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Prof. dr Srba Mladenović
Prof. dr Čedomir Maluckov

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UTILIZATION OF WASTE IN GEOPOLIMERIZATION – A REVIEW

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Abstract

The aim of this article is to review the utilization of various types of waste in geopolimerization technology processes. The geopolymerization represents a process comprising of the dissolution of aluminosilicate solids in a strongly alkaline medium followed by condensation of free alumina-silica oligomers to form a tetrahedral polymeric structure. Advantage of this technology represents the possibility of utilization of any silica and alumina-containing waste material that could be dissolved in an alkaline solution. Production of geopolymers from waste not only provides less raw material consumption but also addresses issues regarding the disposal of wastes. Fly ash, red mud, construction and demolition waste (C&DW), slags, or mine waste are the most utilized waste types in combination with supplementary waste materials according to their characteristics. Conducted investigations showed that the use of various waste materials leads to the production of geopolymers with a broad range of final properties. Despite a high number of published publications and patents, the large-scale utilization of waste is still missing.

***Keywords**: waste, geopolymers, geopolymerization, recycle, reuse*

1. INTRODUCTION

The fast technological progress led to an increased non-renewable natural resource extraction, energy consumption, and realization of a large amount of waste to the environment [1-4]. Consequently, the safe disposal of different kinds of waste materials and industrial by-products has become a key concern for the global community [4-5]. Nowadays, problems arising from the generated waste quantity have gained great social and environmental importance [1]. The investigation of the possibility to recycle and reuse waste to produce economic value, i.e. new products have been carried out on a large scale [6-7]. Environmental pollution, the occupation of a large surface of the soil, the cost of disposal of various types of waste, and efficient use of raw materials and energy sources [8] are the main reasons for such investigations.

Likewise, many state-of-the-art technologies have been proposed. One of them is the geopolymerization technology. The term geopolymer and its description as cement-free green cementitious material first were introduced in 1978 [4]. In recent years, geopolymerization technology has been shown advantages in reusing various types of waste for the production of the new materials for many purposes. These new class of materials, the so-called inorganic polymers [4], have been proposed for the utilization of solid aluminosilicate waste and the development of new “high added value” materials [9-10]. Geopolymers represent a small environmental footprint and contribute saving of natural resources [11-12]. However, their most important advantage is that, depending on their design, they acquire properties tailored to the needs of the end-user [12].

The aim of this article is to review the heretofore utilization of various types of waste in geopolimerization technology processes.

2. GEOPOLYMERS

Geopolymers are structurally and chemically comparable to rocks and synthesized by condensation mechanism similar to organic polymers [4]. The geopolymerization represents a process comprising of the dissolution of aluminosilicate solids in a strongly alkaline medium followed by condensation of free alumina-silica oligomers to form a tetrahedral polymeric structure [4,13].

During geopolymerization, activated aluminosilicate is dissolved in an alkaline solution to form free SiO_4^- and AlO_4^- ions charge-balanced by hydrated alkali cations. These ions are tetrahedrally coordinated and linked to the form of amorphous or semi-crystalline oligomers. Finally, geopolymer gels are formed by polymerization and hardening of these oligomers [14].

The general empirical formula of geopolymer is [4,15]:

$$M_n[-(SiO_2)_z-AlO_2-]_n \cdot\cdot\ wH_2O$$

where:

M – alkaline or alkaline-earth cation such as Na^+, K^+ or Ca^{2+};

n – degree of poly-condensation;

z – values 1, 2 or 3, indicating the crystal lattice and is generally <3 for three-dimensional structural geopolymers;

w – number of crystalline water molecules.

Geopolymers can be produced at ambient or slightly elevated temperature, unlike the cement that requires a high-temperature clinkering for its production [4]. Compared to conventional construction materials, the synthesized geopolymers show adequate physico-mechanical properties, such as high strengths and durability [16].

3. WASTE MATERIALS IN THE GEOPOLYMERIZATION

The geopolymerization technology application of different types of industrial by-products or wastes instead of raw materials has been studied extensively. Production of geopolymers from waste not only provides less raw material consumption but also addresses issues regarding waste disposal.

Advantage of this technology represents the possibility of utilization of any silica and alumina-containing waste material that could be dissolved in an alkaline solution. Such a waste material might be used as a precursor for geopolymer synthesis. The fundamental limitation is a sufficient quantity of reactive silica and alumina [14].

Fly ash, red mud, construction and demolition waste (C&DW), slags, or mine waste are the most utilized waste types in combination with supplementary waste materials according to their characteristics, e.g. silica and alumina amount, generated quantities and physico-chemical properties. A by-product of coal combustion power plant – fly ash has attracted investigators most attention due to its chemical and mineralogical suitability, powdery form, good workability and worldwide easy availability [17-21].

The most synthesized, investigated, and used waste materials are shown in Table 1.

Table 1 - Different types of waste materials used for geopolymerization

Waste type (basic)	Supplementary waste / material	Ref.
fly ash	bottom ash, crushed rock, red mud, clay, waste glass	[17-21]
red mud	fly ash, ground slag	[22-23]
C&DW (clay brick, concrete, ceramic)	alone, with sand or C&DW mixture, brick	[24-27]
ground steel, blast furnace or metallurgical slag	nano-meter silicon dioxide, silica fume, fly ash, metakaolin	[28-30]
mine tailings, flotation wastes	metakaolin, kaolinite	[26, 31-32]

Conducted investigations showed that the use of various waste materials, as well as the controlled variance of synthesis parameters and manufacturing conditions, leads to the production of geopolymers with a broad range of final properties [33]. These new generations of materials are already finding applications in many fields of industry. For example, manufacturing of special concretes, fire-resistant coatings and insulators, stabilization of waste dumps, immobilization of toxic chemical or liquid radioactive waste, water control structures, noise barriers, and utilization in aluminum alloy foundries and metallurgy [4,17, 34-35].

Although the term geopolymer and its description were introduced back in the late XX century, the large-scale utilization of waste is still missing, despite a high number of published publications and patents. Among the utilization options, construction and building materials still pose a lower risk for implementation.

4. CONCLUSION

The aim of the present study was the utilization of waste in geopolimerization processes. Geopolymers from different types of waste materials can be synthesized from fly ash, red mud, clay brick, concrete, C&D and ceramic waste, cement kiln dust, mine tailings, asbestos, etc. These types of waste may cause serious environmental issues. Geopolymerization technologies have been proved advantages in reusing various types of wastes to the production of new materials for many purposes. Production of geopolymers from wastes could solve waste disposal problems, and provide less raw material consumption. Geopolymeric materials have already found the applications in many fields of industry, but construction and building materials still pose a lower risk for implementation. Despite a high number of published publications and patents, the large-scale utilization of waste in geopolimerization is still missing. Investigations of the waste utilization geopolymerization technologies still need to be conducted. Further studies are required though to improve the technology and strengthen its potential for commercial applications in order to reduce the environmental footprint.

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