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WORK SAFETY DURING THE INJECTION MOLDING PROCESS OF POLYMER MATERIALS

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Abstract: Injection molding is one of the fundamental processes used in the processing of widely utilized engineering materials, such as polymer materials. The injection molding method is commonly employed in the processing of both thermoplastic and thermosetting polymers. Despite the various technical measures implemented by manufacturers to mitigate risks to operators and the environment, injection molding machines still present potential hazards that could lead to accidents. This paper will describe the hazards associated with operating injection molding machines, as well as the preventive measures used by designers and those involved in the injection molding process. In the context of material modification, particularly polymer materials, injection molding plays a crucial role not only in shaping components but also in modifying the material properties. The ability to modify polymers during the injection molding process, such as through the inclusion of additives or reinforcements, allows for the creation of materials with enhanced mechanical properties, thermal resistance, or other desired characteristics. The safe and efficient execution of these processes requires a thorough understanding of both the material behavior and the potential operational hazards associated with the molding machines. This paper will also touch on how these material modifications impact the safety protocols and preventive measures in place to ensure smooth operation.
Keywords: plastic injection process, injection moulding, occupational safety

1. INTRODUCTION

The development of the global economy in recent years has been characterized by rapid change. This phenomenon has created a range of new, often challenging issues for companies, requiring them to be highly adaptable. Many industries, including the plastics industry, have undergone significant transformations in recent years (Traczyk, 2023). Particularly stringent changes have occurred in the field of occupational health and safety management. Over time, approaches focused solely on addressing the consequences have gradually been replaced by those centered on prevention and the creation of proper working conditions. As a result, the field of occupational health and safety has gained an increasing number of supporters and is developing rapidly. This is because more and more manufacturing companies are recognizing the benefits of a rational approach to these issues (Lis et al., 2024). There is also growing awareness among managers that simply producing quality products is not enough to attract customers. It is equally important to address other aspects of manufacturing, such as occupational health and safety, which can play a crucial role in the customer's decision to establish a partnership. This is because, to a large extent, workplace safety is closely linked to the overall production conditions within a company. The level of safety depends on the company's resources—human, financial, technological, and material. An effective system for collecting and processing information is essential for making informed decisions to improve health and safety based on collected data. Effective decisions are rooted in data and information analysis.

The plastics industry, despite the odium caused by media arguing for "green policy", is still of growing importance, as it is associated with both lower energy expenditure in production than in the metal industry and provides practical means of reducing pollution with heavy metals (Radzymińska-Lenarcik and Ulewicz, 2015; Radzymińska-Lenarcik and Ulewicz, 2019). It also supplies materials that, by modifying physical and chemical properties, significantly improve medical products, including orthopedic products (Wojnar et al., 2019; Jasiewicz et al., 2021) and implants (Dudek and Kolan, 2010; Dudek, 2011). However, plastics, to effectively compete with metal materials (Ulewicz et al., 2013; Szczotok et al., 2017; Markovic et al. 2021), require careful design in terms of strength, especially in the case of composites (Wrońska et al., 2019; Krysiak et al., 2020). They then become a convenient and cheap material both in construction (Orman et al., 2022) and in railways (Radek et al., 2019), which, however, requires careful education of engineering staff (Radek et al., 2023) and supporting systems also (Dwornicka and Pietraszek, 2018).

This paper characterizes the plastics industry and the occupational health and safety management systems in polymer materials processing enterprises. It also discusses the plastic injection molding process and the hazards associated with operating processing machinery. Preventive measures to improve occupational safety, both in the design and operation of injection molding machines, are also outlined.

2. CHARACTERISTICS OF THE PLASTICS INDUSTRY

The term "plastics industry" is commonly used to refer to the broader polymer materials industry. It encompasses various sectors, with the main ones being grouped into four categories: 1) the production of plastics (including manufacturers of additives, polymer-based composite blends - compounders, and distributors), 2) the processing sector, which produces semi-finished and finished products made from plastics and rubber, 3) the manufacturing of processing equipment and accessories, and 4) recycling (Fig. 1).

