A VIEW ON THE IMPACT OF METEOROLOGICAL FACTORS ON MINING EQUIPMENT AND MACHINES

ILIE-RADU MISCHIE[1], ANDREI ANDRAŞ[2]

Abstract: Both surface and underground mining operations, are significantly influenced by environmental conditions that directly impact machinery performance, durability, and safety. Factors such as extreme temperatures, humidity, precipitation, wind, and airborne particulates accelerate the degradation of mining equipment, leading to increased corrosion, mechanical failure, and operational delays. Corrosion, in particular, poses a critical threat to the longevity and reliability of mining machinery, with various forms including uniform, pitting, galvanic, crevice, and stress corrosion cracking.

This article explores the mechanisms through which adverse weather conditions and corrosive environments affect mining equipment, highlighting the detrimental effects on structural components and operational efficiency. By identifying key vulnerabilities and adopting preventive measures, mining companies can mitigate corrosion risks.

Adherence to international standards, such as ISO 12944 and ISO 8502, plays a vital role in guiding industry best practices for corrosion control. Implementing these strategies not only extends equipment lifespan but also enhances productivity, reduces downtime, and contributes to overall cost savings.

Keywords: Corrosion Control, Mining Machinery, Environmental Conditions, Preventive Maintenance, Protective Coatings, Material Degradation

1. INTRODUCTION

Mining operations in general, whether surface or underground, are directly influenced by the environmental conditions in which they operate, regardless of whether the exploited material is coal, ores or minerals. This influence acts on all areas of the mining operations, as they have been identified in relevant literature, with vulnerabilities identified in all phases of these mining operations.

[1] *Ph.D. student, University of Petroşani, r.mischie@yahoo.com*
[2] *Prof. Ph.D. Eng., University of Petroşani, andrei.andras@gmail.com*

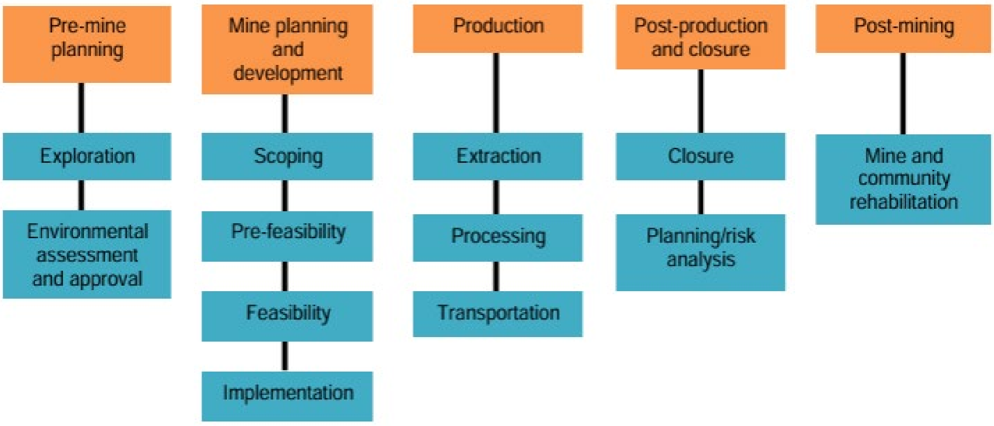

Fig. 1. Mining operations and processes affected by environmental conditions.

From intense heat to freezing temperatures, heavy rainfall, and high humidity, meteorological factors play a crucial role in determining the efficiency, durability, and safety of mining activities.

Studies show that adverse weather conditions can significantly disrupt mining operations. For example, extreme heat can lead to the overheating of engines and mechanical systems, while cold climates can cause materials to become brittle and prone to failure. Research on thermal management strategies for underground mines highlights the importance of mitigating temperature extremes to maintain equipment functionality. Additionally, humidity and precipitation exacerbate corrosion, reducing the lifespan of mining machinery and increasing maintenance costs. Wind and particulate matter further contribute to equipment degradation, influencing air quality and operational efficiency.

Besides problems caused to mining operation in general, harsh and unpredictable weather can create significant challenges for the machinery and equipment essential to these operations. Extreme weather not only affects the physical integrity of machinery but also increases the frequency of breakdowns, accelerates wear and tear, and contributes to operational delays. As mining companies expand operations into more remote and environmentally diverse regions, understanding and mitigating the impact of meteorological factors becomes increasingly vital. This article explores the various ways in which weather conditions influence mining equipment and machinery, drawing from recent research and offering strategies for minimizing adverse effects.

