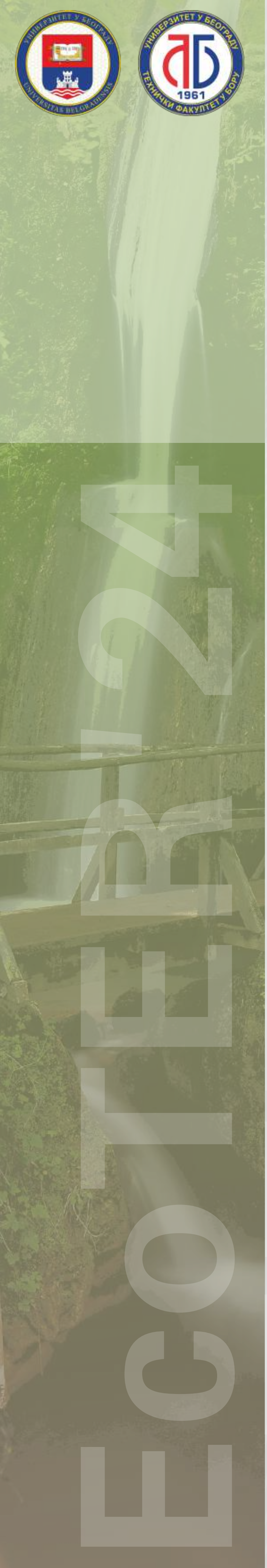

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Technical Faculty in Bor

31st International conference

Ecological Truth & Environmental Research

Editor
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PROCEEDINGS

Hotel Sunce, Sokobanja, Serbia
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PREFACE

The 31st international conference Ecological Truth & Environmental Research – EcoTER'24 focuses on showing the latest research findings and innovations in the field of ecology, environmental protection and sustainable development. The conference will be held in Sokobanja (Serbia) in hotel Sunce in the period of 18–21 June 2024.

The aim of the conference is to connect the experts in various fields in order to transform attitudes and behaviors in everyday practices, as well as in the industry and economy sector which is essential for achieving the desired changes that our society must undergo.

The 31st international conference Ecological Truth & Environmental Research – EcoTER'24 is organized by the University of Belgrade, Technical Faculty in Bor, and co-organized by the University of Banja Luka, Faculty of Technology; the University of Montenegro, Faculty of Metallurgy and Technology – Podgorica; the University of Zagreb, Faculty of Metallurgy – Sisak; the University of Pristina, Faculty of Technical Sciences – Kosovska Mitrovica and the Society of Young Researchers – Bor.

These Proceedings encompass 119 papers from the authors coming from the universities, research institutes and industries in 15 countries: Brazil, Norway, USA, Spain, Austria, Libya, Italy, Israel, Slovenia, Croatia, Romania, Bulgaria, Montenegro, Bosnia and Herzegovina, North Macedonia, and Serbia. It is a great honor and pleasure to cordially wish a warm welcome to all the participants of the conference.

As a part of this year's conference, the 6th Student Section – EcoTERS'24 will be held. We appreciate the contribution of the students and their mentors who have also participated in the conference and hope that students will continue to explore and to be curious, since education is a never-ending process, and knowledge is continuously growing.

The organization of the EcoTER'24 conference has been financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia.

The support of the Donors and their willingness and ability to cooperate has been of great importance for the success of the EcoTER'24 conference. The organizing committee would like to extend their appreciation and gratitude to the Platinum donors of the conference – Serbia ZiJin Copper doo Bor and HBIS SERBIA, to the Gold donor of the conference – Elixir Group, as well as to the Silver donor of the conference – Serbian Chamber of Engineers.

We would like to express our sincere appreciation to all the authors who have contributed to the Proceedings. We would also like to express our gratitude to the members of the scientific, organizing and honorary committees, reviewers, speakers, chairpersons and all the conference participants for their support of the EcoTER'24. Sincere thanks go to all the people who have contributed to the successful organization of the EcoTER'24.

