{R}, Pe, Po)$ on the dimensionless thermal resistance ($\bar{R}$) of the heat exchange criteria for the similarity of Pecle (Pe) and Pomerantsev (Po).

KEY WORDS: HEAT TRANSFER, ENCLOSING, CONSTRUCTION, FILTRATION, CONDENSATION, HUMIDITY, AIR PERMEABILITY, THERMAL AND ENGINEERING NETWORKS.

1. Introduction

Depending on the purpose of the room (construction), climatic conditions and the time period of the year, the processes of heat and moisture transfer, filtration of the vapor - air mixture and liquid through the capillary-porous solid layers of the enclosing structure are accompanied by such physical phenomena as condensation heating or evaporative cooling. Therefore, the processes of molecular-molar heat and mass transfer through piecewise homogeneous media are quite complex and interrelated [1-5].

Modern energy-saving buildings and constructions are built mainly from capillary-porous and capillary-porous-colloidal materials, which are used not only in civil and industrial construction, but also in industrial heat and power engineering (thermal and electrical networks, high-temperature heat exchangers, turbine blades, brickwork heat- and electric generating units, systems of nuclear reactors with internal cooling, etc.), the aerospace industry (casing of high-speed flying vehicles, rocket nozzles, etc.) and others, where various elements of heating equipment are subjected to high thermal stresses arising under the influence of high gradients of transport potentials [6-9].

2. Materials and methods

The transfer of thermal energy in the enclosing structures (ES) occurs through the solid skeleton of the material, liquid and vapor moisture, which are contained in capillary-porous and capillary-porous-colloidal bodies. The differential equation (DE) of steady-state nonlinear transfer taking into account filtration (vapor-gas mixture and liquid) in the presence of internal volumetric negative or positive heat sources (HS) under generally accepted assumptions in relation to classical forms in Cartesian, cylindrical and spherical coordinate systems (CS) can be written in the form of an ordinary differential inhomogeneous equation (ODIE) of the second order:

$$[\lambda(t)r']' + \frac{\Gamma}{r}[\lambda(t)t]' + sgn[G]G(t)c_p(t)t' + sgn[I]I(t) = 0, \quad (1)$$

where $t(r)$ – the temperature; r – the current coordinate $r \in [0, h]$, h – the thickness of the MES; λ – the coefficient of thermal conductivity OK (possibly taking into account its volume porosity Π); Γ – the shape constant ($\Gamma = 0, 2$, respectively, «0» - unlimited plate, «1» - cylinder or square bar, «2» - ball or cube); c_p – the isobaric heat capacity of the steam – air mixture; G – the flow density of the steam – air mixture, here "+" means the process of exfiltration, "-" – infiltration of the steam – air mixture; $I(t)$ – the capacity of the internal (+) or sink (-); «'» (upper stroke) – differentiation with respect to r ; $sgn[.]$ - (signum) "sign" function. If $I = const$, then a continuously uniformly distributed positive or negative HS acts in the considered region of thermal resistances. If $I(t) \neq const$, then local, concentrated, or distributed positive or negative HS acts in this region.

With a generalized physical description of the processes of cooling the MES (possibly evaporative) or heating (possibly condensing), similar to equation (1), heat balances can be drawn up for both the region $r \in [-\infty, 0]$, and the region $r \in [0, +\infty]$, which lead to new DE of gas (or liquid) flows entering the ES and outgoing from the ES with boundary conditions (BC) corresponding to the new closed intervals r . In this case, one or two more second-order ODIE and, respectively, two or four BC are added to the DE (1), depending on the conditions of the boundary value problem (BVP). Therefore, in order to obtain an unambiguous solution, the set BVP of the transfer processes in the MES will have to contain three second-order DEs of the and six BCs. The temperature field $t(r)$ in this case can be expressed in terms of the ambient air temperatures from both sides of the MES. In a more simplified version, these boundary DE for the MES are replaced by BC of the third kind, with possible consideration of surface sinks or HS at the boundary of the MES surfaces [10, 11].

Therefore, equation (1) with BC of the third kind can be replaced by simpler BC of the first kind, provided that constant fictitious (equivalent) boundary layers are introduced. The analysis of the molar heat transfer showed that in this case, the BC of the third kind can be written as the BC of the first kind. Then, when solving the ODIE (1) and the presence two isothermal surfaces in the BC, it is convenient to apply the Kirchhoff transformation [12, 13], which, through a new auxiliary variable θ and the average coefficient of thermal conductivity λ_c leads the ODIE (1) to formalize the following BVP:

$$\left\{ \begin{aligned} \theta'' + \frac{\Gamma}{r}\theta' + sgn[G]\frac{G(\theta)c_p(\theta)}{\lambda_c}\theta' + sgn[I]\frac{I(\theta)}{\lambda_c} &= 0, \quad (2) \\ \theta(0) = \theta_1 = t_1, & \quad (3) \\ \theta(0) = \theta_2 = t_2, & \quad (4) \\ \lambda_c\theta' = \lambda(t)t', & \quad (5) \end{aligned} \right.$$

where $\lambda_c = (1/\Delta t) \int_{t_1}^{t_2} \lambda(\xi) d\xi$, $\Delta t = t_2 - t_1$, $t_2 > t_1$, t_2 and the temperatures of the opposite surfaces of the MES. The direction of the heat flow relative to $r \geq 0$ is determined by the BC of the BVP.

The formalized BVP (2)–(4) can be rewritten in a criterial form using the Peclet (Pe) and Pomerantsev (Po) criteria and dimensionless scales of temperature (T) and thermal resistant $\bar{R}$, which is especially convenient, since it allows converting a MES into a single-layer one.

In this case, omitting intermediate transformations, BVP (2) - (4) can be written as:

$$\left\{ \begin{aligned} T'' + \frac{\Gamma}{r}T' + sgn[Pe]Pe(T)T' + sgn[Po]Po(T) &= 0, \quad (6) \\ T(0) = 0, & \quad (7) \\ T(1) = 1, & \quad (8) \end{aligned} \right.$$

where $T = (\theta - \theta_1)/(\theta_2 - \theta_1) \in [0, 1]$ - dimensionless temperature, $\bar{R} = R/R_0 \in [0, 1]$ - dimensionless thermal resistance,

here $R = r/\lambda$ – current thermal resistance, R_0 – total thermal resistance (total, reduced, required or multilayer wall), which is selected depending on the accepted BC; $Pe = G(T)c_p(T)R_0$ ((in construction thermophysics the expression Gc_pR_0 is called the relative coefficient of filtration heat transfer, which characterizes the ratio of the thermal capacity of the air flow Gc_p to the heat transfer coefficient of the enclosure structure $K = 1/R_0$). If we take into account the volumetric porosity of the MES, then $Pe = [G(T)c_p(T)R_0]/[1 - I]; Po = [I(T)h^2]/[\lambda_c \Delta T]$, in this formulation of the BVP ΔT in the Pomerantsev criteria can be omitted, since the maximum temperature difference is equal to one; «'» (upper stroke) – differentiation according to $\bar{R}$.

If the limits of variation of the similarity criteria Pe and Po are set, then the sign of the signature in ODIE (6) can be omitted, provided that Pe and Po are specified in the interval $[0,1]$. In this case, Pe and Po can be written as:

$$\bar{Pe} = [Pe - \inf(Pe)] / [\sup(Pe) - \inf(Pe)],$$

$$\bar{Po} = [Po - \inf(Po)] / [\sup(Po) - \inf(Po)] \in [0,1].$$

Therefore, all dependent and independent variables and parameters of the generalized BVP are dimensionless and they will belong to the four-dimensional normalized unit space $(T, \bar{R}, \bar{Pe}, \bar{Po})$, and the BVP (6) – (8) will be rewritten as:

$$\left\{ T'' + \frac{\bar{R}}{T} T' + \bar{Pe}(T) T' + \bar{Po}(T) = 0, \right. \quad (9)$$

$$T(0) = 0, \quad (10)$$

$$T(1) = 1. \quad (11)$$

Therefore, the above transformations significantly simplify the mathematical formalization of the BVP, eliminate physical dimensions and signs, and solve the issues of scale transition [11].

The initial ODIE (1) with variable transfer parameters $[\lambda(t), Pe(T), Po(T)]$ and BC of various kinds (possibly mixed and nonlinear), taking into account surface positive (or negative) HS (sinks), in the most general case, is solved by numerical or approximate methods of solving ODIE, and under certain conditions of the indicated transfer parameters, it can be reduced to solving the well-known DE of Bessel, Legendre or to solving a linear inhomogeneous DE of the n -th order (in our case - of the 2nd order) with variable coefficients of the form [6]

$$\sum_{i=0}^n a_{n-i}(r) t^{(i)}(r) = f(r), \quad (12)$$

where $a_i(r)$ – are the variable coefficients of an inhomogeneous n -order DE; (i) – the superscript at t means the number of the derivative, $t^{(0)} = t$; $a_0 = 1$.

The general solution of ODIE (12) is sought in the form

$$t(r) = t_{00}(r) + t_{chn}(r), \quad (13)$$

Where $t_{00}(r), t_{chn}(r)$ – respectively, the general solution of the homogeneous DE ($f(r) = 0$) and some particular solution of the inhomogeneous DE.

If a linearly independent fundamental system of solutions $t_i (i = \overline{1, n})$ of the corresponding homogeneous DE (12) is known on some interval, then the general solution of the inhomogeneous DE can be found by the method of variation of arbitrary constants. In this case, the solution to equation (12) is sought in the form [12]:

$$t(r) = \sum_{i=1}^n c_i(r) t_i(r), \quad (14)$$

where $c_i(r)$ – unknown functions are found from the system of n equations:

$$\begin{cases} \sum_{i=1}^n c_i'(r) t_i(r) = 0, \\ \sum_{i=1}^n c_i'(r) t_i'(r) = 0, \\ \dots \\ \sum_{i=1}^n c_i'(r) t_i^{(n-1)}(r) = f(r), \end{cases} \quad (15)$$

Solving system (15) with respect to $c_i'(r)$, we obtain

$$c_i' = Y_i(r), \quad (16)$$

from where

$$c_i = \int Y_i(r) dr + \bar{c}_i, \quad (17)$$

where $\bar{c}_i$ – arbitrary constants of integration determined from the BC of the BVP [10].

Further, substituting the obtained values $c_i(r)$ into (14), we obtain the general solution of the inhomogeneous DE (12). For example, for a second-order equation, system (15) takes the form

$$\begin{cases} c_1' t_1 + c_2' t_2 = 0, \\ c_1' t_1 + c_2' t_2 = f(r), \end{cases} \quad (18)$$

решая ее относительно c_1' и c_2' , найдем:

$$\begin{cases} c_1(r) = - \int \frac{t_2 f(r)}{W[t_1, t_2]} dr + \bar{c}_1, \\ c_2(r) = - \int \frac{t_1 f(r)}{W[t_1, t_2]} dr + \bar{c}_2, \end{cases} \quad (19)$$

where $W(r) = W[t_1, t_2] = \begin{vmatrix} t_1(r) & t_2(r) \\ t_1'(r) & t_2'(r) \end{vmatrix}$ – Wronskian for functions $t_i(r), i = \overline{1, 2}$.

Fig.1 shows some typical distribution profiles $t(R)$ in the ES depending on the transfer parameters $[\lambda(t), Pe(T), Po(T)]$ and their signs [13].

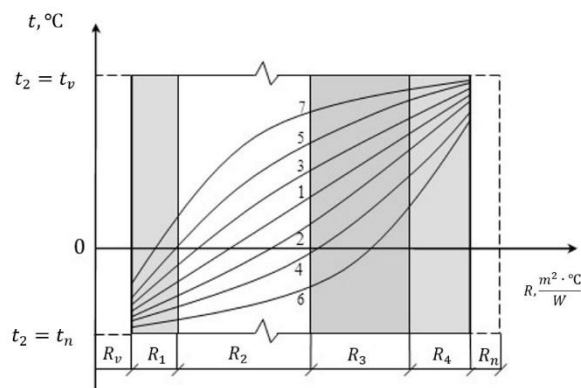


Fig. 1. Typical partial graphical dependences of the distribution in the MES: (1) – excluding air filtration, HS and $\lambda = \text{const}$; (2) – taking into account air infiltration; (3) – taking into account air exfiltration; (4) – taking into account air infiltration and heat sink (the presence of moisture in the ES); (5) – taking into account the exfiltration of air and HS; (6) – curve (4), (6) – curve (4), but taking into account the linear dependence $\lambda(t)$ at $\beta < 0$; (7) – curve (4), but taking into account the linear dependence $\lambda(t)$ at $\beta > 0$.

For linear inhomogeneous DE with constant coefficients and with the right-hand side of the form:

$$f(r) = e^{\alpha R} [P_e(r) \cos \beta r + Q_m(r) \sin \beta r], \quad (20)$$

where $P_e(r)$ and $Q_m(r)$ – respectively, the polynomials of degree e and m with indefinite coefficients, a particular solution of the inhomogeneous equation (2) can be found more simply - by the method of indefinite multipliers (selection method). In this case:

$$t_{chn}(r) = r^s e^{\alpha R} [\tilde{P}_k(r) \cos \beta r + \tilde{Q}_k(r) \sin \beta r], \quad (21)$$

where $k = \max(m, e)$; $\tilde{P}_k(r)$ and $\tilde{Q}_k(r)$ – polynomials of r k -th degree of the general form with indefinite coefficients; s – is the multiplicity of the root $\gamma = \alpha \pm i\beta$ of the characteristic homogeneous equation (if $\gamma = \alpha \pm i\beta$ is not the root of the characteristic equation, then $s=0$).

Therefore, depending on the moisture content, the structure of the capillary-porous materials, the thermophysical characteristics of the MES, and other factors, the function $f(r)$ can be selected as a special case of expression (20). Particular solutions for various types $f(r)$ of equation (12) for $a_i = \text{const}, i = \overline{1, n}$ can be found in [10 and others].

3. Results and discussion

Let us consider as examples several simplified special cases of solving the BVP, some of which can be reduced to known solutions, presented, in particular, in [1-10].

I. For $\Gamma=1$, $\lambda(t)$, $Pe=\text{const}$, $Po=\text{const}$ and an artificially omitted sign of the signature (since $Pe, Po \in [0,1]$) the BVP (6)–(8) can be written in the form [6]:

$$\begin{cases} T'' + PeT' + Po = 0, & (22) \\ T(0) = 0, & (23) \\ T(1) = 1, & (24) \end{cases}$$

where at $Pe < 0$ there is infiltration in the MES, at $Pe > 0$ – exfiltration, at $Pe = 0$ – there is no air filtration or infiltration and exfiltration compensate each other; at $Po < 0$ the negative HS acts, at $Po > 0$ – positive HS acts, at $Po = 0$ – there are no sinks and heat sources, or they compensate each other.

The analytical solution to BVP (22) - (24) is obtained in the form:

$$T(\bar{R}) = \frac{\exp(-Pe\bar{R}) - 1}{\exp(-Pe) - 1} \left(1 + \frac{Po}{Pe}\right) - \frac{Po}{Pe} \bar{R}, \quad (25)$$

which already covers all combinations of the above special cases of transfer parameters (Pe , Po) under the given single-valuedness conditions.