2. ADVERSE WEATHER CONDITIONS AND ITS INFLUENCE ON EQUIPMENT PERFORMANCE

Meteorological conditions such as extreme temperatures, humidity, wind, precipitation, and solar radiation have a considerable effect on mining machinery. Research indicates that weather conditions that deviate from the nominal design conditions for mining machines adversely affect performance. Factors like snowstorms, fog, and intense solar radiation can degrade materials and hinder machinery operations. For instance, snowstorms can cause significant mechanical stress, leading to misalignments and operational halts. Prolonged exposure to freezing conditions can reduce the elasticity of rubber components, causing cracks and leaks in hydraulic systems. A study of coal mining operations revealed that snow accumulation on haul roads often delays transportation and reduces tire traction, increasing the likelihood of accidents.

Similarly, high temperatures can lead to metal expansion, affecting the precision of machinery components. In regions with frequent heat waves, mining sites report increased engine failures and hydraulic malfunctions due to overheating. Thermal expansion can distort metal components, compromising structural integrity. In open-pit mines, high temperatures accelerate wear on conveyor belts and drilling equipment, reducing operational efficiency. Extreme humidity poses another challenge, as it can facilitate the formation of condensation within machinery, leading to electrical short circuits and corrosion of internal components. Equipment such as electric shovels and draglines are particularly vulnerable in humid environments. Proper insulation and anti-corrosive coatings are essential to mitigate these risks.

Additionally, wind and precipitation can erode the surfaces of mining equipment, reducing their lifespan. Wind-driven sand and particulate matter accelerate surface abrasion, which can lead to structural weaknesses in metallic components. Heavy precipitation can flood mining areas, resulting in the submersion of machinery and increasing repair costs.

Fig.2. Bucket wheel excavator in Olteania overturned due to landslides caused by heavy rains

3. CORROSION AND ITS EFFECT ON MINING MACHINERY

3.1. A few words about corrosion

In the mining industry, where machinery and equipment are subject to harsh and varying environmental conditions, corrosion poses a significant threat to operational efficiency, safety, and cost management. Corrosion is a major issue affecting mining equipment, driven by environmental factors such as humidity, precipitation, and chemical exposure. During all mining operation, whether they are underground or open pit ones, heavy machinery operates under extreme environmental conditions, making the corrosion of metal components an inevitable challenge. Various forms of corrosion affect these massive machines, each posing unique threats to their structural integrity and performance.

One of the most common forms is **uniform corrosion**, where metal surfaces gradually thin over time due to constant exposure to air and moisture. While predictable, if left unchecked, it can weaken structural components, leading to potential equipment failure.

Pitting corrosion, on the other hand, is far more insidious. This localized form of corrosion creates small, deep pits in the metal, often concealed beneath layers of dust or paint. Though the affected area may seem minor at first glance, these pits can severely undermine the strength of critical components such as hydraulic arms, shovels, and buckets.

In areas where different types of metals meet, **galvanic corrosion** can take hold. When dissimilar metals come into contact in the presence of an electrolyte like water or salt, one metal corrodes at an accelerated rate. This type of corrosion is frequently found in joints, connectors, and fasteners, where metal combinations are essential for construction.

Corrosion doesn't always occur in plain sight. **Crevice corrosion** forms in tight, enclosed spaces such as beneath gaskets or between metal plates. In these areas, stagnant water lingers, creating a highly corrosive microenvironment that eats away at the hidden metal surfaces. In some cases, external forces compound the issue.

Stress corrosion cracking (SCC) arises when tensile stress combines with a corrosive environment, causing fractures to form in the metal. Over time, these cracks expand, compromising the integrity of large structural components vital to mining operations.

Finally, **erosion corrosion** affects machinery exposed to high-speed particles or liquids. Excavator buckets, conveyor belts, and dump truck beds frequently suffer from this aggressive wear, as the constant bombardment erodes protective coatings and directly attacks the metal beneath.

Each form of corrosion presents distinct challenges, but understanding their mechanisms is the first step toward mitigating their impact and ensuring the longevity of open-pit mining machinery. The various types of corrosion are grouped and illustrated in figure 2.