Prof. Snežana Šerbula,

President of the scientific and organizing committee

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THE IMPACTS OF WASTE MATERIALS UTILIZATION IN LIQUID RADIOACTIVE WASTE SOLIDIFICATION BY MORTAR MATRIX

Ivana Jelić[1*], Aleksandar Savić[2], Tatjana Miljojčić[1], Maja Rajković[1], Marija Janković[1], Nataša Sarap[1], Slavko Dimović[1], Milica Ćurčić[1], Vojislav Stanić[1], Dragi Antonijević[3], Marija Šljivić-Ivanović[1]

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Abstract

The nuclear industry generates significant radioactive waste (RW) amounts, with its safe disposal being a primary safety and environmental issue. RW management involves solidification and disposal, often in deep underground facilities. Cement mortar is commonly used for liquid RW solidification due to its cost-effectiveness and simplicity. However, Portland cement concrete production raises environmental concerns, such as CO_2 emissions and natural resource depletion. Additionally, RW storage and disposal costs drive research into low-cost matrices, especially those made from final waste products. The main requirements for matrix materials for liquid RW immobilization, which accept the role of primary barrier, are compatibility with RW material, good mechanical properties, and resistance to chemical and biological agents. However, partially substituting cement with waste materials can reduce strength and durability, increase susceptibility to cracking, porosity, and corrosion, further leading to harmful substance release. The matrix material must demonstrate long-term stability under various environmental conditions, including changes in temperature, humidity, and exposure to radiation ensuring that RW remains stable and safe within the matrix for decades or centuries. In addition, factors such as groundwater infiltration and seismic activity should also be considered when evaluating the long-term effectiveness of a protective structure. To manage these hazards, the selection, treatment, and preparation of recycled waste are crucial, alongside with proper design and utilization of such concrete. Monitoring concrete performance over time and implementing maintenance measures are necessary to ensure the long-term durability and reliability of structures. This work aims to assess the overall impact of recycled materials utilized in liquid RW solidification matrix.

Keywords: nuclear industry, radionuclide, disposal, recycling.

INTRODUCTION

Nuclear energy is recognized as a significant aspect of the new energy landscape and the factor of energy stability, particularly amidst the current global energy crisis. Moreover, it is regarded as a substitute for fossil fuels, offering a potential solution to mitigate their adverse environmental effects. This is crucial for reducing greenhouse gas emissions, which would help slow down global warming and climate change. However, the activity of the nuclear industry generates significant amounts of liquid and solid radioactive waste (RW) and the primary safety and environmental concerns related to nuclear power are its safe disposal. RW is created in the processes of the nuclear fuel cycle, the industry of exploitation, processing, and enrichment of uranium ore, the activities of the reactors of nuclear power plants and research centers, the use of radionuclides in research institutes, hospitals, and industry [1,2].

RW has to be processed to make it safe for storage, transportation, and final disposal. This process involves waste conditioning to immobilize it before storage and disposal. Immobilization of waste radionuclides in durable waste forms provides the most significant barrier to contribute to the overall performance of any storage and disposal system. RW immobilization is the conversion of waste into a waste form by solidification, embedding, or encapsulation that reduces the potential for migration or dispersion of radionuclides during the operational and disposal stages of the waste lifecycle. RW can be immobilized by chemical incorporation into the structure of a suitable matrix like cement, glass, or ceramic, which captures it and prevents it from escaping. The distinction between chemical and physical immobilization mechanisms is not always clearly defined. Chemical immobilization occurs at atomic distances, while physical immobilization occurs at larger distances, e.g. at the microscope level. High-level waste (HLW) is usually chemically immobilized, while physical immobilization (encapsulation) involves surrounding the waste with material, like bitumen or cement, to isolate the RW and retain the radionuclides.

Materials used to immobilize RW are essential for multibarrier systems that isolate waste from the environment, ensuring safe disposal in the long term. The volume of liquid RW is much larger than solid, and its processing increases the storage capacity and ensures the safe release of decontaminated liquid into the environment. Compared with the HLW liquid, the amount of the intermediate-level waste (ILW) and low-level waste (LLW) liquids is much larger, accounting for more than 90% of the total RW.

Very high costs of immobilization, temporary storage and final disposal of liquid RW stimulate research into the development of cost-effective, low-cost matrices, especially those that represent final waste during production or after their useful life. In particular, it is necessary to pay attention to the European legislation that encourages the development of the “circular economy”, which implies the efficient use of materials [3]. The aim of this study is to assess the impact of recycled materials used in liquid RW solidification matrix.

ASPECTS OF CEMENT USAGE IN RW SOLIDIFICATION

Cement is the oldest and most extensively researched base material for solidifying and stabilizing various types of solid waste. Cement solidification is a well-established technology that relies on the hydration of cement and its gelatinizing effect to immobilize radioactive elements. This method is widely used for treating LLW and ILW liquids due to its cost-effectiveness and the simplicity of the process [2,4].