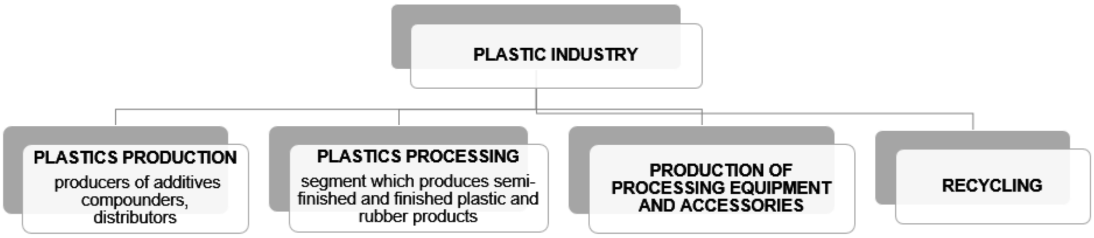

Fig. 1. Division of the plastics industry

Global plastics production in 2022 exceeded 400 million tons and was 1.6% higher than in 2021 (Fig. 2).

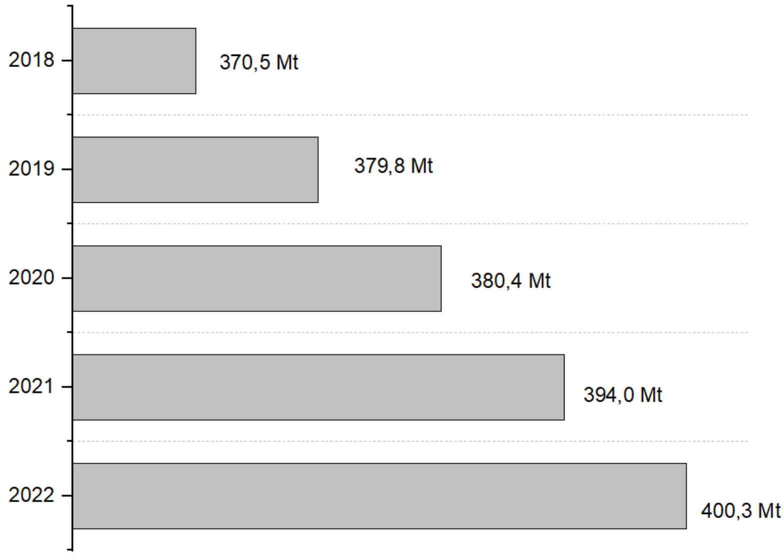

Fig. 2. World plastics production 2018÷2022 Source: (Plastics – the fast facts 2023, Plastics Europe Enabling a sustainable future)

In contrast, a downward trend was observed in EU countries: plastics production in 2022 decreased by 3.45%. In 2021, it was 60.8 million tons, while in 2022, it fell to 58.7 million tons. In recent years, the position of Asian countries, led by China, has significantly strengthened. In 2022, China's share of global production was 32%, or 128 million tons. Despite this, Europe, with a global market share of 14% (56 million tons), remains a major player. Germany dominates the European market in terms of demand for plastics and plastic products. Poland, with a demand accounting for 7.7% of the European market, ranks sixth, behind Germany, Italy, France, Spain, and the United Kingdom. Compared to the rest of Europe, the Polish plastics industry is developing at a good pace. Despite the clear decline in 2020 due to the COVID-19 pandemic, by the end of 2021, the growth in production was at a high level. Unfortunately, as of 2022, due to the war in Ukraine and the resulting energy crisis in Europe, the production of plastic products has remained stagnant, with a downward trend. Low global economic indicators have contributed to a reduced demand for plastic products. The plastics processing segment is the largest and fastest growing segment of the plastics industry. The main areas of plastics processing in Poland are the production of packaging (containers, bottles, boxes, plastic packaging), the production of pipes and profiles (for use in construction), the production of products for the automotive industry, and the production of cables (Fig. 3).

