POSSIBILITIES OF MUNICIPAL WASTE RECOVERY IN GEOPOLYMERS: A STUDY

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ABSTRACT

Growth in the production of industrial, agricultural and municipal waste is among growing global problems and it has recently reached very worrying levels. Solid waste arising from human activities significantly contributes to environmental pollution. The effort of the whole society is therefore its ecological, energy and economic recovery Hence, one of the possible uses is the incorporation of solid waste into geopolymer composites which are considered to be green material when compared to conventional Portland concrete. Geopolymers are nowadays referred to as green materials of the future and they consist of aluminosilicates activated by alkaline elements. Municipal solid waste can be used as an aggregate, precursor, filler, reinforcement which can have a positive impact on mechanical, physical or chemical properties of geopolymers. Geopolymer composites containing municipal waste have potential of application in the areas of concrete, noise and refractory materials, catalyst, adsorbent and many others. The present paper is an overview of scientific studies and research focused on the recycling and recovery of solid municipal waste in geopolymer composites together with the impact on the change of properties and their possible use.

***Keywords**: geopolymer, municipal solid waste, green material*

INTRODUCTION

The European Union set new and ambitious targets in 2018 for recycling and reducing landfill waste that represents the individual steps in building a circular economy. Things are not thrown away after the first use in this type of economy; however, they are reused and recycled. The average amount of municipal waste per one European is 502 kg. More detailed data on the municipal waste generation of the individual EU member states can be seen in Fig.1. The European Commission introduced the action plan for the circular economy in March 2020, the main aim of which is to make better use of potential resources and thus reduce the amount of generated waste. [1] An important aspect concerning waste is the assessment of the impact on the environment, health and to prevent further reintroduction of pollutants into the material cycle. [2] Municipal solid waste usually comes from residential life, institutional and commercial activities and is represented by, for example, food waste, glass, plastics, paper and many others. Much of municipal waste cannot be degraded naturally and needs a very long time to do so; hence there is an urgent need to find solutions for alleviating this issue. [3] Treatment and disposal of solid municipal waste are done by physical methods (incineration, evaporation, crushing, etc.), chemical methods (gasification, pyrolysis, etc.) and biochemical ones (decomposition, oxidation, absorption, etc.). However, the threat of secondary pollution persists even after this treatment and one of the appropriate possibilities appears to be the application of waste to new green materials; hence geopolymer composites.