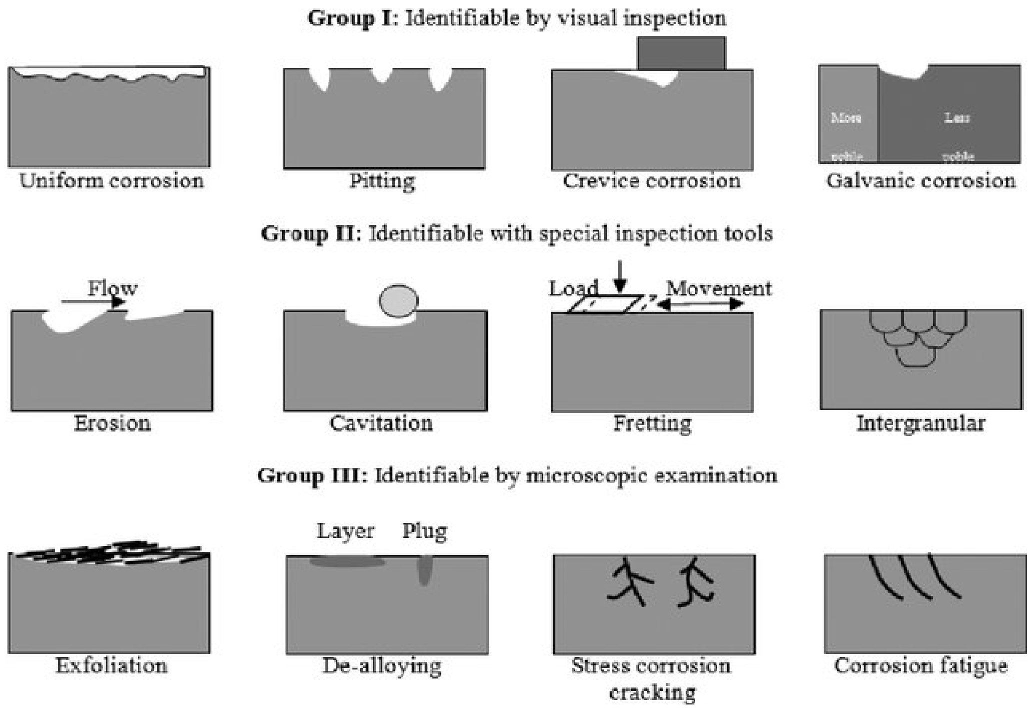

Fig.2. Main forms of corrosion grouped by their ease of recognition

3.2. Mining machinery and equipment subject to corrosion

Corrosion can severely weaken structural components, leading to equipment failures and costly downtime. Underground mines with high humidity levels are particularly vulnerable, as moisture accelerates oxidation of metallic parts. In coastal or salt-laden environments, chloride ions exacerbate the corrosion process, further reducing equipment lifespan. Besides underground mining machines, open pit mining operations are also affected. The metallic structures used in headframes, which facilitate the hoisting systems for material extraction, along with the large mining machinery (excavators, stackers, belt transport systems) operating at open cast mining sites, are also vulnerable to environmental-induced corrosion. Acknowledging the types of environmental conditions that intensify corrosion and implementing appropriate preventive measures are crucial for maintaining the functionality and safety of mining infrastructure.

During operation in the challenging environments found in mines that combine several corrosive elements, creating a highly reactive context for metallic structures, mining machinery and their metallic structures are consistently exposed to:

1. **Humidity and Moisture**: Underground mines are often damp environments with high humidity levels. Surface mines, particularly those located in tropical regions, are also prone to frequent rain, which accelerates corrosion. Moisture acts as a medium for electrochemical reactions, leading to rust and degradation on exposed metal surfaces.