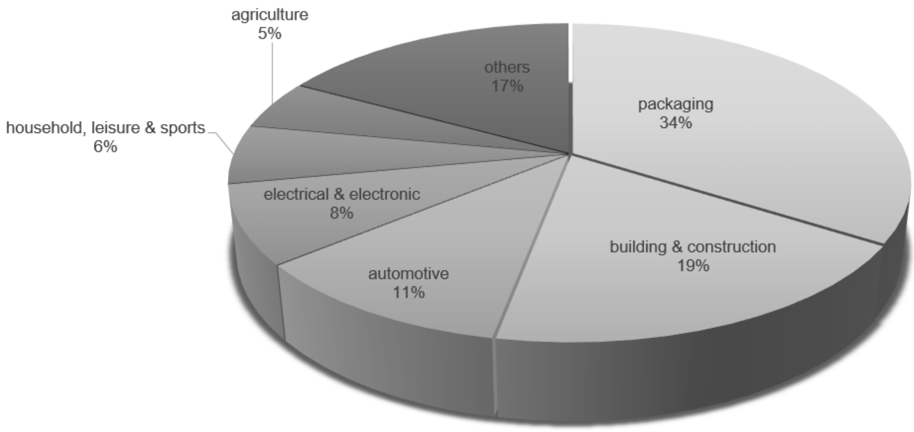

Fig. 3. Main fields of application of plastics in Poland Source: (Raport PlasticsEurope Polska, 2020)

The production of plastics involves the intensive processing of polymeric materials, leading to the creation of products or semi-finished goods. According to statistical data (Statistical Yearbook of the Republic of Poland, 2023), in 2022, the plastics and rubber processing industry employed 237,500 people. It was the third largest industrial sector in terms of employment, after the production of food products (431.6 thousand people) and the production of metal products (374 thousand people).
The equipment used in plastics processing (such as injection molding machines, extruders, etc.), despite modern design solutions aimed at preventing risks to both operators and the environment, still creates situations that pose various accident hazards. During the injection molding process, the most common causes of accidents include human error, crushing by transported materials, contact with moving sharp tools, being struck or grabbed by machinery, and burns from contact with hot plastics and surfaces.

Table 1
Accidents at work in the plastics and rubber processing sector

Research period	**Number of accidents**			
	total	fatal	heavy	with different results
2018	2688	1	18	2669
2019	2741	1	11	2729
2020	2112	1	30	2081
2021	2239	3	12	2224
2022	1928	0	14	1914

Source: (Accidents at work, GUS, 2019÷2023)

Statistics from the Central Statistical Office (CSO) show that 1,928 workers in the plastics and rubber processing sector suffered accidents at work in 2022 (Table 1). Unfortunately, an analysis of the data in Table 1 reveals that workplace accidents in plastics processing are quite common. Comparing the data from 2018 to 2022, it is evident that approximately two thousand accidents occur annually in the industry. Therefore, when using and operating machinery, it is crucial to implement measures that improve safety and working conditions.