II. For $\Gamma=2$, $\lambda(t) = \lambda_0(1 + \beta t)$ (λ_0 – the known coefficient of thermal conductivity at the control temperature t_0 , β – the temperature coefficient of thermal conductivity), $Pe=0$ and $Po=0$ we obtain an intermediate known solution of BVP (2) - (4) in the form:

$$\theta(r) = t_1 + (t_2 - t_1) \frac{\ln(r/r_1)}{\ln(r_2/r_1)}. \quad (26)$$

The original dependent variable $t(r)$ is found using semidefinite integration (5) and for the case of linear dependence $\lambda(t)$ we obtain a quadratic equation of the form

$$\frac{\beta t^2}{2} + t = t_1 + \frac{\beta t_1^2}{2} - \frac{\lambda_c(t_1 - \theta)}{\lambda_0}, \quad (27)$$

where

$$\lambda_c = \lambda_0 \left[1 + \frac{\beta(t_1 + t_2)}{2}\right], \quad (28)$$

solving which with respect to t (the root from physical considerations is taken with the positive sign of the radical) taking into account (26) and (28), we obtain

$$t = \frac{1}{\beta} \left\{ (1 + \beta t_1) \sqrt{1 - \left[1 - \frac{(1 + \beta t_2)^2}{(1 + \beta t_1)^2} \right] \frac{\ln(r/r_1)}{\ln(r_2/r_1)}} - 1 \right\}. \quad (29)$$

Mathematical analysis of the results for constant λ and variable $\lambda(t)$ showed that the variability of $\lambda(t)$ at $\beta > 0$ increases, and at $\beta < 0$ decreases heat transfer, and the formula for calculating the increase in the relative change in the heat flow due to the variability of $\lambda(t)$ will be

$$\Delta q = [q(\beta) - q]/q \quad (\text{for } \beta > 0) \\ \text{or} \\ \Delta q = [q - q(\beta)]/q(\beta) \quad (\text{for } \beta < 0). \quad (30)$$

III. For $\Gamma=2$, the linear dependence $\lambda(t)$, $Pe=0$ and $Po=\text{const}$ the general solution of the DE (2) by intermediate replacement of the variable $U = \theta + Ir^2/4\lambda_c$ can be reduced to the solution of the DE for the previously considered case II (when $Po=0$). Then the general solution of equation (2) for $Po=\text{const}$ considering the indicated replacement, can be written as [6]

$$\theta(r) = c_1 \ln r - \frac{Ir^2}{4\lambda_c} + c_2, \quad (31)$$

and after determining c_1 and c_2 from the BC (3), (4) the solution $\theta(r)$ is

$$\theta(r) = \left[t_2 - t_1 + \frac{I(r_2^2 - r_1^2)}{4\lambda_c}\right] \frac{\ln(r/r_1)}{\ln(r_2/r_1)} - \frac{I(r^2 - r_1^2)}{4\lambda_c} + t_1, \quad (32)$$

For a more simplified presentation of the algorithm for moving to the source variables of the BVP, we take $t_1 = t_2 = 0$. Then equation (32) takes the form [13]

$$\theta(r) = \left[\frac{I(r_2^2 - r_1^2)}{4\lambda_c} \right] \frac{\ln(r/r_1)}{\ln(r_2/r_1)} - \frac{I(r^2 - r_1^2)}{4\lambda_c}, \quad (33)$$

and the quadratic equation with respect to t is

$$\frac{\beta \lambda_0 t^2}{2} + \lambda_0 t - \lambda_c \theta = 0, \quad (34)$$

from the solution of which it follows

$$t = \frac{\sqrt{1 - 2\beta\gamma} - 1}{\beta}, \quad (35)$$

where

$$\gamma = \frac{I \left[(r_2^2 - r_1^2) \frac{\ln(r/r_1)}{\ln(r_2/r_1)} - (r^2 - r_1^2) \right]}{4\lambda_0}. \quad (36)$$

For $\beta = 0$ it follows that $t = \gamma$, and for $\beta > 0$ it follows $\beta \leq 1/2 \max \gamma$.

From the analysis of the obtained solutions, similarly to example II, an estimate of the temperature profile is derived depending on $\lambda(t)$ both at $\beta > 0$,

and at $\beta < 0$.

IV. For $\Gamma=1$, $\lambda = \text{const}$, $Po=\text{const}$ and $Pe=0$ the solution to the BVP (6) - (8) will be [6]

$$T = \frac{\bar{R}(\sqrt{1 - 2\beta\gamma} - 1)}{\beta}, \quad (37)$$

and if the heat flow coincides with the positive direction of the axis r , it will be

$$T = (1 - \bar{R}) \left(1 + \frac{Po\bar{R}}{2}\right). \quad (38)$$

Fig. 2 shows the $T(\bar{R})$ dependences for different values of Po .

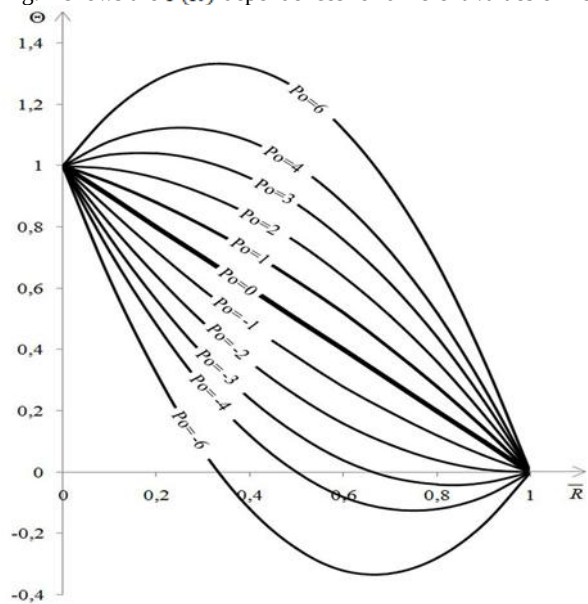


Fig. 2. Graphic dependence $T(\bar{R})$ at $-6 \leq Po \leq 6$.

If $Po > 0$ «+» HS, if $Po < 0$ «-» HS, $Po=0$ – then this is stationary thermal conductivity (no HS)

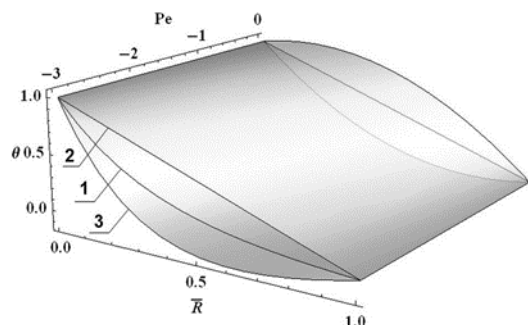
The numerical results of changes in the relative temperature $T(\bar{R})$ for various Po criteria showed that depending on the Po criterion, the temperature of the ES can be significantly higher than the maximum surface temperature of the ES at $Po \geq 3$ and less than the minimum surface temperature of the ES at $Po \leq -3$ [14-17].

Therefore, the higher the moisture content of the MES (negative HS), the deeper the moisture condensation front shifts into the MES (the period of the year with negative temperatures) and the wider the condensation zone.

In this case, the dimensionless temperature depends on the independent variable $\bar{R}$ and two transfer parameters Pe and Po .

Graphical dependences $T(\bar{R})$ at different values of Pe and Po are shown in Fig. 3.

a)



b)

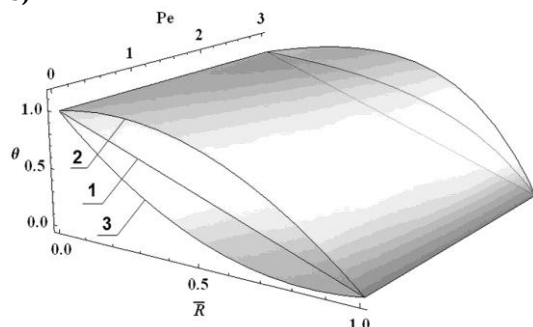


Fig. 3. Change in the dimensionless temperature along the wall thickness for various physical processes in the ES: (a) 1 – infiltration ($-3 \leq Pe \leq 0,01$; $Po=0$); 2 – infiltration ($-3 \leq Pe \leq 0,01$) and heat source ($Po=3$); 3 – infiltration ($-3 \leq Pe \leq 0,01$) and heat sink ($Po=-3$); (b) 1 – exfiltration ($0,01 \leq Pe \leq 3$; $Po=0$); 2 – exfiltration ($0,01 \leq Pe \leq 3$) and heat source ($Po=3$); 3 – exfiltration ($0,01 \leq Pe \leq 3$) and heat sink ($Po=-3$).

Further, based on the constructed temperature fields, considering the infiltration (or exfiltration) of air and negative (or positive) HS, it is possible to calculate the humidity regime of the MES. For this purpose, the saturated mixing ratios $E[t(x)]$ are determined for each layer of the MES. Then, according to the dependencies $E(x)$ or $E(R_{vap})$, (where R_{vap} – water vapor permeability resistance in the MES) and the relative humidity of the inside air and the external atmospheric environment surrounding the MES, the presence or absence of CZ moisture in the MES is graphically determined [2, 18-24]. In the presence of CZ, the amount of moisture condensing in the MES under stationary conditions of water vapor diffusion is determined. Then, the densities of mass flows of moisture of air entering the CZ from the room ($\bar{J}_{m1}$) and leaving the CZ outside ($\bar{J}_{m2}$) are found. Then the specific density of the amount of condensing moisture in the MES ($\bar{J}_k$) will be:

$$\bar{J}_k = |\bar{J}_{m1} - \bar{J}_{m2}|. \quad (39)$$

The considered method for calculating the humidity conditions of the MES also allows to calculate the rate of drying or desiccation of the MES after the cessation of moisture condensation in it during the period with positive outside atmospheric air temperatures [25].

4. Conclusions

The proposed generalized MM (9)–(11) of nonlinear transfer processes in ES allows you to:

- calculate temperature fields, values of heat fluxes, as well as various transfer coefficients, etc. derived characteristics of the ES, taking into account the moisture content, for various types of physical phenomena or processes (including in engineering, thermal and electrical networks).
- take into account, when calculating the transmission field (heat, moisture, vapor-gas mixture), the change in thermophysical

characteristics from the thickness or the value of the thermal resistance of ES [6];

- use the results obtained for calculation in practice when designing ES buildings and structures, creating or updating building codes and codes of rules for thermal protection of buildings [14, 15], etc.;
- perform calculations on heat and mass transfer for different types of ES for canonical systems. Therefore, with precision to the reinterpretation of symbols, it is possible to successfully use the obtained patterns for other transfer processes.

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Comparison of 2D and 3D digital image correlation in determining of deformation distribution

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Abstract: Digital image correlation tests were performed during cold deformation on aluminum - magnesium alloy. The comparison of strain distribution obtained with 2D and 3D digital image correlation was analyzed and compared. The comparison of strain distribution in static tensile tests was performed with qualitative strain distribution and quantitative line analysis and strain-time relationship. The tests showed that there were no significant differences in the strain values and distributions obtained using the 2D and 3D digital image correlation when comparing the qualitative and quantitative results.

Keywords: DIGITAL IMAGE CORRELATION, 2D AND 3D DIGITAL IMAGE CORRELATION, STRAIN DISTRIBUTION, STATIC TENSILE TESTING, ALUMINUM ALLOYS

1. Introduction

Digital image correlation (DIC) is known as a very good method for determining and analyzing displacements and deformations in various metallic materials [1-3]. One of the advantages of DIC is that it can be used in laboratories for testing materials, but also in various industries when it is necessary to monitor displacements or deformations on the tested material or on the finished products. Digital image correlation is widely used in various fields such as mechanical engineering, metallurgy, biomedicine, construction, automotive and aircraft industries, etc [3-8].

This method is commonly used in the forming of various metallic materials such as steel, aluminum, Al-Mg alloys and others [9-12]. It is very important when used during plastic deformation because it is possible to obtain information about the deformation behavior in real time by determining the strain distribution of different metals and metal alloys [9]. It is known that with digital image correlation it is possible to determine the displacements and strain values as well as their distribution on test samples [11,13], but also on finished products during metal forming.

In the forming and plastic deformation of metals and alloys, there are both flat and curved surfaces on products and test samples. Therefore, in addition to the use of 2D DIC, there is an increasing need to test with 3D DIC [14]. This is because 2D DIC can only be used to test the flat surface of the product or test sample, whereas 3D DIC can be used to test samples with different 3D shapes and dimensions.

Another important limitation of 2D DIC inspection is the use of a single digital camera, which must be positioned perpendicular to the plane of the inspection sample or product. However, with 3D DIC testing is possible to position digital cameras or sensors freely in front of the test sample or product. Calibration before the test is also very important. It is more complex with 3D DIC, but also more precise than calibration for testing with 2D DIC [15].

Today, numerous studies with 2D and 3D DIC are carried out on various metallic materials [3]. In the study [16], 2D DIC strain distribution tests were performed on DP600 steel using different types of analysis such as line, point and strain over time. Strain distribution during plastic deformation of low carbon steel in different areas of the deformation zone was investigated using 3D DIC tests [4].

There are also some studies comparing 2D and 3D DIC, but the tests are performed on different metallic and non-metallic materials [7,17]. For example, in [18] is compared the application possibilities and the results achieved with 2D and 3D DIC during indentation process of AISI 304 steel. It was concluded that in certain situations, 2D DIC proved to be a simpler and better solution for the application, while in other, more complex situations, 3D DIC investigation was more suitable.

However, it is not clear whether there are significant differences in the distribution and value of strains during the 2D and 3D DIC tests.

Therefore, a qualitative and quantitative comparison of the distribution and values of strains between the 2D and 3D DIC results was performed in this paper.

2. Materials and methods

The tests were performed on samples from a cold-rolled sheet of Al-Mg alloy 5754 with a thickness of 3 mm. The prescribed chemical composition of Al-Mg alloy 5754 is magnesium 2.60 - 3.60 wt %, silicon 0.0 - 0.40 wt %, chromium 0.0 - 0.30 wt %, copper 0.0 - 0.10 wt %, others 0.0 - 2.0 wt % and the rest is aluminum.

The dimensions of the test samples were parallel length 50 mm, width 20 mm and thickness 3 mm. The samples were subjected to a static tensile test with a constant stretching rate. The tensile test on the test samples was carried out on a Hegewald & Peschke 100kN tensile machine. A constant stretching rate of 30 mm/min was applied during the tests.

The test samples for the 2D and 3D DIC tests were prepared by applying a RAL 9000 white matt coating to the sample surface. Then the random black patterns were applied to the white background using the black matt coating GRAPHIT 33.

The test samples during the static tensile tests were recorded in parallel with cameras for 2D and 3D DIC tests, Fig. 1. Digital camera Basler ace acA2500-14um with a resolution of 5 MPix was used, which was mounted perpendicular to the test sample. In addition to the 2D DIC camera, the front camera in Fig. 1, the ARAMIS Adjustable 2D/3D 12M system was also used for the 3D DIC, the back cameras in Fig. 1. The ARAMIS Adjustable 2D/3D 12M system has two cameras with a resolution of 12 MPix.

The calibration procedure was carried out separately on the camera for 2D DIC tests and for 3D DIC tests on the ARAMIS system, as there are different calibration procedures and the process for 3D DIC tests is much more complex.

The analysis of the recorded results was performed for both test methods (2D and 3D DIC) using the GOM Correlate software package for the analysis of displacements and strains. For both methods, the same parameters were used for the correlation of the recorded digital images.



Fig. 1 Equipment during 2D and 3D DIC test.

3. Results and discussion

Qualitative (deformation maps) and quantitative (line) analysis was performed to analyze in detail the comparison of the measured strain values and their distribution by 2D and 3D DIC at selected points during the static tensile test. Points at different times during the static tensile test were selected for analysis: 0 s (A), 10.3 s (B), 15.7 s (C), 25.9 s (D), 29.7 s (E), 36.1 s (F), Fig. 2.