Cement is a porous material, with a wide range of pore sizes that are filled with liquid under normal conditions. Incomplete filling of the space between the clinker grains in the reaction of formation of hydration products creates mesopores, usually in the size range of

0.05–1 μm [5]. Entrapped air or gas contributes to the creation of macropores larger than 1 μm, filling 1–10 cubic meters. % hydrated cement. During solidification, the volume of the cement-waste mixture decreases and shrinks. As a result of shrinkage, based on gel drying or crystallization, gel pores are formed, with diameters in the range of 10 mm–0.0005 mm. Their volume fraction decreases with the time of hydration and reaches 20–30% of the hardened cement paste fraction. Gel pores are not significant from the point of view of leaching and corrosion. Capillary pores are also formed by evaporation of excess free water. Capillary pores reach a diameter of 1–10 mm. They increase with the water content in the mixture and with advancing hydration. If there are large particles in the cement paste, e.g. grains of sand or gravel, and due to the formation of zones of poor packing on the boundary surface of paste particles, the total mesoporosity increases. The total porosity of the cement paste is in the range of 16–24% [5]. As the curing time of the cement increases, the porosity decreases steadily in the first 6–12 months.

In the past few decades, the production of concrete has raised significant environmental concerns not only related to CO_2 emissions but also regarding the depletion of natural resources. It is known that concrete consumes large amounts of natural resources, specifically gravel and sand. Environmental issues, in particular climate change caused by carbon dioxide emissions, have aroused huge attention across the world. The biggest contributor to the carbon footprint of the construction industry is the production of Portland cement [6]. Currently, approximately 4 to 6 GJ of energy are used per ton of cement clinker produced, with energy costs accounting for up to 40% of the total production cost. One ton of cement clinker production typically results in the release of around 0.8 tons of CO_2 into the atmosphere and contributes to approximately 7% of total CO_2 emissions, exacerbating the greenhouse effect and consuming around 5% of global industrial energy [6,7]. This inefficiency is a major environmental concern due to its contribution to global warming and climate change. Also, the energy-intensive manufacture of cement emits not only carbon dioxide but also other hazardous gases such as NO_x and SO_2.

PARTIAL SUBSTITUTION OF CEMENT WITH WASTE MATERIALS

Each treatment of RW creates a specific concentrate. Depending on the treatment process, the concentrate will be solid (spent ion-exchange resins, filter cartridges, filter cakes, sludge, etc.) or liquid (evaporator concentrates, membrane process concentrates). To immobilize RW of low and medium activity levels, solidification of the concentrate is carried out by binding it into inactive matrices: cement, bitumen, polymer materials, and rarer glass. The processes available for treating liquid RW effluents can be divided into three main categories: ion exchange, chemical precipitation, and evaporation (evaporation) [8,9].

The primary requirements for matrix materials for liquid RW immobilization, which serve as the primary barrier, include the following [10]:

- Compatibility with RW: Matrix materials must be compatible with the RW itself. Ensures that the matrix material chemically and physically bonds well with the liquid RW, preventing separation or degradation over time. This means that they must not react with the radioactive material in a way that could compromise the stability or integrity of the container or structure that holds the waste.

- Mechanical properties: These materials should have good mechanical properties in order to withstand physical stresses and loads during the handling, transport, and long-term storage of RW. These include factors such as strength, flexibility, elasticity, resistance to cracking or breaking, and toughness.
- Durability: Ensures long-term stability under various environmental conditions such as temperature fluctuations, humidity, and radiation exposure.
- Resistance to chemical and biological agents: The material must resist degradation caused by chemical reactions with the waste or exposure to environmental conditions, including resistance to acids, alkalis, and microbial activity. Resistance to corrosion and degradation is critical to ensure the long-term stability and safety of RW containment systems.
- Permeability: The matrix should be impermeable to water and gases to prevent the leaching or release of radionuclides into the environment.
- Processing Feasibility: The material should be easy to process, handle, and apply using existing technologies and equipment.
- Cost-effectiveness: The use of the matrix material should be economically viable, considering the costs of production, application, and long-term maintenance.

The matrix material must demonstrate long-term stability under various environmental conditions, including changes in day temperatures, air humidity, and radiation exposure. This ensures that RW remains stable and safe within the matrix for decades or even centuries. Moreover, factors such as groundwater infiltration and seismic activity must be considered when evaluating the long-term effectiveness of a protective structure.

PARTIAL REPLACEMENT OF CEMENT WITH WASTE: IMPLICATIONS AND BENEFITS

Partial replacement of cement with waste materials can reduce the strength and durability of concrete structures [11]. Utilizing scrap raw materials may lead to uneven material distribution, making it challenging to achieve consistent performance. This inconsistency can increase susceptibility to cracking, porosity, and corrosion. In homogeneous concrete, uneven distribution of waste particles can cause localized weakening or heightened corrosion susceptibility. Variations in the quality and characteristics of recycled materials can result in performance inconsistencies, complicating efforts to achieve predictable and reliable concrete structures.