3. HEALTH AND SAFETY MANAGEMENT SYSTEM IN PLASTICS ENTERPRISES

The basic definition of safety, as found in the Polish language dictionary, is: “Safety is a state of non-threat, calmness, certainty. Occupational safety and health (OSH), on the other hand, refers to a set of conditions that ensure the elimination or maximum reduction of the negative impact of the working environment on the worker’s body” (Dictionary of the Polish Language, 1994). According to A. Maslow’s hierarchy of needs, safety is one of the basic human needs, and only when a person’s safety needs are met can they focus on higher-order needs. Employers should keep this in mind, as employees are more likely to perform their tasks effectively in an environment free from fear and uncertainty. The traditional instrument used by employers to improve the safety and health protection of employees is legislation. One key piece of legislation essential for the management of occupational health and safety in organizations across the European Union is the Framework Directive 89/391/EEC, which introduces measures to encourage improvements in the safety and health of workers at work. The provisions of this directive are reflected both in the Labor Code and in a number of accompanying implementing acts. Accordingly, employers, in addition to complying with these regulations, must also actively participate in the creation of a safe and healthy work environment through the use of various preventive measures. The primary objective of the occupational health and safety management system in plastics companies is to continuously improve performance in the area of occupational health and safety, particularly in preventing workplace accidents and work-related illnesses, and to ensure healthy and safe working conditions. An important role in this process is played by standards that address occupational health and safety management in a systematic way, facilitating the implementation of measures that lead to improved working conditions. Currently, ISO 45001:2018 plays a key role in promoting and implementing OSH management systems. The model of an OSH management system according to this standard is shown in Fig. 4. This standard outlines the requirements and guidelines for an OSH management system, and its Polish version (PN-ISO 45001:2018-06) was published in 2019.

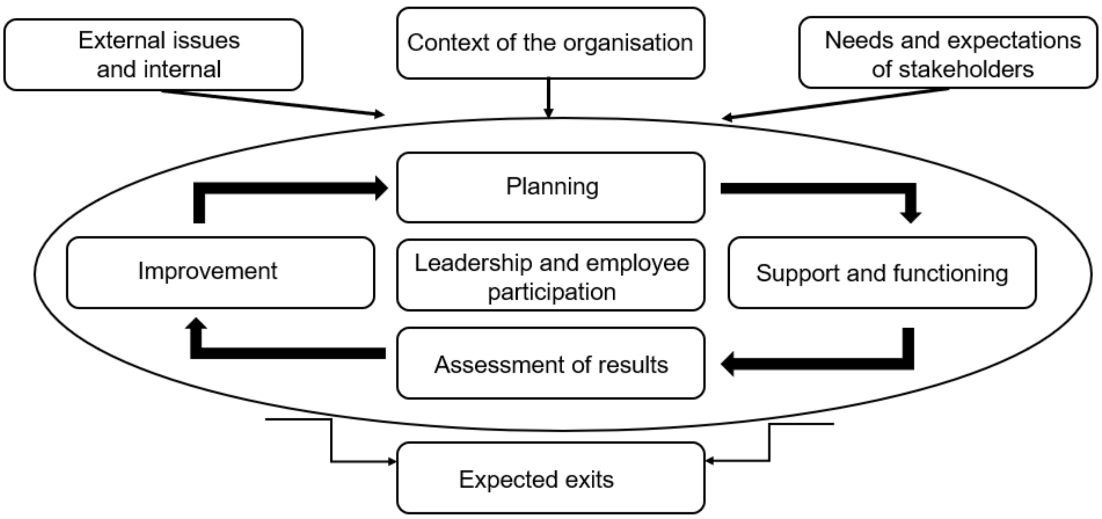

Fig. 4. Occupational health and safety management system model according to PN-ISO 45001:2018-06.

An enterprise's occupational safety management system is a comprehensive set of interconnected elements that work closely together at all levels (Pawłowska and Skład, 2019). It should be characterized by a well-secured and properly supervised technical infrastructure, clear documentation, and a committed workforce. Adequate working conditions, including employee safety, are key elements of a well-functioning enterprise. Implementing an occupational health and safety management system in accordance with current standards enables more effective management, ensuring ongoing compliance with legal requirements and facilitating monitoring in the field of occupational health and safety. These activities directly contribute to the measurable reduction of losses in this area and allow for the assessment of the effectiveness of applied organizational solutions in hazard identification, as well as in the prevention and reduction of occupational risks. These elements are particularly important in plastics industry companies, where specific activities are associated with numerous hazards and high occupational risks. Therefore, it is crucial to continuously monitor processes, detect irregularities early, and focus on the ongoing improvement of the occupational health and safety system.