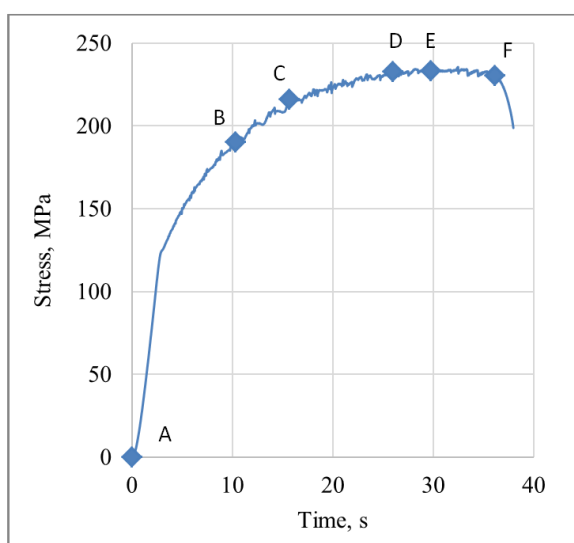


Fig. 2 Stress-time diagram with test points A-F.

Qualitative results (deformation maps) show a comparison of the coloration on the deformation maps obtained by the 2D and 3D DIC during the static tensile test. The deformation maps showed almost identical colors at selected points, i.e. values and distribution of strains in the deformation zone of the tested samples, Fig. 3. It can be concluded that the qualitative results showed no differences in strain distribution.

A comparison of the quantitative results for the maximum values of the strain values was carried out, as the qualitative analysis showed no significant differences in the strain distribution between 2D and 3D DIC. The results of the quantitative analysis and the comparison of the strain values and distribution during 2D and 3D DIC testing of the Al-Mg alloy are shown in Fig. 4.

Obtained quantitative results show that there are no significant differences between the maximum strain amounts of the 2D and 3D DIC results over time, Fig. 4. It can be clearly seen that the measured maximum strain values overlap very well from the beginning of the deformation process to the fracture of the samples.

In order to determine in detail possible differences in the results of the strain values and distribution determined by the 2D and 3D DIC during the static tensile test, a line analysis was performed at the selected test points (points A-F), Fig. 5.

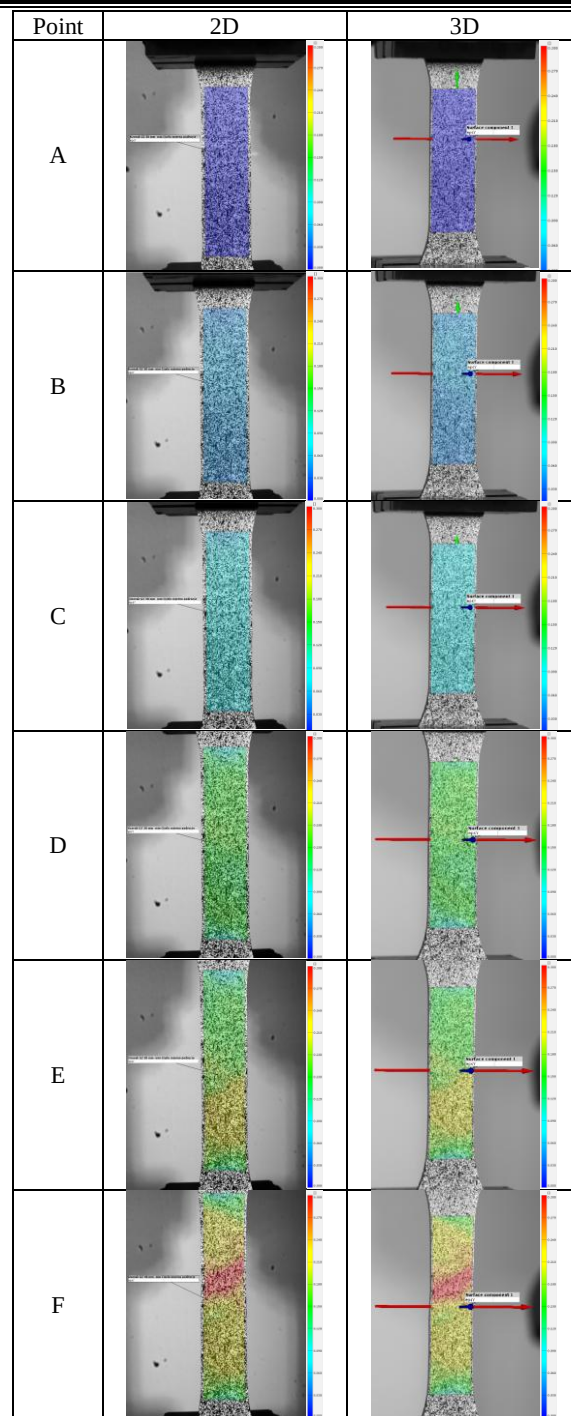


Fig. 3 Comparison of the qualitative DIC results of the strain distribution.

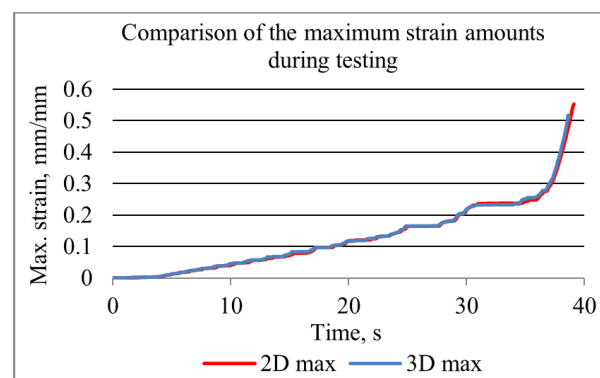
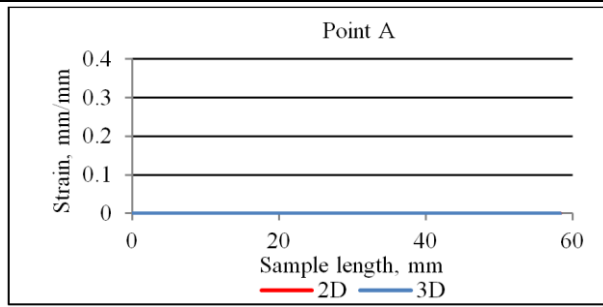
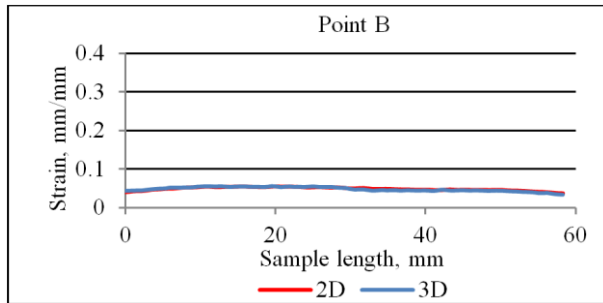


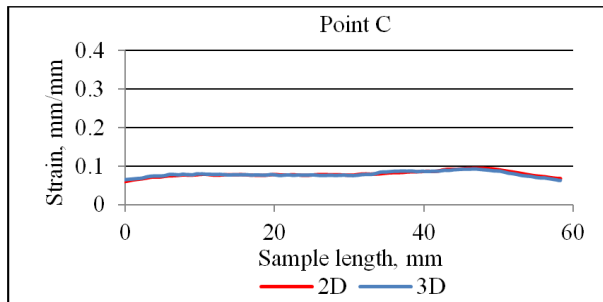
Fig. 4 Comparison of the quantitative DIC results of the strain distribution over time.



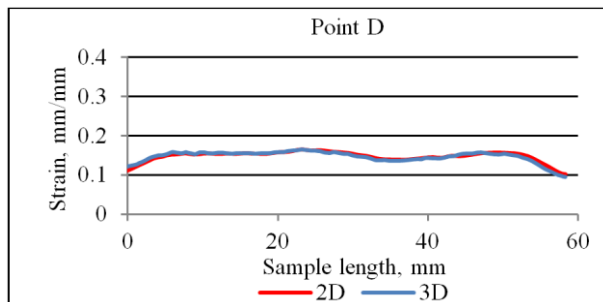
a)



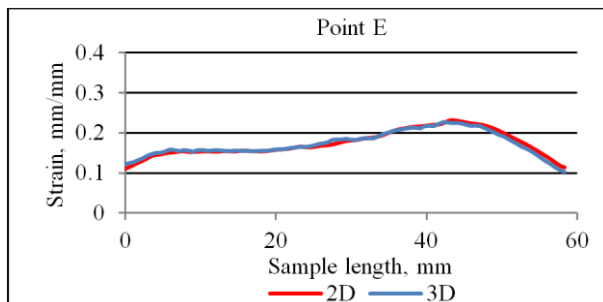
b)



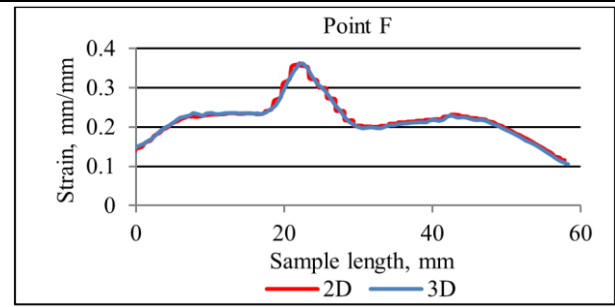
c)



d)



e)



f)

Fig. 5 Line analysis of the strain amounts along the length of the test sample at the points: a) A, b) B, c) C, d) D, e) E and f) F.

It was found that the measured strain values determined with the 2D DIC corresponded very well with the strain values determined with the 3D DIC over the entire length of the test samples during comparing the results obtained by quantitative line analysis.

Negligible differences in strain amounts between the 2D and 3D DIC were found only in certain parts of the deformation zone before fracture of the test samples, Fig. 5. It can be concluded that there are no significant differences in the measured strain values and distribution during testing with the 2D and 3D DIC.

4. Conclusion

The study has shown that there are no significant differences in the distribution of strain values in the deformation zone during static tensile testing with 2D and 3D DIC on the Al-Mg alloy.

The comparison of the qualitative results showed that there are no differences in the strain amounts and distribution obtained with 2D and 3D DIC. The quantitative results confirmed that there are no differences in the measured strain values and distributions.

A more detailed quantitative line analysis did not reveal a significant difference in the strain values and distributions determined with the 2D and 3D DIC.

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Use of precise implantological surgical guides in reconstructions adjacent to teeth with unusual anatomy - use of Dentistry 4.0 technology

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Abstract: This study aims to present the practical application of the Dentistry 4.0 concept based on obtaining data on the patient's intraoral situation and bone base using CBCT, processing them into a digital model, creating a digital twin, and then developing an intra-procedural navigation procedure through a dedicated surgical guide and then designing and manufacturing, using 3D printing, implant-prosthetic restorations. The study describes the results of the author's work, indicating the engineering aspects of implant prosthetic treatment based on the description of cases related to the reconstruction of single missing teeth using dental implants implanted in the case of difficult anatomical conditions of the bone base and/or adjacent teeth, with a discussion of the material selection methodology, technological and structural design, using additive manufacturing.

The technology for the design, manufacture and application of implant-prosthetic restorations developed by the author, preceded by a fully navigated implantation procedure of dental screw implants, illustrates in practice the full application of the Dentistry 4.0 concept, where the latest technologies, including primarily computer-aided design and computer-aided CAD/CAM manufacturing, the use of a digital twin, supporting surgical procedures through the use of templates navigating the operator's actions and additive manufacturing allow for a radical increase in the availability of implant-prosthetic solutions for patients with difficult anatomical conditions, both due to a limited bone base and anomalies of the anatomy of adjacent teeth. Thanks to the latest technology, not only is it possible to perform this type of procedure, but it is also possible to perform the procedure in a short time, with minimal interference in the patient's tissues and ensuring the optimal shape of the prosthetic restoration itself.

Keywords: TITANIUM ALLOY, 3D PRINTING, COMPUTER-AIDED DESIGN, COMPUTER-AIDED MANUFACTURING, SURGICAL GUIDE, DENTAL ENGINEERING, DENTAL IMPLANTS

1. Introduction

Dentistry 4.0 is an original concept [1-4] of using the achievements of the latest technology consistent with Industry 4.0 [5-7] in dental engineering and dentistry to ensure maximum repeatability and predictability of the developed prosthetic solution, optimal use of tissue conditions, and maximum accuracy of the manufactured prosthetic restoration in the shortest possible time available in a specific clinical case (fig. 1).

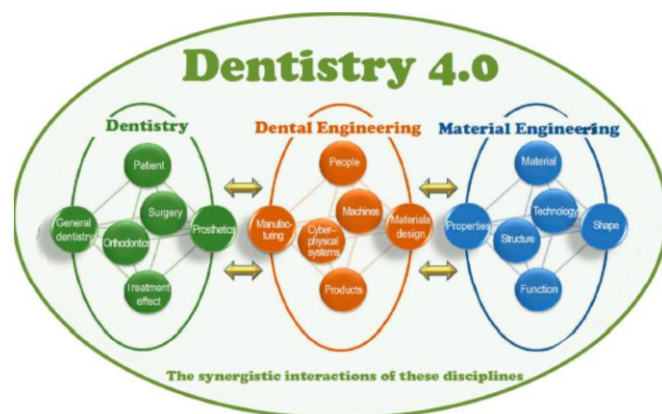


Fig. 1. General diagram of the Dentistry 4.0 model showing synergistic relations between dentistry, dental engineering, and materials engineering [8]

The design of optimal prosthetic reconstruction based on implants should always be started at the consultation visit when the patient presents with a damaged or missing tooth requiring prosthetic reconstruction. Already at this stage, the cooperation between the dentist conducting the treatment and the dental engineer begins, who supports the process of assessing the conditions in the patient's oral cavity to select the appropriate implantological or prosthetic solution properly. The basis for the consultation should be data obtained from CBCT cone beam tomography, which, combined with data obtained from an intraoral impression (made both digitally with an intraoral scanner and

traditional methods using impression materials), will allow obtaining a digital twin of the conditions in the oral cavity [9-11]. On this basis, the patient is qualified for implant treatment. At this stage, decisions are also made about possible regeneration or reconstruction procedures. In this study, the author focuses on the reconstruction of single missing teeth based on screw implants in atypical anatomical conditions of teeth immediately adjacent to the implantation zone, radically limiting the volume of the bone base that can be implanted and the case of maximum use of the natural course of the bone base in the form of the septum of the maxillofacial sinus to avoid the need for procedures to raise the floor of the maxillofacial sinus [12].

Using the Dentistry 4.0 concept, according to the model of the three most important aspects of coincidental horizontal factors (fig.2), particularly concerning CAD/CAM design and 3D printing, allows us to limit the necessary scope of the procedure [13,14]. First of all, accurate, repeatable, and easy-to-install surgical templates allow for limited interference with the patient's alveolar tissue [15-17]. Thanks to this, the doctor performing the procedure does not have to separate these tissues with a large margin, enabling visual control of the insertion of the guide drills. Then, the procedure consists of making one drill, deepening and enlarging with three drills, and creating an implant bed into which the implant is inserted. Additionally, the risk of damaging adjacent teeth or perforating the bottom of the maxillofacial sinus in the case of the upper arch or damaging the dental nerve canal in the case of the lower arch is reduced to an absolute minimum. The procedure also allows you to reduce the duration of the procedure by at least 60% [8]. This also increases the profitability of the dental clinic, which can perform more comprehensive smile reconstructions simultaneously. Additionally, the risk of complications resulting from implantation procedures is reduced by at least 50% [8].

