MME SEE CONGRESS 2023

5th Metallurgical & Materials Engineering Congress of South-East Europe
Trebinje, Bosnia and Herzegovina
7-10th June 2023

CONGRESS PROCEEDINGS

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The Association of Metallurgical Engineers of Serbia

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The Faculty of Metallurgy at the University of Zagreb in Sisak, Croatia;
The Faculty of Natural Sciences and Engineering at the University of Ljubljana, Slovenia;
The Faculty of metallurgy and technology at the University of Podgorica, Montenegro.

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5th Metallurgical & Materials Engineering Congress of South-East Europe

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PREFACE

On behalf of the Scientific and Organizing Committee, it is a great honor and pleasure to wish all the participants a warm welcome to the Fifth Metallurgical & Materials Engineering Congress of South-East Europe (MME SEE 2023) which is being held in Trebinje, Bosnia and Hercegovina, 07 - 10 June 2023.

The MME SEE 2023 is a biannual meeting of scientists, professionals, and specialists working in the fields of metallurgical and materials engineering. The aim of the Congress is to present current research results related to processing/structure/property relationships, advances in processing, characterization, and applications of modern materials. Congress encompasses a wide range of related topics and presents the current views from both academia and industry: Future of metals/materials industry in South-East European countries; Raw materials; New industrial achievements, developments and trends in metals/materials; Ferrous and nonferrous metals production; Metal forming, casting, refractories and powder metallurgy; New and advanced ceramics, polymers, and composites; Characterization and structure of materials; Recycling and waste minimization; Corrosion, coating, and protection of materials; Process control and modeling; Nanotechnology; Sustainable development; Welding; Environmental protection; Education; Accreditation & certification.

The editors hope that Congress will stimulate new ideas and improve knowledge in the field of metallurgical and materials engineering. The Congress has been organized by the Association of Metallurgical Engineers of Serbia, with the co-organization of the Institute for Technology of Nuclear and Other Mineral Raw Materials, Belgrade, Serbia, Faculty of Technology and Metallurgy, University of Belgrade, Serbia, Faculty of Technology, University of Banja Luka, Bosnia and Herzegovina; the Faculty of Metallurgy, University of Zagreb, Sisak, Croatia; the Faculty of Natural Sciences and Engineering, University of Ljubljana, Slovenia; and the Faculty of Metallurgy and technology, University of Podgorica, Montenegro.

Financial support from the Ministry of Science, Technological Development and Innovation of the Republic of Serbia to researchers from Serbia for attending the congress is gratefully acknowledged. The support of the sponsors and their willingness to cooperate have been of great importance for the success of MME SEE 2023. The Organizing Committee would like to extend their appreciation and gratitude to all sponsors and friends of the conference for their donations and support.

We would like to thank all the authors who have contributed to this book of abstracts and also the members of the scientific and organizing committees, reviewers, speakers, chairpersons, and all the conference participants for their support of MME SEE 2023. Sincere thanks to all the people who have contributed to the successful organization of MME SEE 2023.

On behalf of the 5th MME SEE Scientific and Organizing Committee

Miroslav Sokić, PhD

INNOVATIVE INDUSTRIAL SYMBIOSIS APPROACH FOR ACIDIC MINE DRAINAGE NEUTRALIZATION

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Following the principles of sustainable development and circular economy, an innovative industrial symbiosis approach has been developed that uses already disposed voluminous waste. The research was focused on the utilization potential of vast amounts of flotation tailings, fly ash and acidic mine waters. Numerous previous case studies have pointed out the harmful, long-lasting environmental damage from waste disposal. In this case, the emphasis is on finding a practical approach for using industrial waste, specifically thermal power plant fly ash, in order to neutralize acidic mine waters resulting from tailings disposal. The proposed treatment gives waste a practical value, eliminates its harmful effect on the environment and redefines (lowers) regular waste management costs. In addition, it is possible to obtain valuable metals by exploiting and reprocessing acidic mine drainage.