4. CHARACTERISTICS OF THE INJECTION MOLDING PROCESS

Plastic injection molding is a cyclic process used to manufacture products from polymeric materials. The process involves heating a specific plastic (usually in the form of granules, though less commonly in chips or powder form) to a temperature at which plasticization occurs. The plasticized material is then subjected to pressure, causing it to flow rapidly (injection) into the mold cavity. The cavity of the injection mold replicates the shape of the part to be produced. After injection, the plastic solidifies as the temperature drops. Once the plastic has solidified, the finished part (molded product) is removed from the mold, and the process cycle begins again. Injection molding is one of the primary methods used to process plastics (Górska and Caban, 2021). It is primarily used for thermoplastics, although it can also be applied to the processing of duroplastics. This method is employed to produce both small, simple parts (mass < 1 mg) and larger, more complex components (mass > 10 kg) with precise shape and dimensional requirements.

Injection molding machines, which serve as production equipment, are multifunctional, highly complex, and precise devices. While the design of different types of injection molding machines is similar, they may vary depending on the specific requirements of the manufacturing process (Fig. 5).

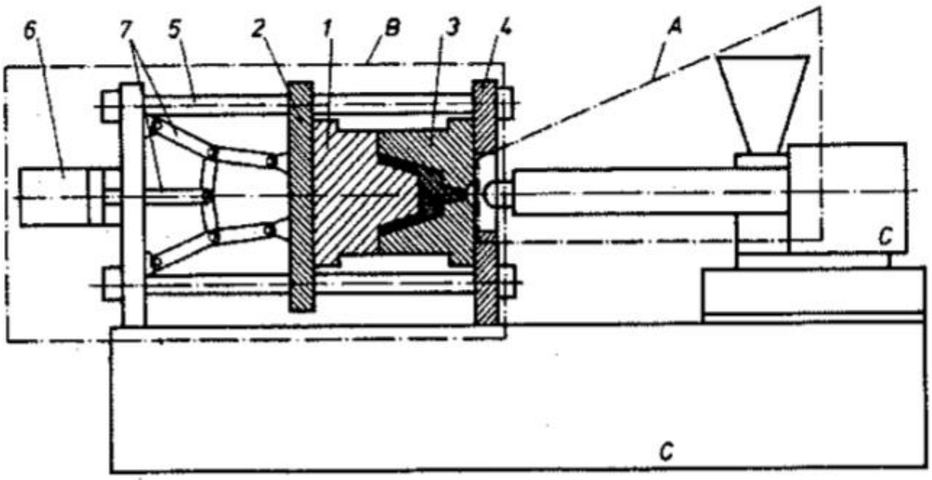

Fig. 5. Injection moulding scheme: A- plasticizing system, B – tool layout, C – drive system. 1 – movable part of the form, 2 - movable injection molding table, 3 - stationary part of the form, 4 - stationary injection molding table (Sikora, 1993)

There are two basic functional units in an injection molding machine: the plasticizing-injection unit (which includes the piston and screw) and the clamping unit. The clamping unit primarily consists of the injection mold and auxiliary components. The injection mold itself is a tool (fixture) that is individually designed and manufactured for each component to be produced; it is not an integral part of the injection molding machine (Koszkul et al., 2010). Injection molds are highly complex tools, weighing anywhere from tens to hundreds of kilograms. An injection mold is made up of two subassemblies (plates): one attached to the moving platen of the injection molding machine (the moving subassembly) and the other attached to the stationary platen (the stationary subassembly). During the injection molding process, the two halves of the mold are closed with a very high force, ranging from tens to thousands of tons. This high closing force prevents the mold from separating when molten plastic is injected into it at high pressure, typically ranging from tens to up to 300 MPa.