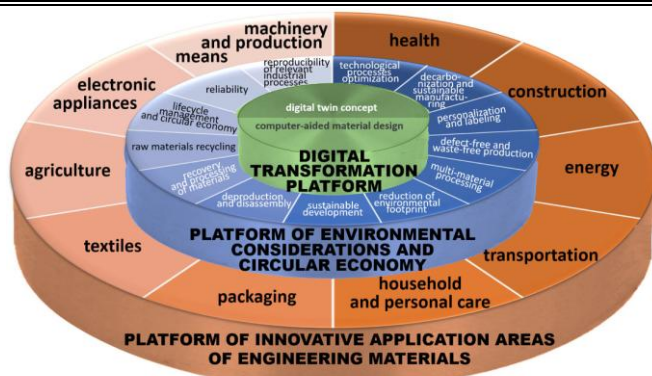


Fig. 2 The Author's model of the three most important aspects of coincidental horizontal factors concerning the development of engineering materials, widespread computerisation of technological processes, and minimisation of the environmental footprint [8]

The use of 3D printing in producing elements necessary for implant prosthetic treatment also brings significant benefits related to a radical increase in the accuracy of the elements made compared to those made using casting techniques or CNC milling technology [18]. Firstly, it is possible to reduce the weight of manufactured elements. The author's research allowed for the conclusion that printed elements are up to 25% lighter than those milled from the same design. This is because prosthetic elements have very complex, irregular shapes, which means that milling requires the use of very thin tools, the diameter of which does not exceed 1 mm. Despite this, some areas, e.g., the prosthetic bridge, are inaccessible to these tools. Additionally, CNC milling technology does not ensure perfect shape repeatability due to the need to ensure tool access in a specific production axis. The main advantage is also a radical reduction in production time, which, in the case of large prosthetic elements, can be reduced by up to 4-5 times [8,13].

All these aspects mean that 3D printing has deep justification for applications in dental engineering, especially implant prosthetic treatment procedures.

This study presents the practical application of CAD/CAM design technology using 3D printing in two technologies: SLA stereolithography using polymeric materials used to produce a surgical template plate and selective laser sintering/selective laser melting SLS/SLM in the case of tool guide elements in surgical templates and prosthetic restorations.

2. Procedure for designing an implantological and implant prosthetic treatment plan

The process of designing a prosthetic restoration begins when the doctor conducting the treatment, after examining with a cone beam computer tomography, turns to our Dental Engineering Center to prepare an implant treatment plan. The first stage of CAD design is to determine the course of the mental nerve canal, which determines the available volume for the insertion of implants, then determine the necessary distance to the neighboring teeth, which is at least 1.5 mm, so as not to damage the tissues of the nerve running to this tooth. Another necessary parameter is to ensure an appropriate distance between the implanted implants, which should be at least one diameter of the implant, thus ensuring proper introduction of prosthetic elements at the following stages and adequate blood supply and nutrition of the bone tissues around the implant. After selecting the appropriate implants, particularly their length and diameter, as well as the finishing of the implant crown, i.e., the polished area and the plan being approved by the attending physician, you can start designing the surgical template. To obtain the exact situation in the oral cavity, it is necessary to take a CBCT

photo with markers visible in x-ray examinations. Combined with a carefully made intraoral impression and a digital model of soft tissues and teeth in the supragingival section, it is possible to provide information about all tissues, including those not correctly visible in X-ray imaging. This also offers the opportunity to test the fit of the surgical template before implantation. Then, a design of the surgical template is made. If the patient has adjacent teeth, there is no need to use osseous templates. We use dental and mucosal templates. The standard fit of the template plate is 100 micrometers. In the family of templates developed by the author, the standard also includes the use of drill guide sleeves made in 3D printing and SLS/SLM technology, individually for each implant inserted. Both printed guide sleeves and sleeves placed on drills are individualized, both on the pilot and subsequent drills. It is also possible to insert the implant through the template. It is also necessary to provide an appropriate method of cooling the bones when drilling.

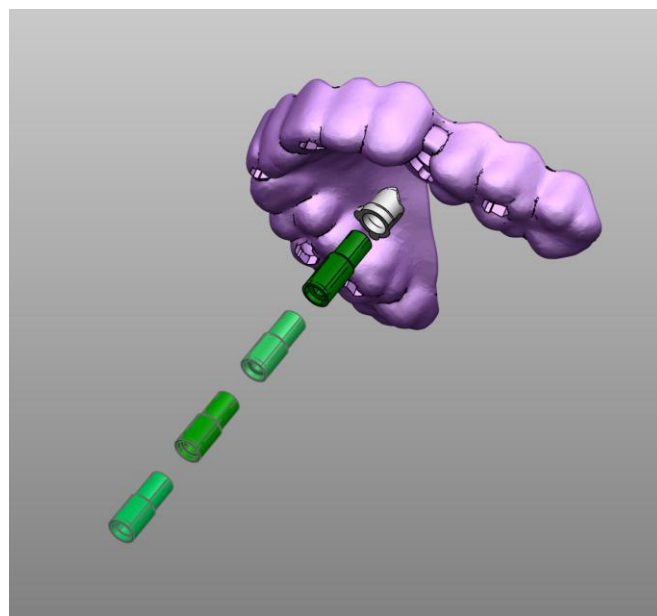


Fig. 3 The entire surgical guide system

After the procedure, a CBCT control photo is taken to assess its effectiveness and the degree of possible deviation from the assumptions.

In the next stage, after a break of 2-4 months, the prosthetic restoration is made. CAD/CAM design based on SLS/SLM 3D printing technology is also used. A design is prepared based on data obtained from the intraoral impression. Information about the patient's bone condition is not required at this stage. If the implant was implanted following the original design, it is possible to make a screw-retained restoration using mono crown and mono bridge technology, where the vectors of occlusal forces acting on the implant-prosthetic restoration system run in the axis of the implant and the mouth of the fixing screw canal are located on the occlusal surface. Thanks to this, there is no need to make an additional element, i.e., an implant connector, which is then glued to the crown. In this way, we eliminate a potential source of complications, which is the incorrect placement of the crown on the abutment during the cementation procedure in the patient's mouth. It is also possible to efficiently service such a prosthetic solution without destroying the crown, which significantly extends the life of the entire solution and minimizes the risk of irreversible complications in the soft tissues surrounding the prosthetic restoration and hard tissues surrounding the implant.

3. Case study

a) CASE 1

The case report concerns 2 cases of implant treatment in patients with single and double missing teeth in the mandible and maxilla's lateral sections.

Patient No. 1, 66 years old, came for the reconstruction of missing pterygoids of the mandible. On the right side, teeth 46 and 47 were missing, and on the left side, tooth 36. The CBCT examination revealed unusual anatomy of teeth 35 and 45, which have a double curved tooth apex, as shown in Fig 4.



Fig 4 Initial condition before starting treatment on the OPG image

The presented anomaly radically reduces the volume of the bone base in the implantation area, which can be used to perform successful implantation.

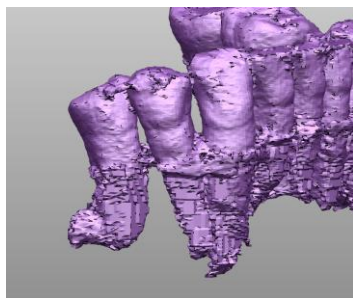


Fig 5 digital model of the patient's isolated teeth

these teeth (fig 5). The procedure failure risk without a surgical guide should be very high. An implant template was designed to consider the shifting of the implantation site to ensure sufficient bone parameters between the teeth and the implants.

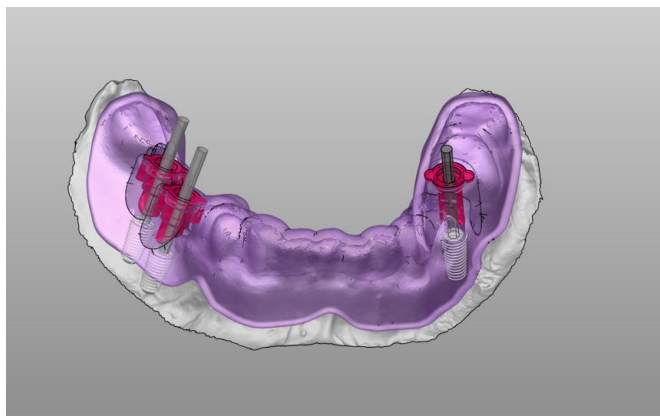


Fig 6 design of implant placement along with a model of the surgical template and all its components

A dental and mucosal template was designed and made using SLA 3D printing technology from a polymer enabling steam sterilization. (fig 6,7)

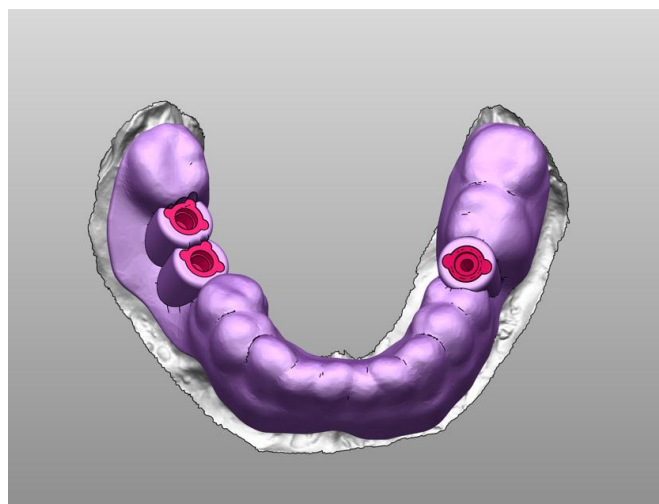


Fig 7 Model of the surgical template on a digital model

The template plate has beds designed to accommodate individual drill guide sleeves made using SLS/SLM 3D printing technology from a titanium alloy. The template was used for implantation. Fig .4 shows the initial clinical situation, and Fig 9 shows the situation after implant insertion. Fig. 8 shows the design of the prosthetic restoration framework. The success of the procedure was verified concerning the project. The design deviation is shown in Table 1

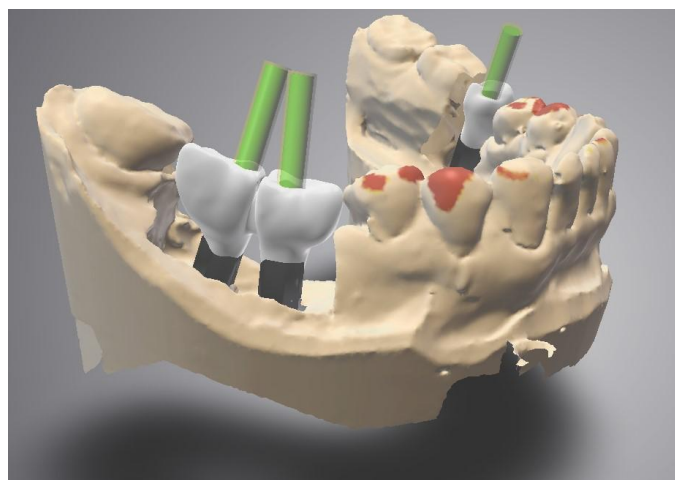


Fig 8 Design of the prosthetic restoration framework

Table 1: table of the difference in the angle of the implant insertion axis in relation to the CAD design after the procedure (in degrees)

ID	36	35	46
36	0	2,9	-
35	2,9	0	-
46	-	-	1,1

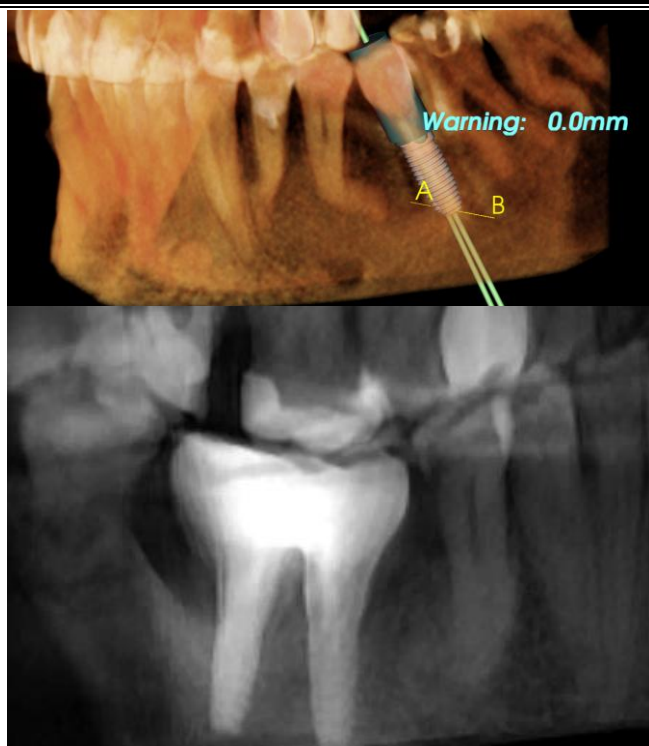


Fig 9 CBCT examination after implantation with a procedure to verify the correctness of implantation concerning the design

b) CASE 2

The design began with selecting an appropriate insertion path and selecting a standard screw implant, also taking into account maintaining a proper margin of bone tissue between the implant and the bottom of the maxillofacial sinus to avoid its perforation. Then, a model of the patient's tissues in the oral cavity was made based on a CBCT image and an intraoral impression (fig 9).

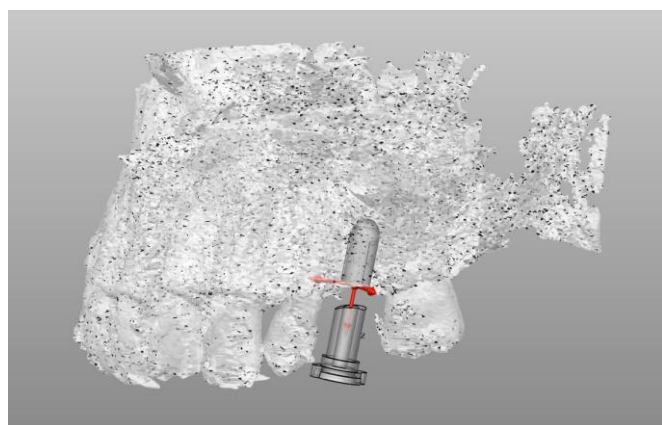


Fig 9 Design of implant placement in the digital twin of the patient's bone base along with the design of the drill guide sleeve

This was done based on a photo taken with a positioning plate, which is part of the template system developed by the Team of which the Author is the leader. After positioning all the collected data in one project,

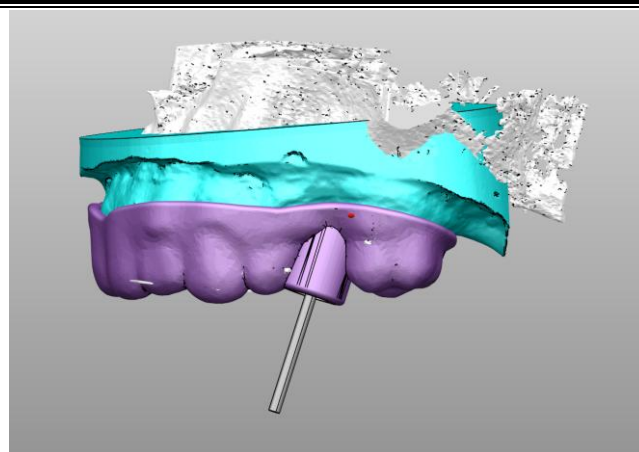


Fig 10 digital assembly of a bone base model, an intraoral scan, and a surgical template model

A template board was made using SLA technology from polymer materials. A bed was designed for a titanium alloy sleeve manufactured using SLS/SLM 3D printing technology. (Fig 10)

The template was made as a dental and mucosal template, so all the components did not encroach on the alveolar tissue zone. The treatment doctor performed the procedure according to the design (fig 11).