2. **Temperature Extremes**: Mining locations often experience wide temperature variations, either diurnally or seasonally, which can lead to thermal expansion and contraction of metal components. These temperature changes create micro-cracks in the metal surfaces, allowing corrosive agents to penetrate deeper, accelerating deterioration.
3. **Acidic Environments**: Many ores, particularly sulfide ores, generate acidic environments due to the oxidation process. Acid mine drainage (AMD) results when sulfide minerals react with water and oxygen, creating sulfuric acid. This acidic runoff can come into contact with machinery, pipes, and metallic structures, causing rapid metal deterioration, especially in carbon steels.
4. **Salinity**: Mining operations located near coastal areas or salt-rich regions face the challenge of saline environments, which are extremely corrosive to metals. Saltwater accelerates galvanic corrosion, where metals with different electrochemical potentials in proximity react more vigorously.
5. **Dust and Abrasives**: Mining environments are rich in dust and particulates that, when settled on metallic surfaces, trap moisture and other corrosive agents. Dust from blasting, drilling, and mineral processing activities often contain corrosive elements, and these particles, when combined with water, accelerate the wear and tear of machinery and headframes.
6. **Industrial Pollutants**: Mining sites generate pollutants, including gases and particulates, from mineral processing, equipment exhaust, and chemical applications. Gases like sulfur dioxide and hydrogen sulfide contribute to corrosion, especially when combined with moisture, creating corrosive acidic compounds on metallic surfaces.

Large mining machinery, such as excavators, haul trucks, drills, and crushers, are subject to heavy wear and environmental corrosion due to constant exposure to water, abrasive particles, and chemical agents. The corrosive effects are often severe, causing:

- **Mechanical Degradation**: Corrosion leads to thinning and weakening of metal parts, reducing the structural integrity of machinery components, such as frames, buckets, blades, and hydraulic systems.
- **Reduced Efficiency**: Corrosion increases surface roughness, adding friction and lowering the operational efficiency of moving parts. This creates inefficiencies in fuel consumption, power output, and productivity.
- **Frequent Repairs and Maintenance**: Corrosion accelerates wear and shortens the lifespan of components, necessitating frequent maintenance, leading to downtime and added operational costs.
- **Increased Safety Risks**: Structural weakening due to corrosion can result in component failure, creating a safety risk for equipment operators and maintenance personnel.

The headframes are a vital structure in underground mining operations, supporting the hoisting system that transports miners, materials, and ore. Bucket wheel excavators, stackers and conveyor belts are vital in open pit mining operations, The metallic components of all these equipment, including beams, pulleys, and support structures, are heavily impacted by environmental conditions that promote corrosion:

- **Loss of Load-bearing Capacity**: Corrosion reduces the thickness and strength of load-bearing components, compromising the structural integrity of the headframe. This can lead to catastrophic failures if left unchecked.
- **Compromised Safety Mechanisms**: Corrosion affects hoisting safety mechanisms, such as brakes, pulleys, and wire ropes, increasing the risk of hoisting failures and endangering lives.
- **Downtime and Replacement Costs**: Replacing corroded headframe components or entire structures is expensive, and corrosion-induced breakdowns contribute to significant downtime.

Some examples of corrosion on the metallic components of large bucket wheel excavators in Romania are presented in figure 3.

Fig. 3. Corrosion of the bucket wheel excavator metallic parts

4. PREVENTIVE MEASURES FOR CORROSION CONTROL IN MINING ENVIRONMENTS

Preventative measures include the application of anti-corrosive coatings, regular maintenance schedules, and the use of corrosion-resistant materials such as stainless steel or specialized alloys. By addressing corrosion through comprehensive mitigation strategies, mining companies can significantly enhance the durability and reliability of their equipment, ensuring sustained productivity and reducing overall operational costs.

International standards are instrumental in guiding corrosion control and maintenance solutions for heavy industrial equipment including mining specific ones, providing a universally recognized framework that emphasizes consistency, quality, and safety in practice. The standards pertinent to corrosion control for cranes and industrial equipment are ISO 12944 and ISO 8502. The first standard outlines guidelines for protective coatings, covering aspects such as types of coatings, application methodologies, and inspection criteria. By adhering to these standards, a standardized approach to combating corrosion across various industrial settings, including those involving cranes and industrial equipment, is ensured. The second standard addresses the preparation of steel substrates before the application of paints and related products. It includes tests for assessing surface cleanliness and evaluating dust on steel surfaces prepared for painting.

These standards is applicable to cranes, heavy equipment and mining machinery constructed with steel structures. Based on these, the industry developed and imposed several m**aintenance strategies for corrosion control.** Implementing maintenance strategies to manage and prevent corrosion is vital for preserving the longevity, safety, reliability, and performance of industrial equipment and infrastructure. Effective corrosion control can lead to substantial cost reductions, with estimates suggesting potential savings of 15% to 35% in corrosion-related expenditures. This equates to global annual savings of up to $875 billion. Corrosion control encompasses a broad range of practices further detailed, including protective coatings, predictive maintenance, and advanced monitoring techniques. By adopting these solutions, industries can safeguard valuable assets, mitigate economic losses, reduce environmental damage, and enhance workplace safety. Outlined in figure 4 are the key industry best practices for corrosion prevention and control.