5. HAZARDS ASSOCIATED WITH OPERATING MACHINERY DESIGNED FOR INJECTION MOLDING

A hazard is defined as a potentially dangerous factor or situation that can cause injury, illness, property damage, environmental damage, or a combination of these outcomes. According to Polish standards, a hazard is any condition in the work environment that has the potential to cause an accident or illness (Polish Standards, 2004). Factors present in the work environment—stemming from the work process and related to the performance of tasks—constitute the so-called working conditions. In plastics processing, two groups of workers can be distinguished: operators (those who directly operate machinery) and service technicians (specialists responsible for maintenance and repair activities). For both groups, it is essential to ensure a high level of safety in their work. Identifying the hazards present in the work environment is crucial for accurately assessing occupational risks and selecting appropriate measures to eliminate or mitigate these risks. Despite the legal regulations in place regarding safety and occupational health (Ordinance of the Minister of Economy, 2002), plastics processing continues to be associated with an increased risk of injuries and occupational diseases. The primary sources of factors leading to accidents in this sector are production and auxiliary machinery, such as injection molding machines, extruders, and similar equipment. The main hazards during the operation of an injection molding machine are mechanical, particularly those related to moving parts of the machine, and especially the moving mold components. These hazards can be mitigated with appropriate safety systems. Moving machine parts can cause accidents, such as impacts, crush injuries, or contact with sharp, moving tools. Workers operating injection molding machines may also be exposed to hot surfaces (e.g., the heated cylinder in the injection system, heating elements of the injection molding machine) or to contact with hot granules (Frymus and Babicz, 2017). Moist granules fed into the injection molding machine can cause thermal burns or eye injuries. Some plastics (e.g., POM or PVC) undergo chemical degradation after the injection molding process, releasing harmful and toxic gases (such as HCl and formaldehyde), which can cause respiratory allergies or skin irritation (Iwko, 2010). The causes of various types of hazards during the injection molding process can also include high pressures from working fluids, electricity, and noise generated by operating machinery. In many plastics processing plants, due to modern demands for high production efficiency, it is essential to ensure that machines are maintained in a state of readiness (Przybyliński, 2014). Interruptions in machine operation, caused by malfunctions or the need for lubrication and maintenance,

not only result in financial losses for the company but also create situations that pose risks to the health and safety of employees performing maintenance and repairs. These employees are often required to carry out their tasks under time pressure, in high-risk environments, with active hazards present and safety devices either disabled or blocked.
Preventive Measures Used by Designers and Injection Molding Process Operators
Injection molding machines used in plastics processing, despite the many technical measures implemented by manufacturers to ensure a high level of safety, still present situations that can lead to various accident hazards. Plastics processing should involve the use of appropriate machinery, installations, and equipment designed to reduce the risk of accidents and near misses, with systematic controls to ensure compliance with occupational safety and health (OSH) requirements during operation. Even at the design stage of processing machines (such as injection molding machines), hazards can be significantly reduced by employing optimal design solutions, planning the use of protective devices (e.g., guards, safety mechanisms), and integrating additional safety measures (e.g., emergency stops, signaling, and visualization devices) (Przybyliński, 2014). Ensuring safety during the operation of injection molding machines is primarily achieved by adhering to the manufacturer's instructions for machine use and operation.
To reduce the level of risk during the operation of plastic injection molding machines, preventive and precautionary measures are implemented. These measures include ensuring the proper technical condition of the machines by following the maintenance schedule and performing corrective actions as soon as a defect is detected. Maintaining order in the workplace, using personal protective equipment (such as boots, work clothes, and protective gloves), and observing working hours all contribute to improving occupational safety. A key strategy to prevent machine hazards is to promote safe behavior among employees (Iwko, 2010). Employers who intensify training efforts for machine operators and increase managerial supervision of occupational health and safety play a significant role in raising the overall safety culture within the plant (Przybyliński, 2014).