Keywords: acidic mine drainage, flotation tailing, circular economy, fly ash

Introduction

The recovery and reuse of waste/discarded resources, from industrial operations and the mining sector, through industrial symbiosis represents a unique opportunity to contribute to the implementation of circular economy (Petronijevic et al. 2020b). Researchers are trying to find innovative solutions to existing waste problems, preferably in areas with extensive waste production, with a dominant negative impact on the environment. The level of demand for new approaches in order to discover sustainable solutions in this field is one of the main findings and recommendations of the 2023 study on the European Union material demand forecast: "new developments in mining and processing require time to enter into operation, while recycling depends on the availability of sufficient end-of-life volumes" (EC, 2023).

The primary flotation tailings, fly ash (FA), and Acid Mine Drainage (AMD) are free voluminous waste which represent a significant challenge for establishing a sustainable and efficient waste management system. All three types of waste, flotation tailing, FA and AMD produce significant costs for industry, as well as a serious concern for society, due to environmental problems closely related to the mining activities (Jarnerud, et al. 2020). This treatment proposes a transformation of these wastes' harmful properties to obtain valuable materials with characteristics that would not cause long-lasting damage to the environment (Alivojvodić et al. 2023). It is possible to significantly reduce the amount of these already disposed waste materials and reduce treatment costs and energy consumption, with the possibility of obtaining new materials by developing new technologies. The researchers' efforts aim to find solutions that would contribute to solving the challenges mentioned above.

The mining industry has played a significant contributing role in the development of the global economy, but it has also generated a series of environmental hazards, such as AMD (Meng et al., 2019). The flotation tailings can be a valuable source of metals (Stanković et al. 2021), but if improperly disposed of, it is also the primary source of AMD formation. AMD can contaminate ground and surface water, damage the ecological environment and cause sincere human health problems (Tolotti et al., 2019). AMD occur due to the disposal of sulphide waste, flotation tailings or ore tailings (Su et al. 2020, Mafra et al. 2020).

They are characterized by a low pH value and high concentrations of potentially toxic dissolved metals, metalloids and sulfates (Stanković et al. 2021). Once formed, these acidic solutions, enriched with high concentrations of metals, are difficult to control, with pronounced adverse impacts on biodiversity (Wang et al.2021). Remediation of this environmental disaster is neither simple nor cheap, so it can be safely said that AMD is both an ecological and a global economic problem, especially considering that they are a concomitant phenomenon of active and closed mines.

In Eastern Serbia, mining is the dominant industry, the development of which has as one of the unwanted consequences the formation of acidic mine waters. A prominent unfavorable example is located near the town of Bor and the international border - the mine Lake Robule. It was created due to the disposal of about 150 million tons of ore slag. More specifically, it is a consequence of the oxidation of pyrite and the leaching of heavy metals due to the influence of atmospherics. As a result, the lake is characterized by a low pH value and a high concentration of metals. Also, it has been estimated that the leaching of mining waste annually irreversibly loses precious metals, first of all, about 290-350 t of Cu, thereby polluting surface streams (Milićević et al., 2013).

One innovative technique for the treatment of AMD has been the use of fly ash and flotation tailings as a pollution abatement process.

Materials and methods

Several authors pointed out in their tests that the water in Lake "Robule" is acidic (the measured pH value is 2.47), as well as that it contains a high concentration of heavy metals, the most abundant of which are aluminum (1017.62 mg/dm^3), iron (287 mg/dm3), copper (66.39 mg/dm^3), manganese (66 mg/dm^3) and zinc (17.6 mg/dm^3) (Petronijević et. al 2020a). Also, extremely high sulfate values (7,500 mg/dm^3) were confirmed. In their investigation, the researchers dealt with different approaches in the treatment of acidic mine waters "Robule" (Gardić et al., 2017), procedures for removing iron, copper and manganese (Marković et al., 2020), i.e. by removing Fe, Al, Cu, As, Co and Ni (Masuda et al., 2019).

Due to their favorable physicochemical characteristics, abundance and low cost flotation tailings and FA materials have become a mainstream of contemporary research on filling materials in mining sites in order to prevent AMD formation (Chen et al. 2020) and also to neutralize acidity if they are already formed (Leiva et al. 2021). Using these two waste raw materials to neutralize acidic mine waters can reduce environmental risks related to their disposal and storage. Also, one should consider the cost reduction of complex strategies for safely handling and disposal of flotation tailings in specially designed disposal sites.