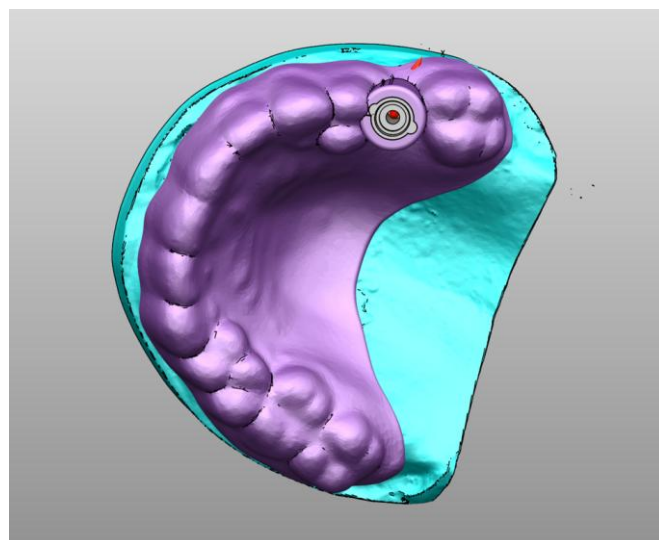


Fig 11 Surgical template digital design



Fig 11 OPG photo immediately after implantation

Then, a mono crown was made using SLS/SLM 3D printing technology, where the individual connector is integrated with the prosthetic crown (fig.12), creating one element, which was then covered with a facing layer of porcelain.

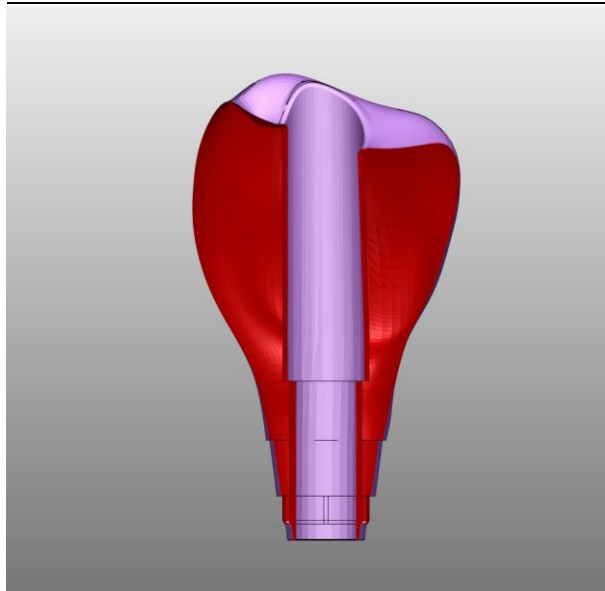


Fig. 12 Cross-section of a prosthetic restoration made as a mono crown with an integrated individual abutment.

The work has been installed and used by the patient (fig 13).



Fig 13 OPG photo immediately after installing the finished prosthetic restoration

3. Summary

According to the Dentistry 4.0 concept, advanced technology allows for a radical change in planning implantological and implant prosthetic treatments. It also enables effective and quick treatment of patients with unusual bone and anatomical conditions for effective implant treatment. Without this technology, the patients in the study would be disqualified for implantation, or the procedure would be burdened with an unacceptable risk of failure. Thanks to the use of surgical templates, not only was the procedure successful, but the procedure was short, and the procedure itself was performed minimally invasively. In addition, patients gain a prosthetic restoration that can be easily serviced. Care was also taken to ensure the correct emergence of the prosthetic crown from the gum. Despite the unusual anatomical conditions, the implants are loaded with occlusal forces along their axis, which is desirable.

Dentistry 4.0, therefore, enables a radical increase in the availability of implantological solutions for patients with difficult bone conditions, ensuring maximum usability of the prosthetic work performed.

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Synthesis and characterization of graphitic carbon foam for different applications

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Abstract: Carbon foam has unique properties due to the three-dimensional graphite-like microstructure of the ligaments that form pores. The possibilities for the application of carbon foam with different characteristics are enormous: space technology - antenna systems, devices based on composites, optical equipment, rocket engines, thermal protection; energy - electrodes for batteries, fuel cells, rods for nuclear reactors; military industry - ultralight armored vests, heat exchangers, "invisible" ammunition; automotive industry - shock absorbers, catalytic converters; construction - abrasives, anti-acoustic fields, filters, fire insulation, thermal insulation, safes; medicine - artificial prostheses and dental implants. In addition, the porous structure of carbon foam enables very good absorption of waves from the microwave region, which makes it material with promising anti-radar properties. The first published synthesis of carbon foam was based on thermo-reactive organic polymers. Later, carbon foam was obtained from coal and petroleum pitch, mesophase pitch from naphthalene polyamide, polyurethane, biomass - melanin, cork, olive stones, etc. Industrial coal pitches modified with inorganic acids and pitches obtained by the pyrolytic treatment of plant materials were found to have suitable physicochemical properties for application in the production of high-tech carbon materials. Usually pitches based on liquid products of coal processing need pretreatment before the foaming process, in order to obtain a precursor which passes into a plastic state upon heating, as well as with sufficiently high viscosity, which allows the formation of bubbles in the reaction mixture. The carbon foam obtained from the pitches modified in this way is characterized by disordered porous structure and high mechanical strength, and relatively low pressure is used during its preparation. A new method was developed that ensures the production of carbon foam with a regulated structure, high mechanical strength and, most important, without the use of pressure during pore formation and without a stabilization stage. As precursors, mixtures of coal pitch with substances (furfural) with high reactivity and a tendency to polymerization were used, which through appropriate thermochemical treatment can acquire the necessary properties for the formation of more uniform porous structure. Carbon foam was characterized by SEM, X-ray structural analysis, N₂ physisorption, physical tests, etc. The carbon foam obtained by the new method is distinguished by high mechanical properties and well developed porous structure.

1. Introduction

Carbon foam has unique properties due to the three-dimensional graphite-like microstructure of the ligaments that form pores. The possibilities for the application of the carbon foam with different characteristics are enormous: space technology - antenna systems, devices based on composites, optical equipment, rocket engines, thermal protection; energy - electrodes for batteries, fuel cells, rods for nuclear reactors; military industry - ultralight armored vests, heat exchangers, "invisible" ammunition; automotive industry - shock absorbers, catalytic converters; construction - abrasives, anti-acoustic fields, filters, fire insulation, thermal insulation, safes; medicine - artificial prostheses and dental implants. In addition, the porous structure of carbon foam enables good absorption of waves from the microwave region, which makes it a material with promising anti-radar properties.

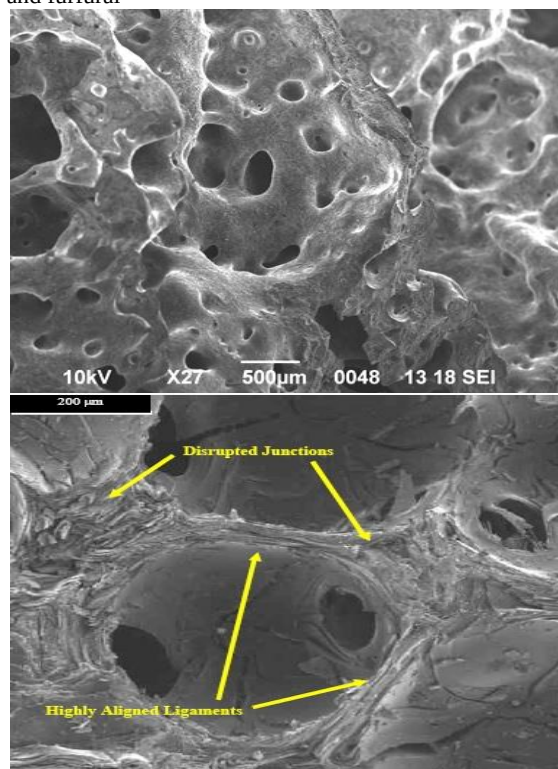
2. Problem discussion

The first synthesis of carbon foam was based on thermoreactive organic polymers. Later, carbon foam was obtained from coal and petroleum pitch, mesophase pitch from naphthalene polyamide, polyurethane, biomass - melanin, cork, olive pits, etc. Industrial coal pitches modified with inorganic acids and pitches obtained by the pyrolytic treatment of plant materials were found to have suitable physicochemical properties for application in the production of high-tech carbon materials.

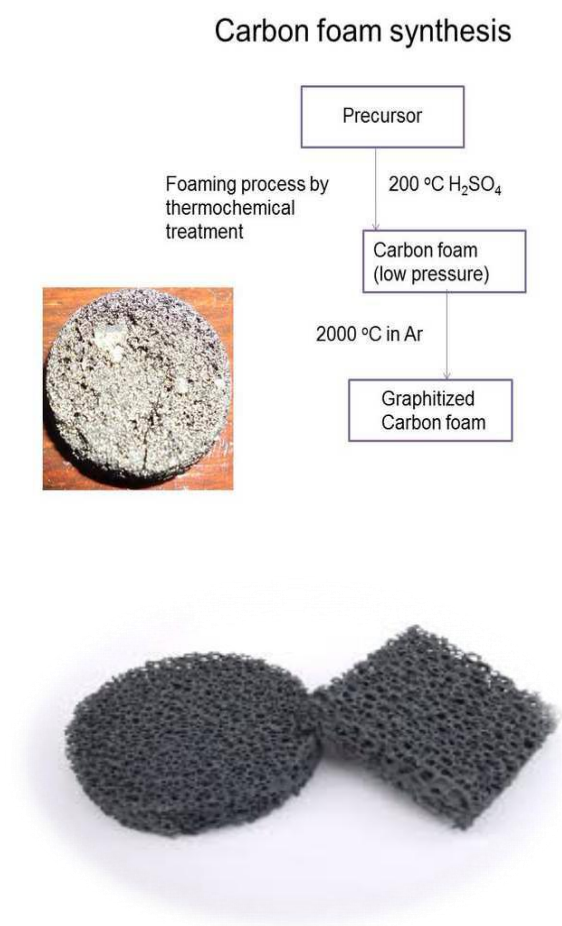
3. Objective and research methodologies

In most cases, pitches based on liquid products of coal processing need pretreatment before the foaming process, the aim being to obtain a precursor which, when heated, passes into a plastic state with a sufficiently high viscosity, which allows the formation of bubbles in the reaction mixture. The carbon foam obtained from the pecks modified in this way is characterized by a disordered porous structure and high mechanical strength, and relatively low pressure is used in its preparation. A new method was developed that ensures the production of carbon foam with a regulated structure, high mechanical strength and, most importantly, without the use of pressure during pore formation and without a stabilization stage. As precursors, mixtures of coal pitch with substances (furfural) with high reactivity and a tendency to polymerization were used, which through appropriate thermochemical treatment can acquire the necessary properties for the formation of a more uniform porous structure.

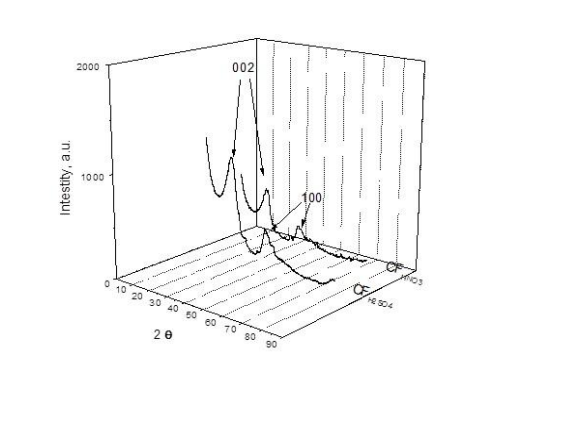
a) SEM images of samples obtained from mixtures of coal tar pitch and furfural



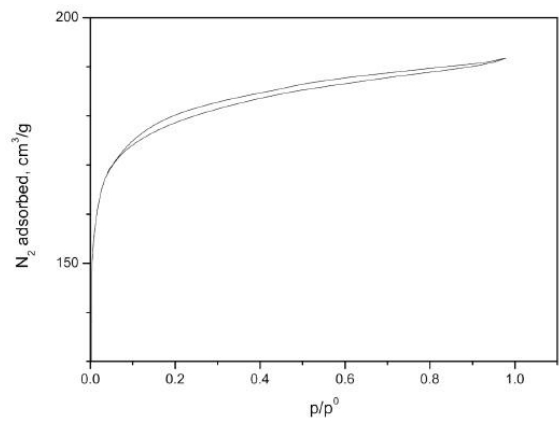
b) Scheme carbon foam synthesis



c) X-ray diffraction patterns of obtained foam.

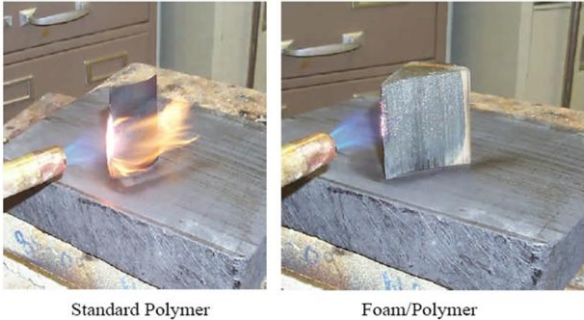


d) N₂ sorption isotherm activated carbon foam sample at -196 C.



3. Conclusion

The obtained results show that the chosen novel approach for increasing the content of micro and mesopores of the carbon foam samples synthesized by the new method is successful. Activation with water vapor at a high temperature leads to a significant increase in surface area and pore volume, especially micropore volume. The reason for this is the relatively high reactivity of the samples obtained by treatment of the raw material with acid and subsequent carbonization up to 600°C. High compressive strength materials was synthesized after heat treatment up to 1000°C. The high surface area and well developed porous structure, containing all types of pores will significantly expand the range of possibilities for application of synthesized carbon foam as construction material, purification equipment and medicine.



Acknowledgements:

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Investigation of the porous texture of new carbon materials obtained from different raw materials and treatment conditions by Porosimeter Autosorb iQ-MP (1 STAT.) VITON

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Abstract: Classification of pores is one of the basic requisites of comprehensive characterization of porous carbon materials. The relative performance of different porous carbon material are highly dependent on its the internal pore structure. For better understanding of physical process, taking place within a porous medium, it is necessary to fully characterize the porous texture of porous materials like pore volume, pore size distribution, the size of the specific surface area etc. To evaluate the porous texture of porous carbon materials obtained in the laboratory, it was investigated by the amount of adsorbed nitrogen at 77 K. Analyzes were performed on an Autosorb iQ-MP VITON, Guantachrome instrument. The results obtained for pore volume, pore size distribution, the size of the specific surface area of porous carbons and carbon foam samples obtained from different raw materials and treatment conditions are presented. Based on the obtained results, a preliminary assessment of the possibilities for their application was made.