6. SUMMARY

Efficient and safe operation of injection molding machines is a primary goal for any manufacturer. Therefore, special attention must be given to various aspects of the work process and safety concerns. Injection molding machines are technologically complex devices. Because they contain moving parts of significant weight, use various working media such as water and oil, and have components that are heated to temperatures between 200÷400°C, they incorporate a variety of electrical and mechanical safety systems. These systems are designed to protect operators from injury, as well as to safeguard both products and machines from damage. The most important regulations governing operations in the plastics processing industry can be found in directives and decisions issued by European Union institutions related to product standards, occupational health and safety, and environmental protection.

REFERENCES

Dudek, A., Kolan, C., 2010. *Assessments of shrinkage degree in bioceramic sinters HA+ZrO$_2$*. Solid State Phenom. 165, 25-30. https://doi.org/10.4028/www.scientific.net/SSP.165.25

Dudek, A., 2011. *Investigations of microstructure and properties in bioceramic coatings used in medicine*. Archives of Metallurgy and Materials, 56 (1), 135-140, DOI: 10.2478/v10172-011-0015-y

Dwornicka R., J. Pietraszek, *The outline of the expert system for the design of experiment*, Prod. Eng. Arch. 20 (2018) 43-48, DOI: 10.30657/pea.2018.20.09

Frymus, J., Babicz, W., 2017, *Hazards at the operator position resulting from the construction of the injection molding machine and the course of the process*, Archives of engineering Knowledge

Górska, M., Caban, R., 2021, *Product Competitiveness and Need for Improving Technologies in Enterprises of the Plastic Industry*, Innovation Management and Information Technology Impact on Global Economy in the Era of Pandemic (red.) SOLIMAN Khalid S., International Business Information Management Association (IBIMA) 2021, 5823-5834

Iwko, J., 2010. *Analiza bezpieczeństwa pracy na stanowisku operatora wtryskarki. Cz. 5 Bezpieczeństwo i higiena pracy na stanowisku operatora wtryskarki,* Poradnik Przetwórcy tworzyw sztucznych

Jasiewicz, B., Pietraszek, J., Duda, S., Pietrzak, Sz., Pruszczyński, B., Parol, T., Potaczek, T., Gądek – Moszczak A., 2021. *Inter-observer and intra-observer reliability in the radiographic measurements of paediatric forefoot alignment*. Foot and Ankle Surgery, 27, 371-376, DOI: 10.1016/j.fas.2020.04.015

Koszkul, J., Caban, R., Nabiałek, J., 2010. *Narzędzia do przetwórstwa polimerów*. CWA Regina Poloniae, Częstochowa

Krysiak, P., Szczepaniak, M., Wojcieszyńska P., Jasiński, W., 2020. *Strength testing of a composite mounting frame for a multi-sensor detection system*. Materials Research Proceedings, 17, 165-170, DOI: 10.21741/9781644901038-25

Lis, T., Nowacki, K., Małysa, T., 2024, *Zarządzanie bezpieczeństwem pracy - aspekty ekonomiczne*, HUMANITAS Zarządzanie, 2024, 1, s. 25-40, DOI 10.5604/01.3001.0054.4974

Marković, S., Arsić, D., Nikolić, R.R., Lazić, V., Hadzima, B., Milovanowić V.P., Dwornicka, R., Ulewicz, R., 2021. *Exploitation characteristics of teeth flanks of gears regenerated by three hard-facing procedures*. Materials, 14 (15), art. 4203, DOI: 10.3390/ma14154203

Orman, Ł.J., Majewski, G., Radek, N., Pietraszek J., 2022. *Analysis of Thermal Comfort in Intelligent and Traditional Buildings*, Energies 15 (2022) art. 6522, DOI: 10.3390/en15186522

Pawłowska, Z., Skład, A., 2019, *Dostosowanie Systemów Zarządzania BHP do wytycznych wynikających z normy ISO/DIS 45001.2*, Napędy i sterowanie, 4