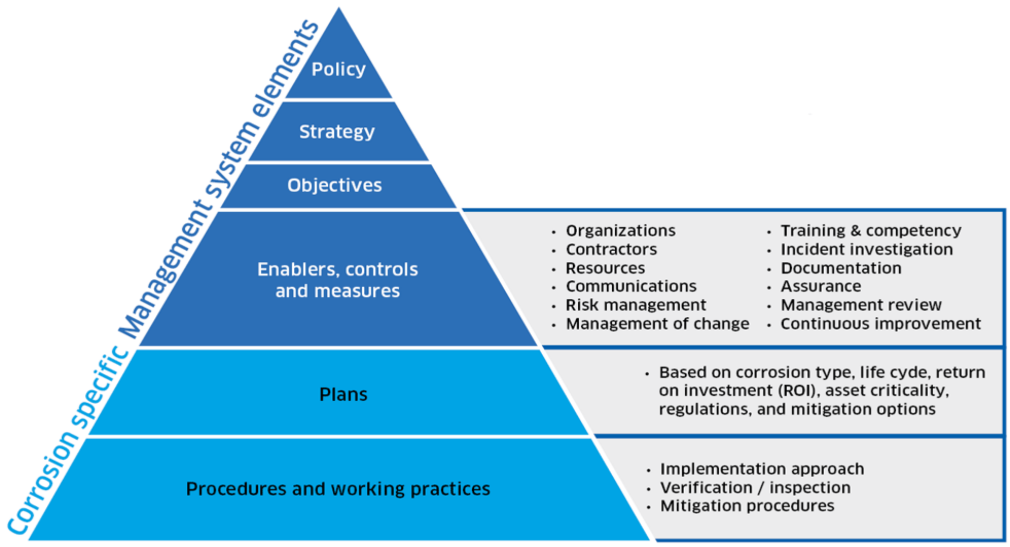

Fig. 4. Key industry best practices for corrosion prevention and control

To protect large mining machinery from corrosion, it is essential to employ effective mitigation strategies tailored to the specific environmental challenges of the mining site. Key preventive measures include:

1. **Material Selection**: Using corrosion-resistant materials, such as high-grade stainless steel, galvanized steel, or coated metals, can significantly reduce the rate of corrosion. Selecting metals based on their compatibility with the specific environmental conditions is a critical first step.
2. **Protective Coatings**: Applying durable coatings, like epoxy or polyurethane, on machinery and headframe structures acts as a barrier against moisture, chemicals, and abrasive particles. Coatings should be inspected and reapplied regularly to maintain protection.
3. **Cathodic Protection**: Sacrificial anodes or impressed current systems can be used to protect metallic structures by diverting the corrosion process away from critical components. This is particularly effective for submerged or buried metal parts, such as those in hoisting systems or structural foundations.
4. **Environmental Control**: Managing humidity and drainage systems, particularly in underground mining operations, can reduce the impact of moisture on equipment. Proper ventilation and dehumidification systems help control moisture levels in underground mines, while cathodic protection systems prevent galvanic corrosion by diverting electrical currents away from vulnerable equipment.
5. **Corrosion Inhibitors**: Chemical corrosion inhibitors can be applied to metallic surfaces to slow down corrosion reactions. This approach is suitable for machinery exposed to water or in contact with acidic environments.
6. **Regular Inspection and Maintenance**: Implementing a rigorous inspection schedule is essential to identify early signs of corrosion. Non-destructive testing (NDT) methods, such as ultrasonic or radiographic testing, can assess metal thickness and structural integrity without dismantling equipment.
7. **Automated Monitoring Systems**: Deploying sensors to monitor environmental factors, such as humidity, temperature, and pH levels, enables real-time data collection and immediate response to changing conditions, helping to prevent corrosive damage before it becomes severe.
8. **Surface Cleaning and Abrasive Control**: Regularly cleaning dust and abrasive particles off surfaces minimizes corrosion risk by preventing moisture and contaminants from settling.