KEYWORDS: POROUS CARBON MATERIALS, CARBON FOAM, CLASSIFICATION OF PORES

1. Introduction

Classification of pores is one of the basic requisites of comprehensive characterization of porous carbon materials. The relative performance of different porous carbon material are highly dependent on its the internal pore structure. For better understanding of physical process, taking place within a porous medium, it is necessary to fully characterize the porous texture of porous materials like pore volume, pore size distribution, the size of the specific surface area etc. To evaluate the porous texture of porous carbon materials obtained in the laboratory, it was investigated by the amount of adsorbed nitrogen at 77 K. Analyzes were performed on an Autosorb iQ-MP VITON, Guantachrome instrument. The results obtained for pore volume, pore size distribution, the size of the specific surface area of porous carbons and carbon foam samples obtained from different raw materials and treatment conditions are presented. Based on the obtained results, a preliminary assessment of the possibilities for their application was made.

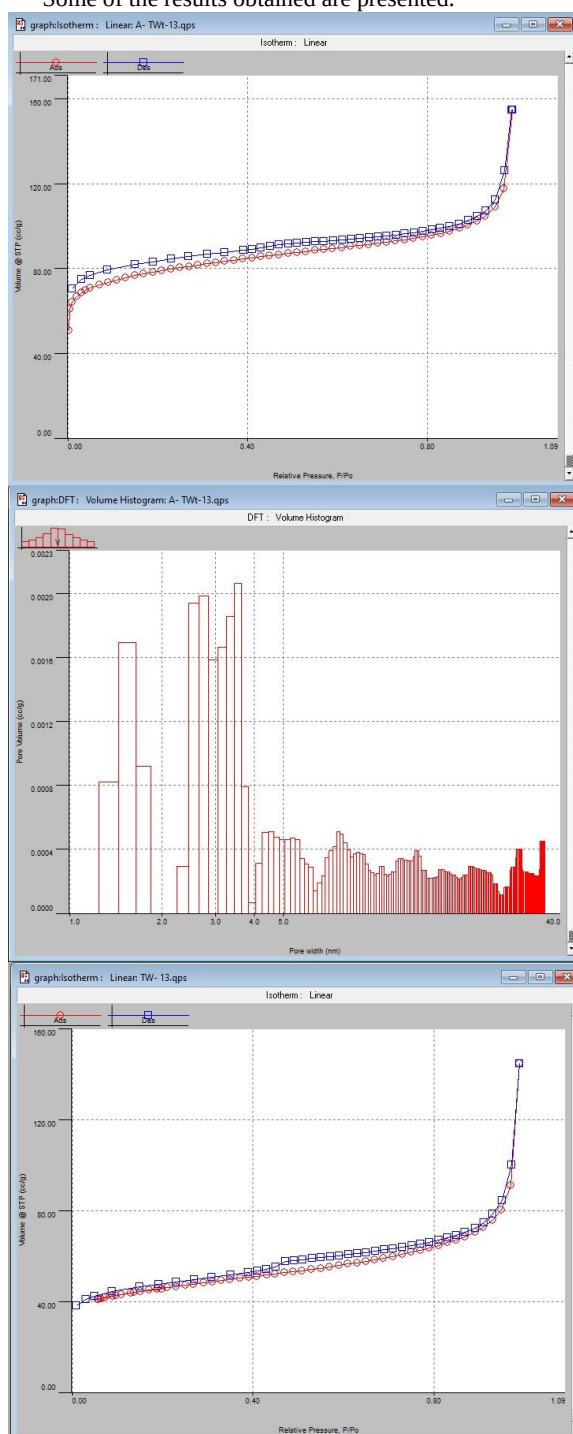
2. Problem discussion

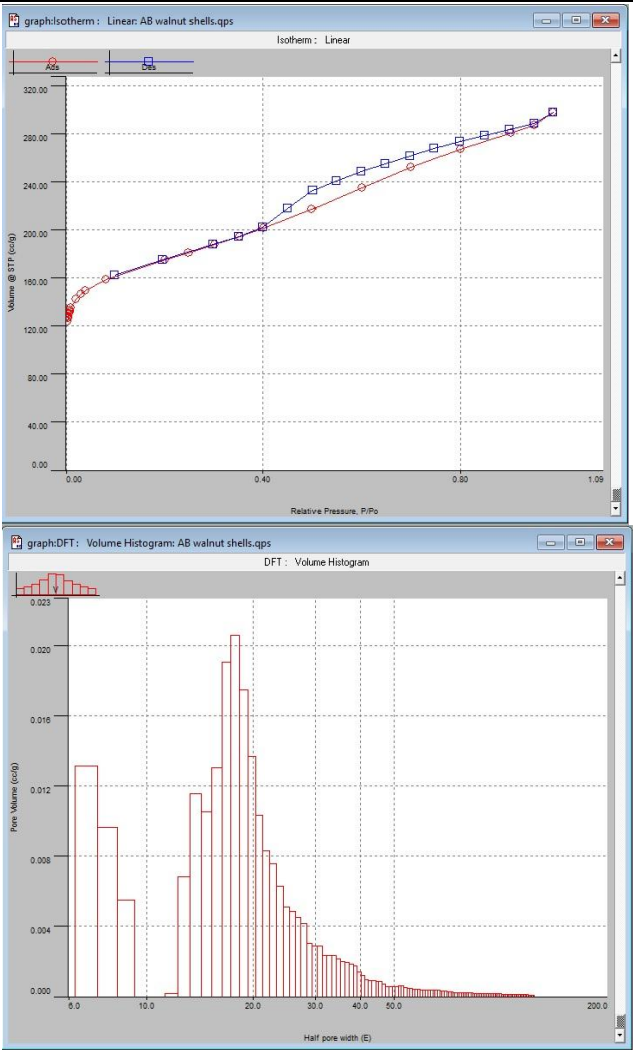
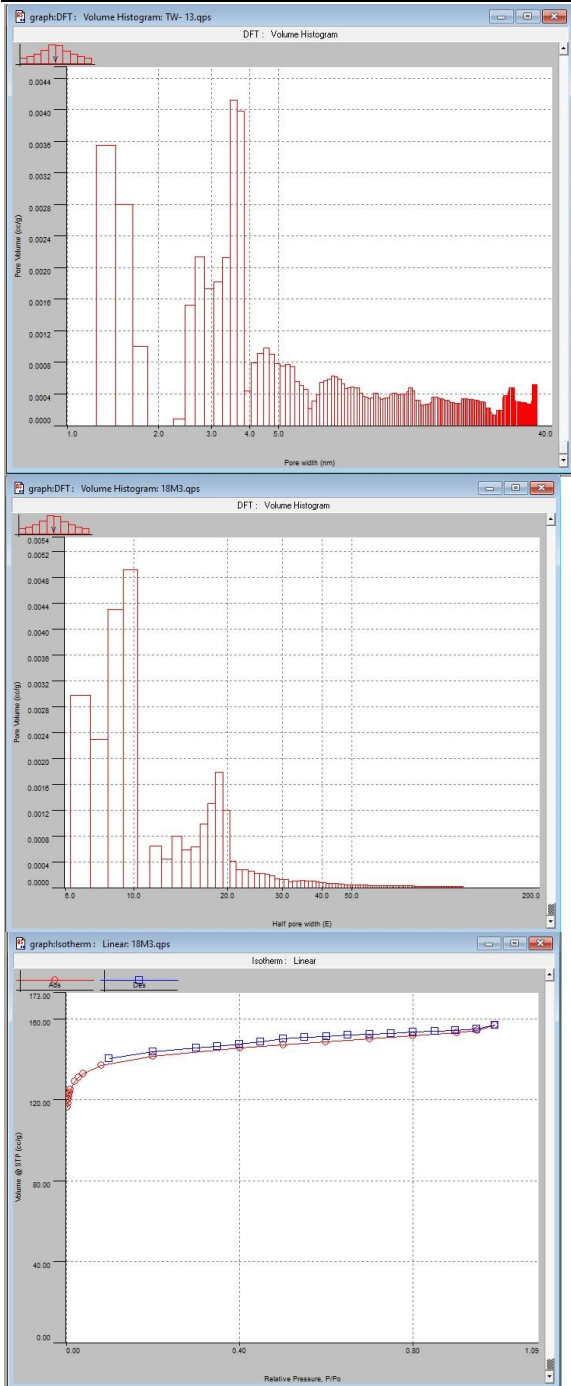
The analysis of the pore texture includes the determination of the surface area, the total volume of the pores and their size distribution. The data obtained from this analysis are important information for determining the applicability of the solid product from the processing of organic waste/especially pyrolysis/ in various fields of technology, mainly purification technology, electrochemistry, use as a catalyst carrier, etc. This is an important task that largely determines the efficiency of the processing used. In this, the information obtained from the analysis of the porous texture of the solid material from its heat treatment is of essential importance.

3. Objective and research methodologies

- Various methods have been developed to obtain information on the porous texture of solid products from the technical treatment of organic waste. They are mainly based on the adsorption of organic substances on their surface/nitrogen, CO₂, iodine, organic substances, etc./ and based on the information about the amount of adsorbed substance and the size of the adsorbate molecule, the surface area and porous texture of the adsorbent are calculated/in our case, the solid product from the thermal treatment of organic waste/. The most used methods for determining these and other characteristics of the solid carbon residue from the thermal treatment of organic waste are nitrogen physisorption at a temperature of 77K and iodine adsorption/iodine number/. For the first method, complex equipment has been developed, and the results it gives are processed with complex software. As a result, accurate data are obtained on the size of the surface of the material, the volume of pores and their size distribution. Additionally, data can be obtained on the course of chemical adsorption, etc.
- On apparatus using nitrogen physisorption, the porous texture of solid products from the processing of organic waste was determined by a developed pyrolysis method under certain conditions. Carbon adsorbents obtained as a result of the application of this method and carbon foam synthesized on the

basis of the liquid products of the treatment were analyzed. Some of the results obtained are presented.





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Analysis

Operator: SD
Sample ID: AB walnut shell
Sample Desc:
Sample Weight: 0.1393 g
Approx. Outgas Time: 9.5 hrs
Analysis gas: Nitrogen
Analysis Time: 8.22 hr:min
Analysis Mode: Standard
VoidVol. Mode: He Measure

Date: 2023/02/18

Filename: AB walnut shells.qps
Comment:
Instrument: Autosorb iQ Station 1
Final Outgas Temp.: 350 °C
Non-ideality: 6.58e-05 1/Torr
Bath temp.: 77.35 K

Report

Operator: 195336
AB walnut shells.qps

Date: 2024/06/10

Extended info: Available
CellType: 6mm

VoidVol Remeasure: off
Warm Zone V: 7.74118 cc

Cold Zone V: 5.32101 cc
Isotherm : Linear

Data Reduction Parameters

Adsorbate model

Thermal Transpiration: on
Nitrogen
Molec. Wt.: 28.013

Eff. mol. diameter (D): 3.54 E
Temperature: 77.350 K
Cross Section: 16.200 E

Eff. cell stem diam. (d): 4.0000 mm
Liquid Density: 0.808 g/cc

3. Conclusion

As a result of the porous texture analysis of the solid products obtained after the treatment according to the developed pyrolysis method of RDF and plant waste obtained from a waste plant, it was determined that a large part of them have a satisfactory porous texture and surface area. The obtained information shows that the solid products from the processing of the organic waste received from the plant can be successfully applied in various fields of technology.

Acknowledgements:

The authors acknowledge financial support for this work by Bulgarian National Science Fund, grant number KP-06-PN-69/7 from 2022, Project KP-06-N59-12/22.11.2021 and Project BG05M2OP001-1.002-0019: „Clean technologies for sustainable environment - water, waste, energy for circular economy“, financed by the Operational program “Science and Education for Smart Growth” co-financed by the European union



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Analysis		Report		
Operator:	SD	Date:2023/07/10	Operator:	195336
Sample ID:	18M3	Filename:	18M3.qps	Date:2024/06/10
Sample Desc:		Comment:		
Sample Weight:	0.2736 g	Instrument:	Autosorb iQ Station 1	
Approx. Outgas Time:	9.5 hrs	Final Outgas Temp.:	350 °C	
Analysis gas:	Nitrogen	Non-ideality:	6.58e-05 1/Torr	
Analysis Time:	35:35 hr:min	Bath temp.:	77.35 K	
Analysis Mode:	Standard			
VoidVol. Mode:	He Measure	Cold Zone V:	5.61941 cc	
			Isotherm : Linear	
			Extended info:	Available
			CellType:	6mm w/o rod
			VoidVol Remeasure:	off
			Warm Zone V:	7.53659 cc

Data Reduction Parameters			
<u>Adsorbate model</u>	Thermal Transpiration: on	Eff. mol. diameter (D): 3.54 E	Eff. cell stem diam. (d): 4.0000 mm
	Nitrogen	Temperature 77.350K	
	Molec. Wt.: 28.013	Cross Section: 16.200 E1	Liquid Density: 0.808 g/cc

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Analysis		Report		
Operator:	BP	Date:2024/03/27	Operator:	BP
Sample ID:	TW-13	Filename:	TW- 13.qps	Date:2024/06/10
Sample Desc:		Comment:		
Sample Weight:	0.3818 g	Instrument:	Autosorb iQ Station 1	
Approx. Outgas Time:	9.5 hrs	Final Outgas Temp.:	350 °C	
Analysis gas:	Nitrogen	Non-ideality:	6.58e-05 1/Torr	
Analysis Time:	16:44 hr:min	Bath temp.:	77.35 K	
Analysis Mode:	Standard			
VoidVol. Mode:	He Measure	Cold Zone V:	4.99872 cc	
			Isotherm : Linear	
			Extended info:	Available
			CellType:	6mm w/o rod
			VoidVol Remeasure:	off
			Warm Zone V:	7.93526 cc

Data Reduction Parameters			
<u>Adsorbate model</u>	Thermal Transpiration: on	Eff. mol. diameter (D): 3.54 Å	Eff. cell stem diam. (d): 4.0000 mm
	Nitrogen	Temperature 77.350K	
	Molec. Wt.: 28.013	Cross Section: 16.200 Å²	Liquid Density: 0.808 g/cc

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Analysis		Report		
Operator:	BP	Date:2024/03/27	Operator:	BP
Sample ID:	TW-13	Filename:	TW- 13.qps	Date:2024/06/10
Sample Desc:		Comment:		
Sample Weight:	0.3818 g	Instrument:	Autosorb iQ Station 1	
Approx. Outgas Time:	9.5 hrs	Final Outgas Temp.:	350 °C	
Analysis gas:	Nitrogen	Non-ideality:	6.58e-05 1/Torr	
Analysis Time:	16:44 hr:min	Bath temp.:	77.35 K	
Analysis Mode:	Standard			
VoidVol. Mode:	He Measure	Cold Zone V:	4.99872 cc	
			Isotherm : Linear	
			Extended info:	Available
			CellType:	6mm w/o rod
			VoidVol Remeasure:	off
			Warm Zone V:	7.93526 cc

Data Reduction Parameters			
<u>Adsorbate model</u>	Thermal Transpiration: on	Eff. mol. diameter (D): 3.54 Å	Eff. cell stem diam. (d): 4.0000 mm
	Nitrogen	Temperature 77.350K	
	Molec. Wt.: 28.013	Cross Section: 16.200 Å²	Liquid Density: 0.808 g/cc

Analysis of the Utilization of Various Energy Sources in Georgia

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Abstract: The main sources of green energy (GE), considered as the cleanest forms of energy or types of renewable energy sources (RES), are wind, water, sun, and earth. While the world, particularly in the most developed countries, has made significant progress in adopting and applying the various forms of green energy (GE), in Georgia this field is in its initial stage and it is not possible to predict when the first major positive developments will be made. This paper presents an analysis of total energy supply (TES) in Georgia for the period 2000-2021. The value of the continuous annual growth rate (CAGR) for TES in Georgia for this period is 7.23.