In order to fully utilize the characteristics of the deposited flotation tailings and fly ash in the most economical way possible, direct treatment of acidic mine waters with these raw materials was proposed, with the examination of treatment possibilities and reaction mechanisms, as well as the stability of the residue after treatment. However, until now, there have been no practical tests on the prospect of using flotation tailings to neutralize AMD. In the research, the following were used as alternative agents for the neutralization of the acidic mine water of Lake "Robule" (pH 2.47): flotation tailings from the Majdanpek copper mine (FJM) and fly ash from two locations: thermal power plant "Nikola Tesla" - Obrenovac (EF) and thermal power plant "Kostolac" (KOST).

Before starting the neutralization process, solid samples of flotation tailings and fly ash were fully characterized. The characterization included chemical analysis using the ICP-OES method, microscopic analysis (optical and electronic), X-Ray Diffraction (XRD), Toxicity Characteristic |Leaching Procedure (TCLP) and EN12457-4 test following the regulations on categorizing solid waste. The Acid Neutralization Capacity (ANC) test determines their capacity to neutralize AMD.

In order to define as close as possible the conditions at the disposal location of FJM and both fly ashes and to simulate the impact of precipitation on the deposited raw materials, long-term leaching tests with melted snow were performed. The mentioned approach was chosen since one of the long-term consequences of exploitation activities is the release of SO_2 into the atmosphere, and the formation of slightly acidic atmospheric precipitation, the impact on the deposited tailings and ash is unknown. According to some authors, precipitation in the form of rain usually has approximately five times higher concentrations of sulfur than snowfall (Nyborg et al., 1997b).

A graphic overview of the detailed characterization of solid samples of flotation tailings and fly ash before and after AMD neutralization is given in Figure 1.

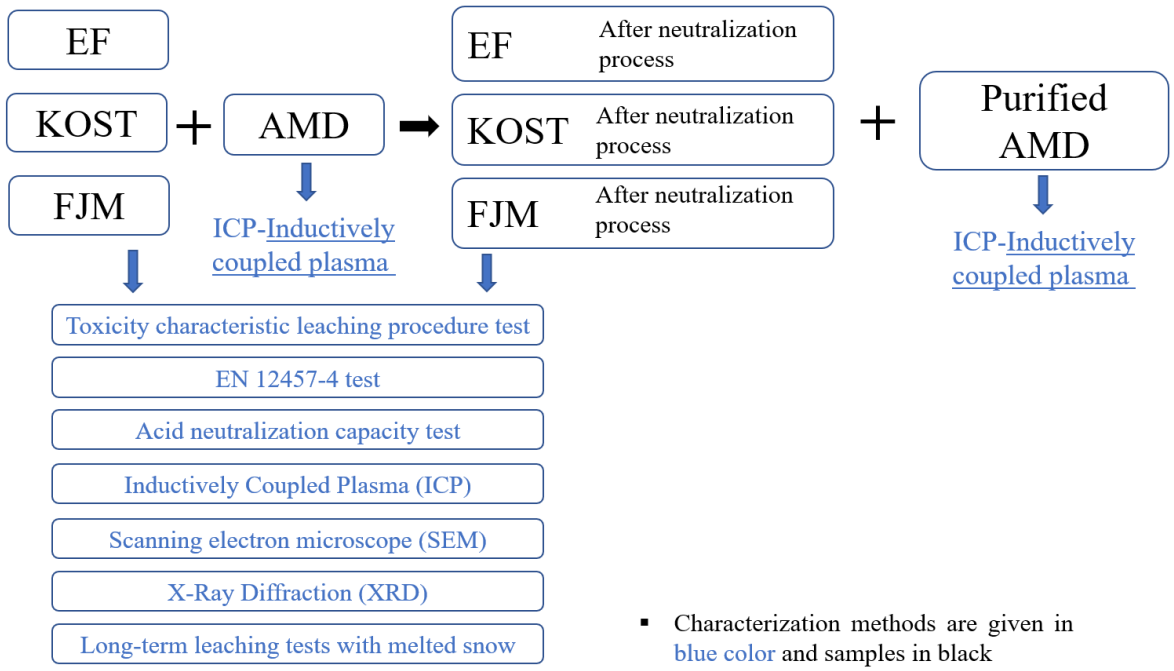

Figure 1 Graphic overview of the detailed characterization of solid samples of flotation tailings and fly ash before and after AMD neutralization

The tests mentioned above were performed on all flotation tailings and fly ash samples before and after treating acidic mine waters. In addition, the characterization of Robula's acidic mine waters before and after treatment was also done.

