Radioactive Waste Management: Construction and Demolition Debris in Geopolymers

Ivana Jelić, Marija Šljivić-Ivanović, Tatjana Miljojčić, Milica Ćurčić and Slavko Dimović

Abstract — **Construction and demolition debris (C&DD) is one of the fastest-growing waste streams due to the global economic development and urbanization process. Therefore, developing more attractive and inexpensive methods and creating more valuable conventional and novel technologies that could more efficiently use these wastes and solve possible environmental problems, especially radioactive waste. The most widespread and economically viable solution for the reuse of C&DD today is civil engineering and the road industry. Also, there are several possible ways to use C&DD in geopolymers as recycled aggregates, activating components (precursors) depending on the composition, and as a hybrid system: with some aluminosilicate material that has better geopolymerization capacity or ordinary Portland cement. This use of C&D enables the synthesis of a wide range of matrices for the immobilization of radionuclides.**

Index Terms — **radionuclides; immobilization; geopolymers; environment; raw materials.**

I. Introduction

Construction and demolition waste (C&DW) is generated during the production of construction products or semi-final products, construction, demolition, and reconstruction. This waste accounts for the largest source of the solid waste stream in most countries worldwide [1-2]. According to European Environment Agency (EEA): "Construction and demolition waste (C&DW) comprises the largest waste stream in the EU, with relatively stable amounts produced over time and high recovery rates. Although this may suggest that the construction sector is highly circular, scrutiny of waste management practices reveals that C&DW recovery is largely based on backfilling operations and low-grade recovery, such as using recycled aggregates in road sub-bases" [3] as unbound aggregates or bound aggregates for concrete mixtures [4]. It is considered that construction is liable for climate changes (50%), increased energy consumption (40%), landfill waste generation (50%), air and water pollution, destruction of natural habitats, and negative impact on human health [5-7]. Thus, C&DW has an overall adverse environmental and economic impact, as well, on the construction sector, contributing to the emergence of additional costs. The main goal of C&DW management is to establish sustainable waste management, monitoring the quantities, types and composition of waste, waste generation, reduction of waste amount, separation and disposal of all types of construction waste, and its recycling and reuse.

Construction and demolition debris (C&DD), as one of the C&DW main fractions, occurs preferably after demolishing or reconstructing buildings (Fig. 1). It represents parts of walls, concrete, ceramic and roof tiles, carpentry, electrical parts, i.e. "discarded materials generally considered to be not water-soluble and non-hazardous in nature, including, but not limited to, steel, glass, brick, concrete, asphalt roofing material, pipe, gypsum wallboard, and lumber, from the construction or destruction of a structure as part of a construction or demolition project or from the renovation of a structure, and including rocks, soils, the tree remains, trees, and other vegetative matter that normally results from land clearing or land development operations for a construction project, including such debris from the construction of structures at a site remote from the construction or demolition project site" [8].

Fig. 1. Construction and demolition debris

This waste type is one of the fastest-growing waste streams due to the global economic development and urbanization process. The rapid progress of the market-oriented production

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economy, industrialization, and population growth generate millions of tons of C&DD per year. This waste type counts the highest percentage of waste worldwide, approximately 75% [1].

Since C&DD represents a significant part of the waste stream, it is aimed for necessarily waste reduction or recycling. C&DD presents a considerable amount of building materials that could be reused or renew, avoiding non-renewable raw materials depletion in the construction sector. This significant recovery and recycling potential is lost via a lack of waste collection facilities or poor recycling practices. Therefore, it is necessary to develop more attractive and low-cost methods and create more valuable conventional and novel technologies that could more efficiently use these wastes and solve possible environmental problems. Resource efficiency and the circular economy concept play an essential role in environmental and economic policy, as well as so-called "6R" principles in sustainable supply chain design (reduce, reuse, recycle, recover, redesign and remanufacture) [9].

Clean C&DD, without plastic, metal, rubber, and wood, is recycled into quality construction material, most often in the form of (unbound) aggregates. C&DD utilization is also increasingly popular in scientific research since it represents a sustainable and environmental-friendly solution. Waste materials utilization reduces the exploitation of non-renewable natural resources and the exploitation of various forms of energy to synthesize or modify natural raw materials or artificial materials. Availability and cost-effectiveness are of great importance for C&DD multipurpose utilization.

Benefits of C&DD reuse & recycling:

- Cost-benefit – lower disposal fees, less need to purchase new materials;
- Natural resources conservation;
- Slowing down the rate at which landfills reach capacity;
- Reducing methane emissions created when landfilled materials break down.

In particular, nowadays, there is a market for aggregates derived from C&DD, such as road base materials, drainage structures, and other construction projects, but its utilization potential is still under-used. Many studies have dealt with C&DD application possibilities in order to develop acceptable utilization techniques. A promising alternative recycling option appears to be offered by alkali-activated materials, i.e. geopolymers, incorporating C&DD as inert aggregates or partially reactive materials. Since geopolymers were shown substantial flexibility in various industrial wastes and by-products utilization, the use of C&DD in these binders has been extensively investigated, with encouraging results.

According to data, the immobilization of radionuclides in the waste-based geopolymers was rarely investigated, unlike very comprehensive research on heavy metals [13]. However, the advantage of these waste-based materials represents the possibility of using any waste containing aluminosilicate, which could be dissolved in an alkaline solution to obtain a matrix for immobilization of radionuclides.

II. C&DD UTILIZATION WORLDWIDE

As mentioned, the most widespread and economically viable solution for the reuse of C&DD today is the use in civil engineering and the road industry. Globally, there is a strong tendency to use recycled building materials exclusively in the same industry rather than expanding to other sectors.