Keywords: Energy, Green energy (GE), Sustainable energy (SE), Clean energy (CE), Wind energy (WE), Renewable energy (RE), Renewable energy sources (RES), Total energy supply (TES).

1. Introduction

Energy is the capacity of a body or system to accomplish work. There are different forms of energy, namely kinetic, potential, thermal (also known as heat), internal, electrical, chemical, elastic potential and many others.

Electricity, a fundamental aspect of nature, is among the most widely utilized forms of energy. Globally, there is a growing trend towards generating electricity from renewable energy sources (RES) due to environmental considerations. The consumption and production of energy worldwide are steadily increasing each year, closely linked to the continual growth of the global human population. Currently, the overwhelming majority of global energy production, (exceeding 80%) comes from non-renewable sources, leading to adverse environmental effects. To address this, sustainable development principles advocate reducing reliance on fossil fuels in energy production and consumption. Consequently, there is a persistent need to substantially increase the use of renewable energy sources (RES) in the future. This shift is imperative due to the diminishing reserves of non-renewable energy sources and their escalating environmental impact observed in recent years. [38-39].

The largest portion of global energy consumption currently goes to industry, accounting for approximately 50%. Transport follows with approximately 25%, while households and the commercial sector together consume the remaining 25%. China and India are currently witnessing the most substantial growth in energy consumption on a global scale, encompassing all forms of energy. Among developed countries, the USA saw the largest rise in energy consumption, while the EU experienced a decrease of approximately 2 [%] in energy consumption. All these facts indicate that the most effective solution to address this situation lies in increasing the utilization of renewable energy sources (RES) and green energy (GE). [1,5,9-10,18-19,22,24,29]. Research and studies detail the current status and future prospects of developing and implementing various types of green energy (GE) across different countries worldwide [3,25-26,34-36,38,42].

Currently, many of the world's most developed countries have significantly advanced the adoption of various forms of green energy (GE). In Georgia, however, this field is still in its early stages, and it is uncertain when significant progress will be

achieved. Nevertheless, Georgian state authorities have formulated a strategy aimed at increasing the utilization of renewable energy sources (RES) by 2040 [12,20,33,39].

2. Classification of Natural Energy Sources

Considering the time possibility of exhaustion, natural or primary sources (forms) of energy can be divided into (Fig. 1) [13-15,17,28,30-32,39-42,45-46]:

1. Non-renewable energy sources (NRES):
 - Fossil fuels (coal, oil, natural gas, oil shale);
 - Nuclear fuels;
2. Renewable energy sources (RES):
 - Water power (energy of water currents, sea currents and waves, tides);
 - Biomass and biogas, including wood and waste;
 - Solar radiation energy;
 - Wind energy;
 - Earth's internal heat (geothermal energy);
 - Tidal energy;
 - Wave energy.

Renewable energy (RE) is that form of energy that is renewable (naturally replenished) and produced from sources that are constantly renewed, meaning that this form of energy is created from natural sources (sun, wind, rain, waves, geothermal heat and similarly).

There are different types and categories of renewable energy sources (RES) (Fig. 1). According to the time of creation, renewable energy sources (RES) are divided into two main categories:

- traditional renewable energy sources such as biomass and energy from large hydroelectric plants and
- "new renewable energy sources" such as solar energy, wind energy, geothermal energy and the like.

In addition to renewable energy (RE), the following terms are often used in the literature: green energy (GE), sustainable energy (SE), and clean energy (CE). The question arises as to whether there is a difference between GE, SE, CE, and RE, and what is the difference.

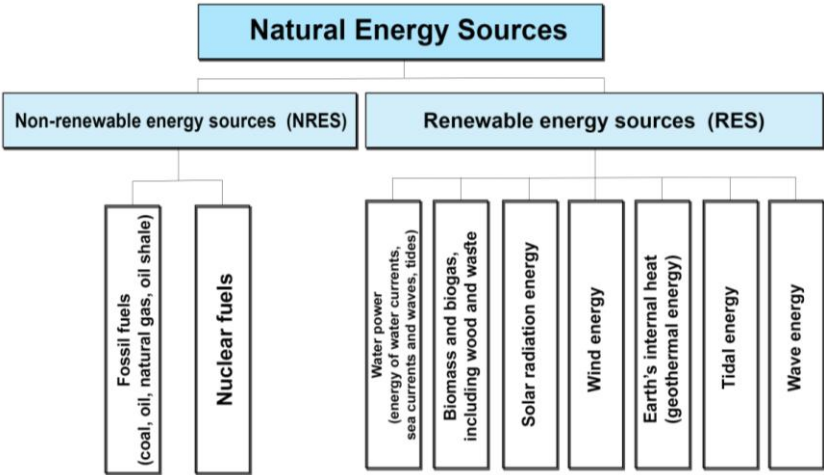


Fig. 1. Division of natural or of primary sources (forms) of energy, considering the time possibility of depletion

Renewable energy sources (RES) in the last thirty years represent a new trend in the use and production of various forms of energy in all areas.

The production of wind energy has been increasing significantly over the last 20 years. Figure 2 shows the graph of wind energy

(WE) generation (including both onshore and offshore wind sources) in [TWh] globally and by regions for the period 1965-2022 [42].

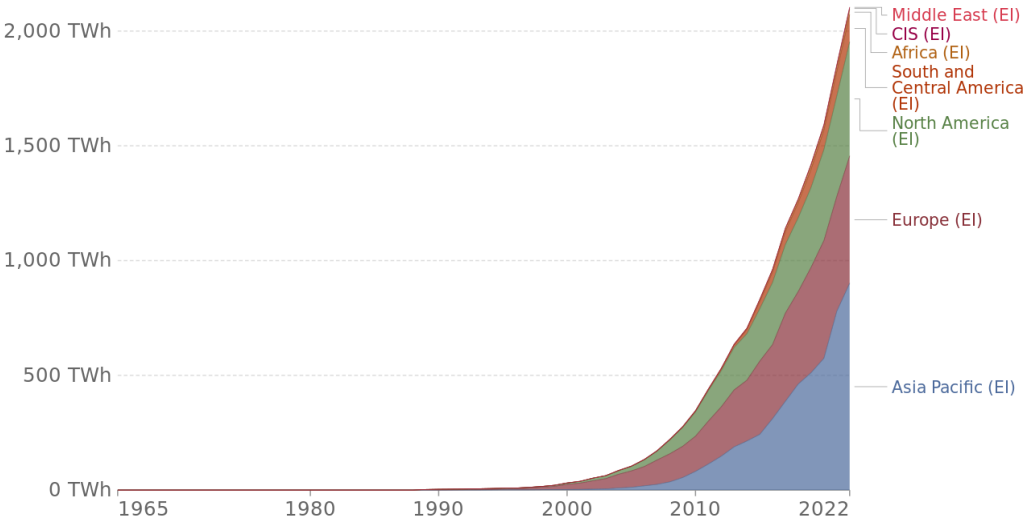


Fig. 2. Wind energy (WE) generation by regions for the period 1965-2022 [42]

3. Analysis of the Use of Energy in Georgia

The energy sector in Georgia is mainly based on hydropower and firewood, in addition to fossil fuel imports. It is also an important transit country for the region, with major oil and gas pipelines passing through its territory.

Reports for the annual use of all types of energy in the world and by regions and countries are given in the annual publication World Energy Outlook (WEO) [43, report for 2023], published by International Energy Agency (IEA), from Paris (France).

The analysis of the use of all types of energy in regions and countries is presented in papers [4,6-8,11,21-22,27,37,44].

The analysis of wind energy utilization is shown in papers [2,16].

The value of total energy supply (TES) in Georgia for the 2021 is 215596 [TJ].

Figure 3 shows graphical representation of the evolution of total energy supply (TES) in Georgia for the period 2000-2021 [12].

In Figure 4 a comparative analysis of the evolution of total energy supply (TES) in Georgia for the year 2000 and year 2021 is shown.

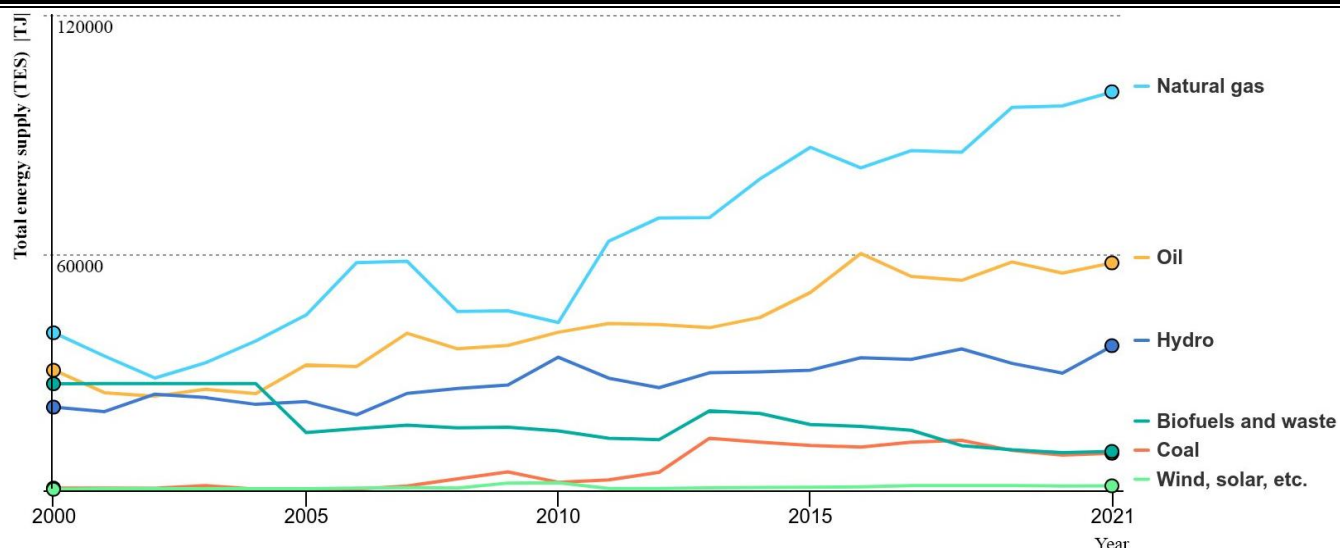


Fig. 3. Graphical representation of the evolution of total energy supply (TES) in Georgia for the period 2000-2021 [12]

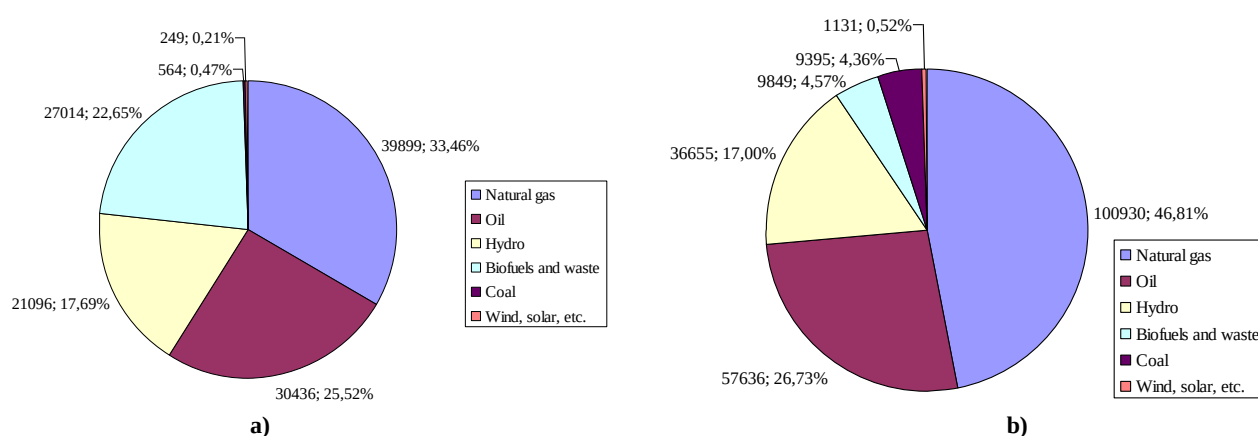


Fig. 4. Comparative analysis of the evolution of total energy supply (TES) in Georgia for the year 2000 (a) and the year 2021 (b)

Table 1 shows the total energy supply (TES) in Georgia for the years 2000 and 2021 by different forms of energy with the calculated value for the continuous annual growth rate (CAGR) for this period.

From Table 1 and Figures 3 and 4, it can be concluded that the total energy supply (TES) in Georgia for the year 2021 is from the following forms of energy: natural gas has 100930 [TJ] or

46.81 %, nil has 57636 [TJ] or 26.73 %, hydro has 36655 [TJ] or 17.00 %, biofuels and waste has 9849 [TJ] or 4.57 %, coal has 9395 [TJ] or 4.36 % and wind, solar, etc. has 1131 [TJ] or 0.52 %, retrospectively.

Table 1. Table representation of total energy supply (TES) in Georgia for the 2000 and 2021 by different forms of energy

Different Forms of Energy	2000		2021		CAGR [%]
	Value [TJ]	[%]	Value [TJ]	[%]	
Natural gas	39899	33.46	100930	46.81	4.31
Oil	30436	25.52	57636	26.73	2.95
Hydro	21096	17.69	36655	17.00	2.54
Biofuels and waste	27014	22.65	9849	4.57	-4.48
Coal	564	0.47	9395	4.36	13.64
Wind, solar, etc.	249	0.21	1131	0.52	7.12
Total	119258		215596		7.23

4. Conclusion

Fossil fuels such as coal, oil or gas are a group of non-renewable energy sources that are decreasing in number (slowly disappearing) and also cause undesirable consequences for the environment, and their harmful influence has become more and more pronounced in the last few years. Whereas, renewable energy sources (RES) and green energy (GE) will not disappear because they are naturally renewable and at the same time do not have a

harmful impact on the environment. Renewable energy sources (RES) and green energy (GE) are predicted to become economically competitive with conventional energy sources over time.

The greatest increase in total energy supply (TES), with the largest continuous annual growth rate (CAGR), in Georgia for the period 2000-2021 is attributed to coal (CAGR=13.64%). Conversely, the decrease in total energy supply (TES) in Georgia for the same period is seen in biofuels and waste (CAGR=-4.48%).

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Evaluating the Compressor performance using two dimensional Lagrange polynomial interpolation and Cubic approximation

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Abstract: This paper talks about how we can use math to create better models based on actual compressor experiments. The goal? To bridge the gap between what we see happening in real life and what we can predict, ultimately helping us optimize HVAC systems for better performance.

Within these systems, parts like compressors, fans, and electrical components play crucial roles. Compressors, especially, are quite dynamic, especially in heat pump setups.

However, the problem is that manufacturers usually only give real-world data on how compressors perform, without detailed models for understanding how they work in different situations. Hopefully in this paper we will try to construct a detailed model in order to be able to evaluate a HVAC system without the necessity of real-world data. Also, we will evaluate two different mathematical models, two dimensional interpolation and approximation in order to see who perform better.

Keywords: Math modeling, HVAC optimization, Real-world data, Heat pump setups, System evaluation, interpolation, approximation

1. Introduction

Lagrange interpolation

In the realm of numerical analysis and computational engineering, the quest for accurate representations of complex systems often relies on sophisticated mathematical techniques. Among these, interpolation stands as a cornerstone method, offering a means to approximate unknown functions based on limited data points. While one-dimensional interpolation methods have seen extensive application, the extension to higher dimensions presents a formidable challenge, particularly in scenarios where precise modeling is imperative.