The effectiveness of treatment with alternative neutralization materials is defined by comparison with neutralization using NaOH as a conventional neutralization agent.

Results and discussion

The detailed characterization results showed that the Majdanpek flotation tailings are rich in carbonate minerals (calcite and dolomite) and have a significant capacity to neutralize acidic mine waters. In addition, due to their basic character, they lead to a change in the pH value of the solution and the precipitation of metals at specific pH values in the form of hydroxide.

The results of the ANC test showed that, in addition to carbonates, aluminosilicates could have a buffering effect that manifests itself at low pH values and can neutralize existing acids. Also, the ANC test showed that the same sample of these tailings could be used repeatedly to neutralize AMD with very high efficiency. The buffer capacity of the tailings increases after each treatment due to the hydrolysis of precipitated metal hydroxides.

According to the TCLP test, tailings samples before and after treatment can be classified as non-hazardous waste. However, EN 12457-4 test data shows that tailings are classified as hazardous waste before treatment. In contrast, tailings after treatment are classified as non-hazardous waste raw materials. Interestingly, the same results as in the EN 12457 test were also shown by research with a long-term snow leaching test, due to which the migration of antimony from the deposited tailings occurs.

Although they belong to the same class of EF and KOST fly ash, KOST fly ash proved to be more effective for neutralizing the acidic mine waters of "Robule" due to differences in mineral composition. These differences in mineral phases are due to the ageing of the KOST fly ash through carbonization of the calcium oxide initially present in the FA by carbon dioxide leading to different neutralization abilities. The results of the ANC test showed different neutralization abilities. The presence of calcite minerals in the KOST sample resulting from the ageing of fly ash and the presence of gypsum in the ANC test of both samples of solid residues formed by the neutralization process was confirmed, as the XRD results have already shown.

Based on the results of the EN 12457-4 test, EF and KOST ash used to neutralize the acidic mine water of Lake "Robule" and their sediments after treatment are classified as hazardous waste due to the increased content of Sb, in contrast to FJM, whose sediment is safe for disposal. In the case of the TCLP test, EF and KOST ashes, both before and after treatment, were classified as hazardous waste due to elevated As and Se values. The effectiveness of treatment with alternative neutralization materials is defined and demonstrated by comparison with neutralization using NaOH as a conventional neutralization agent. Fly ash showed better efficiency in neutralizing AMD than this commercial neutralizing agent due to the absorption of metals on the surface of fly ash particles.

As a result of the treatment, purified acidic mine water from Lake Robule was obtained, as well as flotation tailings sediment after neutralization, which, according to the legal regulations for the characterization of solid waste, is safe for disposal (unlike flotation tailings before treatment and fly ash before and after treatment of AMD).

Conclusion

Flotation tailings and fly ash landfills can trigger ecological problems of catastrophic proportions through environmental pollution through the dispersion of polluting particles, i.e. the formation of acidic mine waters. By applying modern technologies, it is possible to significantly reduce the amount of these already disposed waste materials and reduce treatment costs and energy consumption. However, at the same time, they can also represent an economic loss through costs related to safe depositing, as well as due to spontaneous leaching of valuable components and subsequent additional investment in rehabilitating this irreversibly lost exposure, which pollutes the environment.

By simply mixing tailings and ash, the AMD can be neutralized. The resulting product (new material) can be used as an injection curtain or filling in places critical for forming AMD to prevent further pollution. Combining three wastes (acidic mine waters, fly ash and flotation tailings) opens space to form new ecological and economically valuable by-products. The results of the conducted general research indicate that the mentioned approach can become an imperative of modern mining management.

Mixing flying ash and AMD, reduces their harmful impact on the environment. In this way, the toxic waste after treatment becomes a free resource, as tailing ponds as secondary materials contain a large percentage of metals, with additional positive economic impact, by reducing the cost of management of these waste materials.

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