The global demand for natural aggregates production of concrete is projected to grow by an average of 8% per year by 2022 [10]. Developing countries drive a significant portion of this demand as a result of their rapid industrialization and urbanization growth. The utilization of recycled aggregates (Fig. 2) from C&DD (concrete, bricks, tiles, plastics, etc.) could significantly help conserve natural resources and reduce waste disposal, which gains environmental and economic benefits. Though the incorporation of recycled aggregates from C&DD remarkably decreases the environmental impact and carbon footprint of concrete, the utilization of these aggregates in construction activities in developing countries is yet limited. The main reason is the lack of certainty in the properties of concretes or other construction materials with C&DD recycled aggregates under exploitation conditions. Thus, the use of recycled aggregates, manufactured from recycled products, to replace virgin aggregates and contribute to sustainable construction needs to be encouraged [11-12].

Fig. 2. Recycled Concrete Aggregates [11]

III. C&DD IN GEOPOLYMERS

Ordinary Portland cement (OPC), as the primary ingredient commonly used to prepare concrete binders, requires intensive energy in its production and produces a considerable amount of carbon dioxide and greenhouse gases. It is estimated that the cement industry contributes approximately 5% of global environmental pollution through carbon dioxide emissions [14]. With an estimated annual growth of 4% in cement production [15], carbon dioxide emissions will increase and cause additional environmental burdens [16]. Contrarily, geopolymer is featured with low greenhouse-gas emissions, less energy consumption, and reuse of waste materials, which is critical to future sustainability [17].

The standard procedure for radionuclide immobilization today is transformation into stable insoluble forms by matrix materials (solidification), most often in cement-based matrices.

The term geopolymer and its description as cement-free green cementitious material was coined nearly three decades back by Davidovits for alumino-silicate polymers formed in the alkaline environment [18]. Geopolymerization technology has been shown advantages in reusing various types of waste to produce new materials for many purposes. These so-called inorganic polymers have been proposed to utilize solid aluminosilicate waste and the development of new cementitious materials that could be made without OPC [19]. It is a novel family of building materials, a new material for coatings and adhesives, new binders for fiber composites, waste encapsulation, and new cement for concrete [20].

Geopolymers have attracted attention due to the simplicity of synthesis with low or zero greenhouse gas emissions [10,12]. Hence, the utilization of waste-based geopolymers could show many advantages such as usage of low-cost materials in production, e.g. slags, fly ash, clays, saving natural resources, ambient temperature production, and high compressive and flexural strengths, in particular as compared to cement [18-19]. All these characteristics are placing geopolymers in a category of eco-friendly and sustainable materials.

The chemical composition of geopolymer is somewhat similar to zeolites but with an amorphous microstructure. Unlike OPC/pozzolanic cement, geopolymers do not form calcium-silicate-hydrates (C-S-H) for matrix formation and strength but utilize the poly-condensation of silica and alumina precursors to attain structural strength. Davidovits [21] elucidated a structural model of the geopolymer and assumed an essentially monolithic polymer similar to organic polymers. (Fig. 3).

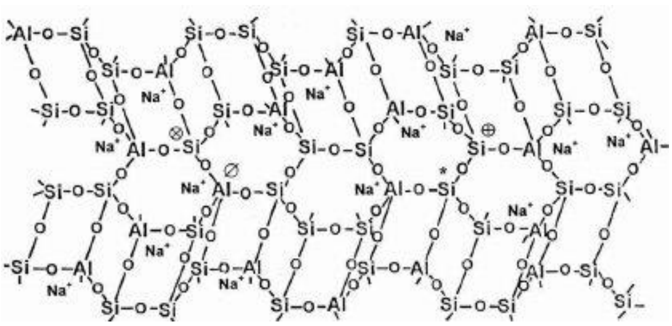

Fig. 3. Davidovits model of geopolymer structure [21]

Scientific publications provide a wealth of information relevant to productive C&DD usage in geopolymerization as processing technologies for value-added products.

Geopolymers based on C&DD differ in debris composition. Since its composition varies, there are many potential types of geopolymeric structures.

Fig. 4. Fly ash-based geopolymers [22]

Hence, there are several possible ways to use C&DD in geopolymers, as:

- recycled aggregates [4,23],
- activating component (precursors) [24-25] depending on the composition (e.g. bricks), and as
- hybrid system: with some aluminosilicate material with better geopolymerization capacity (e.g. metakaolin) or OPC [26].

The binary systems with OPC are synthesized due to the increase in geopolymer compressive strength in cases when it is assumed that geopolymerization will not be enough [26]. For example, this is the case with concrete debris, which is considered not to geopolymerize well due to its predominant participation of calcium carbonate in composition. Namely, the lack of aluminosilicate in almost pure concrete debris would lead to geopolymer non-creation. It was concluded that the addition of OPC in the geopolymerization processes contributed to the better mechanical behavior observed in the hybrid and binary systems. Although the use of cement is unfavorable from an energy point of view, this can affect the more significant usage of debris whose quantities are large, but geopolymerization is low.

However, it is more common for C&DD-based geopolymers to be synthesized with other aluminosilicates, especially waste-based material such as fly ash (Fig. 4) or other industrial waste: furnace slag, red mud, coal slag, etc. [4,27-29].

The stated utilization of C&DD allows the synthesis of a wide range of matrices for the immobilization of radionuclide.

IV. Conclusion

Recycling C&DD into sustainable and energy-efficient construction materials is a viable approach to relieve the stress of pollution and conserve virgin resources for the next generation. This study has reviewed the applications of C&DD as substitute materials in manufacturing sustainable geopolymer composites, specifically in the form of partial or even complete substitution of precursors or aggregates.

All results from cited studies suggest that waste-based geopolymers represent promising materials, but more thorough investigations are needed, especially for the utilization in radionuclide immobilization.

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