This paper delves into the realm of two-dimensional Lagrange interpolation, a powerful tool in the arsenal of computational modeling, specifically tailored to address the intricacies of multidimensional data. Building upon the foundational principles of Lagrange interpolation, which elegantly constructs polynomials to fit given data points, this study explores its application in the context of compressor experiments within HVAC systems.

The motivation behind this endeavor stems from the inherent complexities of HVAC systems, where optimal performance hinges on a nuanced understanding of component interactions and dynamic behaviors. In particular, the compressor, a pivotal element within these systems, exhibits intricate dynamics, especially in the context of heat pump configurations. However, a persistent challenge lies in the scarcity of comprehensive models capable of accurately capturing the compressor's behavior across varying operational conditions.

Through the lens of two-dimensional Lagrange interpolation, this paper endeavors to bridge this gap by offering a systematic approach to constructing detailed models that transcend the limitations of conventional manufacturer-provided data. By harnessing the power of mathematical interpolation, we aim to empower HVAC system designers and engineers with tools capable of evaluating and optimizing system performance, without solely relying on exhaustive real-world experimentation.

In the subsequent sections, we delve into the theoretical underpinnings of two-dimensional Lagrange interpolation, elucidating its principles and methodologies. Through illustrative examples and practical applications within the realm of HVAC system optimization, we demonstrate the efficacy and versatility of this approach. Ultimately, this endeavor seeks to not only enhance our understanding of complex systems but also pave the way towards more efficient and sustainable engineering practices.

For a single variable, the Lagrange polynomial (x) that interpolates the points (x_i) is given by:

Quadratic approximation

In the pursuit of enhancing the efficiency and efficacy of Heating, Ventilation, and Air Conditioning (HVAC) systems, the integration of precise mathematical models is paramount. These models serve as fundamental tools in bridging the divide between real-world observations and predictive capabilities, facilitating the optimization of HVAC systems for superior performance. Among the critical components within these systems, compressors stand as dynamic entities, particularly pivotal in heat pump configurations.

Despite the ubiquitous use of compressors in HVAC systems, a notable challenge persists: the absence of comprehensive models that accurately capture their behavior across diverse operational scenarios. Manufacturers typically furnish real-world performance data, yet these datasets often lack the granularity necessary for a nuanced understanding of compressor dynamics in varied conditions. Consequently, the reliance on empirical data poses limitations on system evaluation and optimization, hindering the attainment of optimal performance levels.

To address this gap, this paper proposes a novel approach centered on two-dimensional quadratic approximation. By leveraging mathematical methodologies, specifically tailored to the complexities of compressor behavior, we aim to construct detailed models capable of extrapolating compressor performance across a spectrum of operating parameters. This endeavor seeks to empower HVAC engineers and practitioners with robust analytical tools, enabling them to evaluate and optimize systems without sole dependency on empirical data.[1]

In this paper, we delve into the theoretical underpinnings of two-dimensional quadratic approximation, elucidating its applicability in capturing the intricacies of compressor dynamics. Through a systematic exploration of its implementation within HVAC contexts, we endeavor to demonstrate its efficacy as a means of enhancing system performance and efficiency. By fostering a deeper understanding of compressor behavior through mathematical modeling, we aspire to catalyze advancements in HVAC technology, fostering a paradigm shift towards data-driven optimization strategies.

2. Methodology

Lagrange multivariable interpolation [2]

For a single variable, the Lagrange polynomial (x) that interpolates the points (x_i) is given by:

$$P(x) = \sum_{i=0}^n y_i L_i(x)$$

Where $L_i(x)$ are the Lagrange basis polynomials defined as:

$$L_i(x) = \prod_{j=0, j \neq i}^n 0 \leq j \leq n \frac{x - x_j}{x_i - x_j}$$

Extending to two dimensions:

For two variables, $f(x, y)$, the interpolation polynomial $P(x, y)$ is constructed similarly. Given a set of points (x_i, y_i, f_i) where $f_i = f(x_i, y_i)$ the polynomial is:

$$P(x, y) = \sum_{i=0}^n \sum_{j=0}^m f_{ij} L_i(x) M_j(y)$$

Where $L_i(x)$ and $M_j(y)$ are the Lagrange basis polynomials for x and y respectively.

Lagrange basis Polynomials in two dimensions:

The basis polynomials L_i and $M_j(y)$ are constructed as:

$$L_i(x) = \prod_{k=0, k \neq i}^n 0 \leq k \leq n \frac{x - x_k}{x_i - x_k}$$

$$M_j(y) = \prod_{l=0, l \neq j}^m 0 \leq l \leq m \frac{y - y_l}{y_j - y_l}$$

The error in multivariable Lagrange interpolation depends on the distribution of the interpolation points and the smoothness of the function f . The error term for two variables can be expressed as:

$$E(x) = f(x, y) - P(x, y) = \frac{\partial^{n+1} f}{\partial x^{n+1}}(\xi_x) \frac{\partial^{m+1} f}{\partial y^{m+1}}(\xi_y) \prod_{i=1}^n (x - x_i) \prod_{j=1}^m (y - y_j)$$

Where ξ_x and ξ_y are points within the interpolation range.

Multivariable approximation using the least square method

The least square method is a mathematical technique used to find the best-fitting curve to a given set of data points by minimizing the sum of squares of the differences between the observed and estimated values. When dealing with multiple variables, this method is referred to as Multivariable Least square Approximation. [3,4]

Consider a dataset with n observations and p independent variables. The model can be represented as:

$$y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} + \dots + \beta_p x_{ip} + \epsilon_i$$

Where y_i is the dependent variable, x_{ij} are the independent variables, β_j are the coefficients to be estimated, and ϵ_i is the error term.

The equations can be written in matrix form as:

$$y = X\beta + \epsilon$$

Where:

- y is an $n * 1$ vector of the dependent variable.
- X is an $n * (p + 1)$ matrix of independent variables (including a column of ones for the intercept term).
- β is a $1 * (p + 1)$ vector of coefficients.
- ϵ is an $n * 1$ vector of errors

Normal equations:

The least squares solution minimizes the sum of the squared residuals:

$$S(\beta) = \sum_{i=1}^n \epsilon_i^2 = (y - X\beta)^T (y - X\beta)$$

To find the minimum, we take the derivative of S with respect to β and set it to zero, resulting in the normal equations:

$$X^T X \beta = X^T y$$

Provided $X^T X$ is invertible, the solution is:

$$\beta = (X^T X)^{-1} X^T y$$

This provides the estimated coefficients β , which can be used to predict the dependent variable.

The estimated coefficients β_j represent the change in the dependent variable for a one-unit change in the corresponding variable, holding all other variables constant.

Experimental Setup

In order to conduct our experiment we take in account a compressor with the parameters as listed below:

Our compressor rating condition are:

- 35 °C Return gas temperature
- 8,3 K Subcooling
- 35 °C Ambient temperature
- 30 rps- compressor frequency

Cooling capacity (W)

		Evaporating temperature (°C)							
Condensing temperature (°C)		-25	-20	-15	-10	-5	0	5	10
	60				761	937	1141	1376	
	50			717	889	1088	1319	1584	
	40	519	659	822	1013	1235	1491	1785	
	30	595	746	924	1133	1376	1657	1979	
	20	670	832	1023	1249	1512			

The data shown on the table 1 & 2, are data that have been acquired in the laboratory. Now in order make the interpolation and the approximation of the 2-dimensional data we use the Matlab app.[5,6,7]

During the interpolation method of the Lagrange 2-dim we get:

Linear model Poly22:

$$f(x, y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2$$

where x is normalized by mean 38.57 and std 13.25

and where y is normalized by mean -8.929 and std 9.56

Coefficients (with 95% confidence bounds):

$$p00 = 1075 \text{ (1069, 1081)}$$

$$p10 = -172.4 \text{ (-176, -168.8)}$$

$$p01 = 414.1 \text{ (410.4, 417.8)}$$

$$p20 = -3.788 \text{ (-7.822, 0.2449)}$$

$$p11 = -56.02 \quad (-61.15, -50.9)$$

$$p02 = 61.1 \quad (57.16, 65.05)$$

Goodness of fit:

SSE: 1.4e+06

R-square: 0.9997

Adjusted R-square: 0.9996

RMSE: 252.2

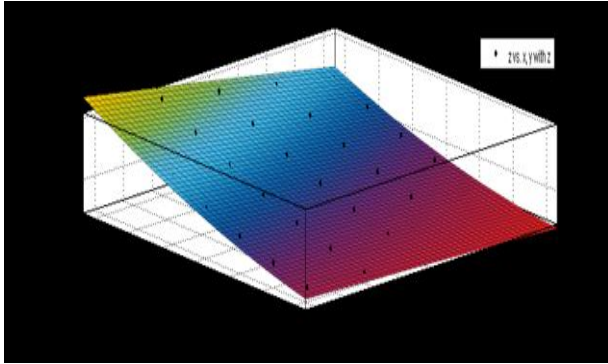


Figure 1. Two-dimensional interpolation using Lagrange interpolation

Now we will make the 2-dimensional approximation in order to approximate the data from table 1 & 2.

Linear model Poly33:

$$f(x,y) = p00 + p10*x + p01*y + p20*x^2 + p11*x*y + p02*y^2 + p30*x^3 + p21*x^2*y + p12*x*y^2 + p03*y^3$$

where x is normalized by mean 38.57 and std 13.25

and where y is normalized by mean -8.929 and std 9.56

Coefficients (with 95% confidence bounds):

$$p00 = 1076 \quad (1076, 1076)$$

$$p10 = -166.9 \quad (-167.2, -166.6)$$

$$p01 = 411.9 \quad (411.6, 412.2)$$

$$p20 = -3.749 \quad (-3.876, -3.623)$$

$$p11 = -52.48 \quad (-52.65, -52.32)$$

$$p02 = 58.74 \quad (58.62, 58.87)$$

$$p30 = 0.08966 \quad (-0.05532, 0.2346)$$

$$p21 = -1.804 \quad (-2.022, -1.585)$$

$$p12 = -8.027 \quad (-8.234, -7.82)$$

$$p03 = 4.107 \quad (3.981, 4.233)$$

Goodness of fit:

SSE: 840.7

R-square: 1

Adjusted R-square: 1

RMSE: 6.834

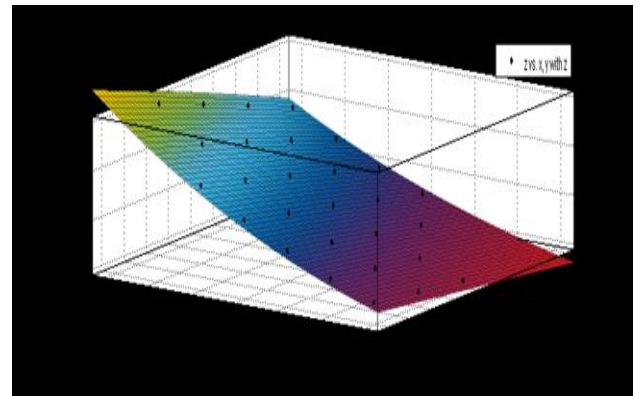


Figure 2. Approximation of 2-dimensional data

Conclusion

From the results above, we can see that both polynomial interpolation and cubic polynomial approximation yield outputs for the gas compressor that are very similar to the data obtained from the laboratory. Both methods converge to the real-time data from the laboratory, though this case consists only of the cooling data output of the gas compressor. The results are very promising, indicating that we can now use these two methods to define the output data, eliminating the need to retrieve data from the laboratory. While Lagrange interpolation performs slightly better than cubic approximation, the difference is not significant.

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

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

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

1. Introduction

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

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

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

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

2. Experimental

2.1. Materials

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

2.2. Method

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

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

3. Results and discussion

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

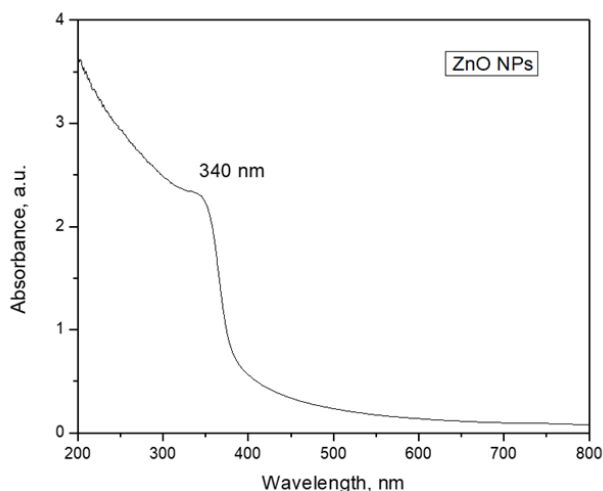


Fig. 1. UV-vis spectrum of as-prepared suspension.

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

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

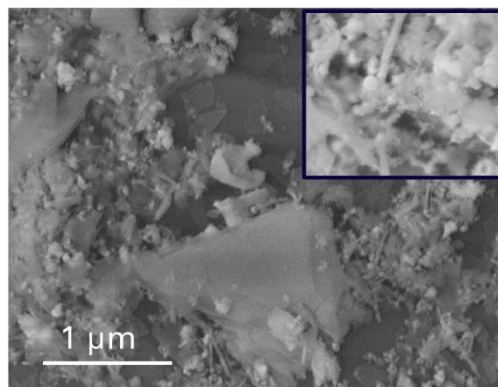


Fig. 2. SEM images in the sample ZnO-Zeo at different magnifications.

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

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

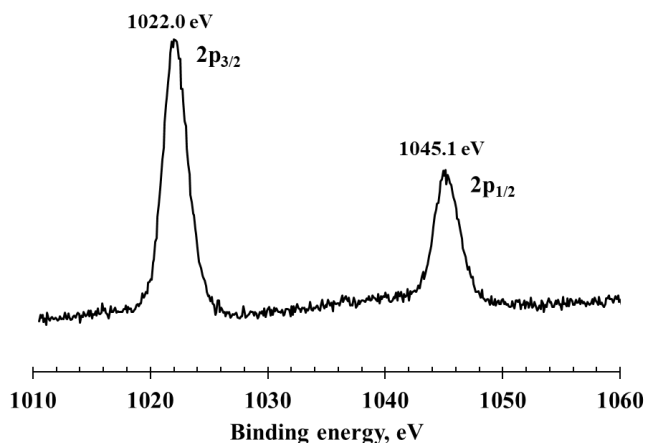


Fig. 3. Zn 2p XPS spectrum of the sample ZnO-Zeo.

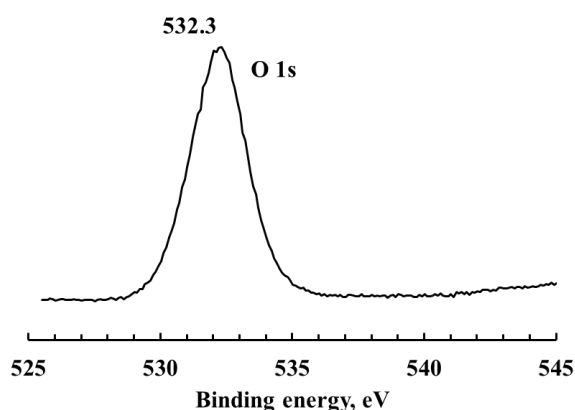


Fig. 4. O1s XPS spectrum of the sample ZnO-Zeo.

4. Conclusions

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

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6. References

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