5. CONCLUSIONS

Corrosion remains one of the most significant challenges facing the mining industry, driven by harsh environmental conditions that accelerate the deterioration of critical machinery and infrastructure. The influence of temperature extremes, humidity, precipitation, and chemical exposure underscores the necessity of adopting comprehensive corrosion management strategies.

By employing a combination of material selection, protective coatings, cathodic protection, and rigorous inspection routines, mining operations can effectively safeguard their assets against corrosion-related damage. International standards provide a framework for best practices, ensuring consistency and reliability across industrial applications.

The long-term benefits of proactive corrosion control are substantial—extending the lifespan of equipment, reducing maintenance costs, and enhancing safety. As mining companies continue to expand into more extreme and remote environments, prioritizing corrosion prevention will be essential for sustaining operational efficiency and profitability.

One potential solution is the development of mining equipment designed to better withstand the effects of extreme weather and climate conditions. This could involve the use of more durable materials, enhanced cooling systems, and advanced weatherproofing technologies to protect critical components from the elements. Additionally, the integration of renewable energy sources, such as solar and wind power, can help reduce the industry's reliance on fossil fuels and mitigate its carbon footprint.

Advancements in automation and control technology also have the potential to improve the efficiency and reliability of mining equipment, reducing the impact of meteorological factors on operational performance. By leveraging these technologies, mining companies can optimize their operations, minimize downtime, and enhance overall productivity, all while minimizing the environmental consequences of their activities.

As the mining industry continues to evolve and adapt to the challenges posed by climate change and extreme weather events, a holistic approach that combines innovative equipment design, renewable energy integration, and technological advancements will be crucial in ensuring a more sustainable and resilient future for the sector. Through these efforts, the mining industry can play a pivotal role in promoting environmental stewardship and supporting the livelihoods of communities across the world.

REFERENCES

[1]. **Hodgkinson, J., Littleboy, A.K., Howden, M., Moffat, K.B., Loechel, B.** *Climate adaptation in the Australian mining and exploration industries.* 2010.

[2]. **Ivanov, S., Ivanova, P., Kuvshinkin, S.** *Weather conditions as a factor affecting the performance of modern powerful mining excavators.* Journal of Physics: Conference Series, 1399, 2019. DOI: 10.1088/1742-6596/1399/4/044070.

[3]. **Sasmito, A., Kurnia, J., Birgersson, E., Mujumdar, A.** *Computational evaluation of thermal management strategies in an underground mine*. Applied Thermal Engineering, 90, 2015, pp. 1144-1150. DOI: 10.1016/J.APPLTHERMALENG.2015.01.062.

[4]. **Olkhovskiy, D., Zaitsev, A., Semin, M.** *Variation of cooling efficiency of air conditioning systems in working spaces of deep mines*. Mining informational and analytical bulletin. 2021. DOI: 10.25018/0236_1493_2021_12_0_110.

[5]. **Asif, Z., Chen, Z., Guo, J.** *A study of meteorological effects on PM2.5 concentration in mining area.* Atmospheric Pollution Research. 2018. DOI: 10.1016/J.APR.2018.01.004.

[6]. **Korban, Z.** Climatic hazard in X coal mine selected issues. *AGH Journal of Mining and Geoengineering*. 36, 2012, pp. 185-193. DOI: 10.7494/MINING.2012.36.3.185.

[7]. **Khazin, M.** International Emission Standards for Mining Machinery and Equipment. 20, 2020, pp. 291-300. DOI: 10.15593/2712-8008/2020.3.9.

[8]. **Petrilean, D.C., Irimie, S.I.** *Solutions for the capitalization of the energetic potential of sludge collected in Danutoni wastewater treatment plant.* J. Environ. Prot. Ecol. **3**(16), 1203–1211 (2015).

[9]. **Roy, J.M., Preston, R., Bewick, R.P.** Classification of Aqueous Corrosion in Underground Mines. *Rock Mech Rock Eng* **49**, 3387–3391 (2016). https://doi.org/10.1007/s00603-016-0926-z

[10]. **Fîţă, N. D., Radu, S. M., Păsculescu, D., Popescu, F. G.** *Using the primary energetic resources or electrical energy as a possible energetical tool or pressure tool.* In International conference KNOWLEDGE-BASED ORGANIZATION (Vol. 27, No. 3, pp. 21-26, 2021).