Plastics – the fast facts 2023, Plastics Europe Enabling a sustainable future

Polskie Normy: PN-N-18001:2004. *Systemy zarządzania bezpieczeństwem i higieną pracy. Wymagania.* Polski Komitet Normalizacyjny, Warszawa

Przybyliński, B., 2014, *Eksploatacyjne ryzyko maszynowe w przetwórstwie tworzyw sztucznych*, Inż. Ap. Chem., 53, 2, 105-106

Radek, M., Pietraszek, A., Kozień, A., Radek, K., Pietraszek, J., 2023. *Matching Computational Tools to User Competence Levels in Education of Engineering Data Processing*. Materials Research Proceedings, 34, 453-459, DOI: 10.21741/9781644902691-52

Radek, N., Pietraszek, J., Pasieczyński, Ł., *Technology and application of anti-graffiti coating systems for rolling stock*, METAL 2019 - 28th Int. Conf. Metall. Mater. (2019) 1127-1132.

Radzyminska-Lenarcik, E., Ulewicz, M., 2015. *The use of the steric effect of the carrier molecule in the polymer inclusion membranes for the separation of cobalt(II), nickel(II), copper(II), and zinc(II) ions*. Polish Journal of Chemical Technology, 17 (2), 51-56, DOI: 10.1515/pjct-2015-0029

Radzyminska-Lenarcik, E., Ulewicz, M., 2019. *Polymer inclusion membranes (PIMs) doped with alkylimidazole and their application in the separation of non-ferrous metal ions*. Polymers, 11 (11), art. 1780, DOI: 10.3390/polym11111780

Raport PlasticsEurope Polska, 2020

Rocznik statystyczny Rzeczpospolitej Polskiej, 2023, Tab.3 (217). *Pracujący wg sekcji i działów*

Rozporządzenie Ministra Gospodarki, 2002, *W sprawie bezpieczeństwa i higieny pracy przy przetwórstwie tworzyw sztucznych* (Dz. U. z 2002 r. Nr 81 poz. 735)

Sikora, R., 1993, *Przetwórstwo tworzyw wielkocząsteczkowych*, Wydawnictwo Edukacyjne, Warszawa

Słownik języka polskiego, 1994, Wyd. Naukowe PWN, Warszawa

Szczotok, A., Pietraszek, J., Radek, N., 2017. *Metallographic Study and Repeatability Analysis of γ′ Phase Precipitates in Cored*, Thin-Walled Castings Made from IN713C Superalloy. Arch. Metall. Mater. 62, 595-601, DOI: 10.1515/amm-2017-0088

Traczyk, W., 2023, *Branża produkcji i przetwórstwa tworzyw sztucznych na sinusoidzie*, MM Magazyn Przemysłowy, 4

Ulewicz, R., Mazur, M., Bokuvka, O., 2013. *Structure and mechanical properties of fine-grained steels. Periodica Polytechnica Transportation Engineering*, 41 (2), 111-115, DOI: DOI: 10.3311/PPtr.7110

Wojnar, L., Gądek-Moszczak, A., Pietraszek, J., 2019. *On the role of histomorphometric (stereological) microstructure parameters in the prediction of vertebrae compression strength*. Image Analysis and Stereology, 38, 63-73, DOI: 10.5566/ias.2028

Wronska, A., Andres, J., Altamer, T., Dudek, A., Ulewicz, R., 2019. *Effect of tool pin length on microstructure and mechanical strength of the FSW joints of Al 7075 metal sheets*. Communications - Scientific Letters of the University of Žilina, 21 (3), 40-47.

Wypadki przy pracy, 2019, Główny Urząd Statystyczny, Warszawa

Wypadki przy pracy, 2020, Główny Urząd Statystyczny, Warszawa

Wypadki przy pracy, 2021, Główny Urząd Statystyczny, Warszawa

Wypadki przy pracy, 2022, Główny Urząd Statystyczny, Warszawa

Wypadki przy pracy, 2023, Główny Urząd Statystyczny, Warszawa