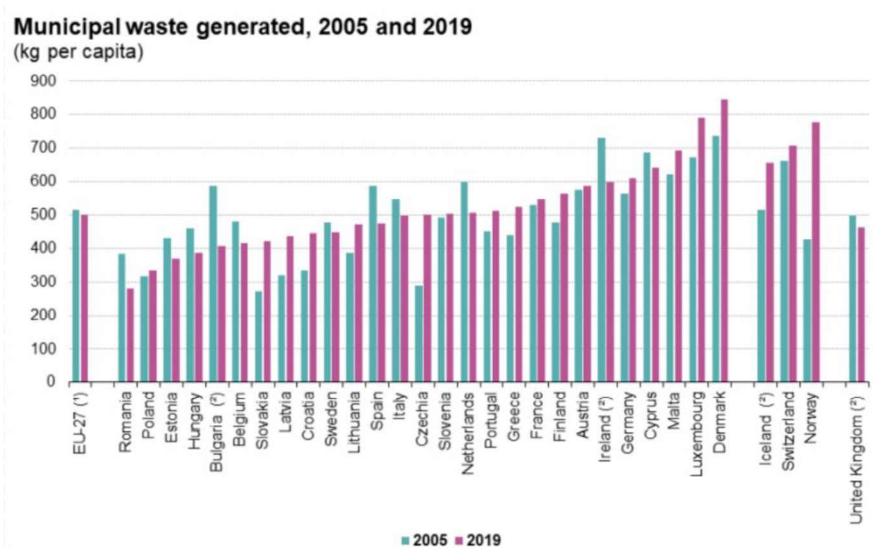

Fig. 1. *Municipal waste generated in the European Union in 2005 and 2019 [1]*

A French professor Davidovits introduced the term geopolymer in 1978 in order to describe the chemical reaction of an aluminosilicate precursor mixture together with alkaline polysilicates to form Al-O-Si bonds. [4] Geopolymers in literature are also referred to as alkali-activated polymers or inorganic polymers. Moreover, geopolymers are referred to as green materials and they are considered to be an alternative to concrete from classic Portland cement. The main advantages include the possibility of using waste raw materials such as slag, fly ash or tailings in the production of precursor geopolymer mixtures, resulting in a reduction in energy intensity and CO2 production when compared to Portland cement. Other benefits include heat resistance, excellent mechanical properties, acid resistance, the ability to encapsulate heavy metals and several others. Thus, thanks to these properties can geopolymer composites find their application as a sustainable and renovation material, thermal and acoustic insulant, material for additive printing, for immobilization of heavy metals and nuclear waste and pH regulators. [5] The issue of geopolymers is being addressed by an increasing scientific base that is discovering and examining in detail new properties on the basis of which they search for other possible applications. The preparation of geopolymers consists of several steps, including the preparation of activator solutions. An activator with prescribed molarity of 8-16 mol/l is produced by mixing and dissolving a certain amount of alkaline compounds in water. The given step must be performed at least 24 hours before preparing the geopolymers due to the need to stabilize and cool the solution. Nowadays, there are plenty of companies that supply alkaline activators according to specific requirements without the need for further processing. The second step of the geopolymer preparation is the homogenization of the precursor mixture in a mixer with additives, fillers, aggregates and all the bulk components that the resulting geopolymer should contain. It is possible to add superplasticizers, regulators and others to the solution prior to the last stage of the geopolymer preparation; thus the mixing of the bulk precursor mixture with the liquid alkaline activator. Mixing time, speed and mixers used are different and vary between authors. Individual steps of the geopolymer production are shown via block diagram in Fig. 2. [6]

The aim of the paper is to create an overview of scientific works that have influenced and improved the properties of geopolymers through the use of municipal waste in order to reduce the amount of waste and its negative impact on the environment.