[11]. A**naee, Rana, Hameed Abdulmajeed, Majid.** Tribocorrosion. 2016. DOI: 10.5772/63657.

[12]. **Alghaithan, A.K.** *The Impact of Corrosion on Heavy Equipment***.** MaintWorld, 2023.

[13]. **Popescu, F.D., Radu, S.M., Andraș, A., Brînaș, I.** *Numerical Modeling of Mine Hoist Disc Brake Temperature for Safer Operation.* Sustainability, 13, 2874, 2021. DOI: 10.3390/su13052874.

[14]. **Fîță N.D., Lazăr T., Popescu F.G., Pasculescu D., Pupăză C., Grigorie E.,** *400 kV power substation fire and explosion hazard assessment to prevent a power black-out,* International Conference on Electrical, Computer Communications and Mecatronics Engineering - ICECCME, 16 – 18 November, Maldives, 2022

[15]. **Popescu, F.D., Radu, S.M., Andras, A., Brinas, I.K.** *A grafo-numeric method of determination of the operation power of the rotor of EsRc-1400 bucket wheel excavator using computer simulation in SolidWorks.* MATEC Web Conf. 290, 04007, 2019.

[16]. **Kovacs, I., Andraş, I., Nan, M.S., Popescu, F.D.** *Theoretical and experimental research regarding the determination of non-homogenons materials mechanical cutting characteristics*. 8th WSEAS International Conference On Simulation, Modelling And Optimization (SMO '08) Santander, Cantabria, Spain, September 23-25, 2008.

[17]. **Popescu, F.D. Radu, S.M**. V*ertical Hoist Systems: New Trends Optimizations*. LAP Lambert Academic Publishing, 2013**.**

[18]. **Bogdan-Zeno Cozma, Vilhelm Itu,** *Trolley for Skip Maneuvring in Lupeni Mining Plant,* 14th International Multidisciplinary Scientific GeoConference: SGEM, pages: 729-736, Sofia, 2014.

[19]. **Dumitrescu Iosif, Cozma Bogdan-Zeno, Itu Răzvan-Bogdan,** *Safety mechanisms for mining extraction vessels*, 16th International Multidisciplinary Scientific GeoConference: SGEM, pages: 759-766, Sofia, 2016.

[20]. **Popescu, F., Radu, S., Kotwica, K., Andraş, A., Kertesz Brînaş, I., Dinescu, S.** Vibration analysis of a bucket wheel excavator boom using Rayleigh's damping model. *New Trends in Production Engineering.* 2(1), 233–241, 2019.

[21]. **Dinescu, S., Andraș, A.** *Environmental friendly equipment and technology for underground civil excavations.* Annals of the University of Petrosani, Mechanical

Engineering, 10, pp. 47-52, 2008.

[22]. Cozma, B.Z., Urdea, G.B. *The study of the detachable bits for rotating drillings.* Mining Revue/Revista Minelor, 15(7), 2009.

[23]. Iosif, D., Bogdan-Zeno, C., Bogdan, U. G. *MODERNIZATION OF EsRc–1400 EXCAVATOR BUCKETS WITH THE HELP OF CAD/CAE SOFTWARE*. International Multidisciplinary Scientific GeoConference: SGEM, 17(1.3), 555-561, 2017.

[24]. Brinas, I.K., Rebedea, N.I., Oltean, I.L. Bucket wheel excavator cutting tooth stress and deformation analysis during operation using Finite Elements Method (FEM). *Mining–Informatics, Automation and Electrical Engineering*, *56*(4), pp.9-13, 2018.

[25]. Mitran, I., Popescu, F.D., Nan, M.S., Soba, S.S. Computer assisted statistical methods for process reliability analysis. In *Proceedings of the 15th AMERICAN CONFERENCE ON APPLIED MATHEMATICS AMERICANMATH* (Vol. 9, p. 166, 2009, April).

[26]. Danciu, C. *Mecanica rocilor*, Editura Universitas, Petroşani, 2011.

[27]. Jármai, K.; Farkas, J.; Virág, Z. *Minimum Cost Design of Ring-Stiffened Cylindrical Shells Subject to Axial Compression and External Pressure.* In Proceedings of 5th World Congress of Structural and Multidisciplinary Optimization, Lido Di Jesolo, Italy, 19–23 May 2003.