Waste materials can affect the porosity of the concrete matrix, leading to increased absorption of water and chemical agents. Increased porosity reduces concrete’s resistance to frost and aggressive chemicals, accelerating deterioration. This can allow the penetration of water, chemicals, and other harmful substances, further weakening the structure and potentially leading to the release of radionuclides.

Despite these challenges, it can be concluded that using recycled materials in the solidification of liquid RW offers significant environmental and economic benefits as follows:

Environmental Benefits

- Reduced Resource Depletion – Preservation of two types of natural raw materials: Using recycled materials decreases the demand for virgin raw materials.

- Energy Savings: Reducing energy consumption associated with processing raw materials can lower greenhouse gas emissions.
- Waste Reduction – Treatment of two types of waste: Recycling helps to minimize waste going to landfills, reducing environmental pollution.
- Lower Pollution Risks: Properly managed recycling can reduce the risk of soil, air, and water pollution from waste materials.
- Climate change and Global Warming Reduction.

Economic Benefits

- Cost Savings: Using recycled materials can lower production costs by reducing the need for expensive raw materials.
- Revenue Generation: The recycling industry can generate revenue through the sale of recycled products.
- Job Creation: Establishing new markets for recycled materials can create jobs and stimulate economic growth at local and national levels.
- Regulatory Compliance: Companies can meet environmental regulations and standards more easily by incorporating sustainable practices.

Overall, the use of recycled materials in the solidification of liquid RW offers a balanced approach, providing environmental benefits by reducing resource consumption and waste generation, and economic benefits by lowering costs and creating new economic opportunities.

CONCLUSION

Nuclear energy can substitute fossil fuels almost completely and significantly reduce greenhouse gas emissions, which is key to mitigating global warming and climate change. However, the nuclear industry generates large quantities of RW, and the safe disposal of this waste is a primary environmental and safety concern. Processing of RW is necessary for safe storage, transport, and final disposal. Immobilization of RW by converting waste into solid form via cement, glass, or ceramics provides a key barrier to waste storage and disposal. Immobilization materials must be compatible with RW, have good mechanical properties, and be resistant to chemical and biological agents.

The use of recycled materials in the solidification of liquid RW brings environmental and economic advantages. Environmental benefits include reduced resource depletion, energy savings, waste reduction, and lower risk of soil, air, and water pollution. Economic benefits comprise cost reduction, revenue generation, and the creation of new jobs and markets for recycled materials.

Despite challenges such as the reduction of strength and durability of concrete structures when partially replacing cement with waste materials, the benefits of recycled materials in the solidification of liquid RW are significant. They enable a more sustainable approach to RW management, reduce the environmental footprint, and contribute to sustainable economic development. This approach represents a balanced path to reducing resource consumption and waste generation, while at the same time bringing economic benefits through cost reduction and the creation of new economic opportunities.

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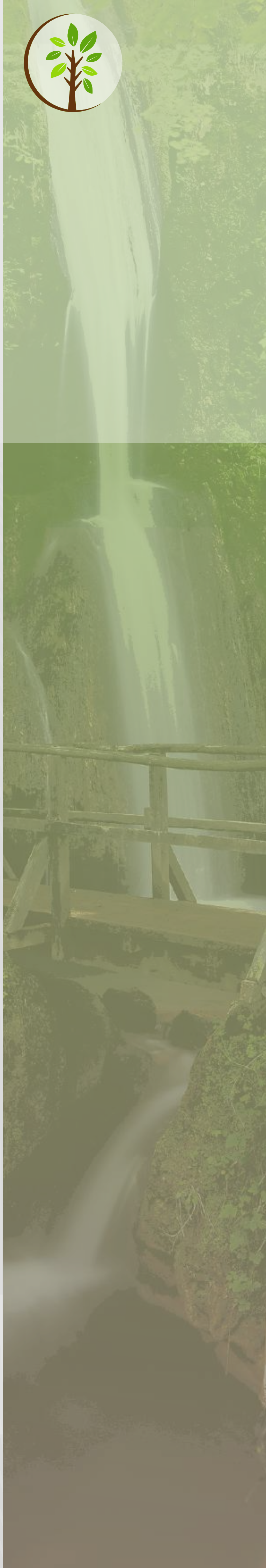

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