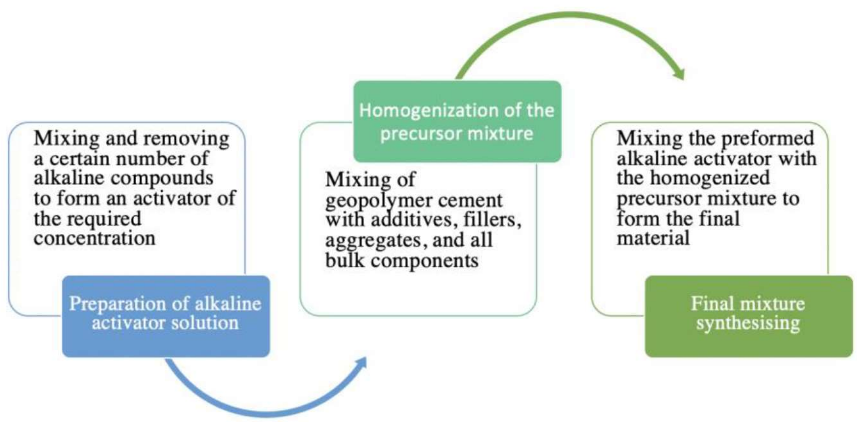

Fig. 2. *Block diagram of the geopolymer production process*

The current status of the given issue

One of the current methods of municipal waste treatment is incineration in order to reduce its volume and in some cases to produce green energy. The remaining ash is usually deposited into landfills; however, it is generally considered to be a hazardous waste due to the content of harmful heavy metals such as Cr, Cu, Pb, Zn, Hg and others. Jin and colleagues investigated in their research the immobilization of fly ash from metakaolin-based municipal solid waste and its resistance to acids and alkalis. The results indicated that geopolymers show very good stability in both types of environments; hence they could be a potential building material in aggressive environments without further secondary contamination. Analyses have shown the involvement of fly ash in geopolymerization, in which heavy metals have bound and improved the polymer structure of the geopolymer. This has resulted in improved impermeability and compressive strength; thus geopolymers are among the alternatives for reducing the amount of fly ash and stabilizing the heavy metals it contains. [7] Bottom ash from the incineration of municipal waste was used as an agent in the production of aerated light geopolymers based on metakaolin in another study; hence the expensive Al powder would be replaced. Samples of geopolymer aerated concrete formed with both types of agents were analysed in detail and subsequently compared. The result was that the bottom ash from the municipal waste incineration process can be used as an alternative agent in the production of aerated concrete geopolymers. [8]

Glass is another type of municipal waste that significantly pollutes the environment and creates so-called rapid landfills, since it usually can not be reused overdue to the mixing of colours and containing impurities. Scientific research by Xiao and colleagues was focused on the use of waste glass bottles that were crushed and synthesized together with class C geopolymer cement and activated with several concentrations of sodium hydroxide solution. The samples were cured at ambient temperature with no use of drying equipment. The geopolymer with the best properties was selected after evaluating the results of the experiments and it was activated with a solution of NaOH with a concentration of 5 mol and glass to cement ratio of 1:3. The sample reached a strength of 34.5 MPa and had the least impact on the environment. [9] Therefore, based on the above studies, it can be stated that glass waste incorporated into geopolymer composites has a great potential in the field of new building materials. Waste glass is in research considered to be a partial replacement for precursor mixtures, a fine or coarse aggregate and a replacement precursor for geopolymer activators as well. Various properties such as shrinkage, sulphate resistance, heavy metal immobilization, thermal conductivity, porosity and others have been observed. Simply stated, the synthesis of municipal waste glass and geopolymers seems to have a very favourable and promising future in the production of green materials due to its durability, efficiency and sustainability. [10]

Tires are also a challenging category of municipal waste. It is estimated that the life cycle of thousands of millions of tires ends each year, about half of them are recycled; however, the rest ends up in landfills without further processing or they are incinerated; thus presents an even greater environmental risk. Hence, these are the reasons why researchers decided to search for other solutions and application options. Aly and colleagues investigated the effects of adding crushed rubber in various percentages with focus on the properties of the slag geopolymer such as compressive, flexural and tensile strength. Several conclusions were drawn from the results of the experiments. The compressive strength was being increased to the limit of 10% of the rubber granulate content; however, the values decreased when above the limit. Tensile strength tests indicated a systematic decrease in values with increasing percentage of rubber aggregate. The elasticity of the geopolymer was increased due to the low stiffness of the rubber which resulted in a significant improvement in impact resistance. Thus, geopolymer composites containing rubber granulate have proven to be a qualified alternative green material that can find its application in the construction of roads and runways. [11]

Plastic is considered to be one of the most consumable materials in the world. However, there is a problem with its disposal due to its well-sustainable properties. There are millions of tons of plastics that float in the sea or they are just dumped in nature. Therefore, the treatment and disposal of plastic waste has become one of the most urgent global issues that needs to be addressed in order to maintain a healthy and clean environment. Several scientific teams have decided to make use of plastic waste and incorporate it into the production and research of new green materials which include geopolymer composites as well. Research led by Ganesha investigated the use of plastic waste in the form of polyethylene terephthalate (PET) bottles, which were crushed and subsequently used as a substitute for fine sand. Crushed plastic materials were added to the geopolymer in volumes of 5, 10 and 15 % while properties such as compressive and tensile strength, processability, water absorption, as well as behaviour and changes in samples at temperatures of 200, 400, 600 and 800 °C were being monitored. The results of the study showed a reduction in the processing ability of the geopolymer composite after replacing a certain amount of sand with plastic granules. The values of compressive and tensile strength increased by the level of 10% of replacement of sand by plastic granulate, as in the research by Aly and colleagues, Compressive strength increased by 5.8% and tensile strength increased as well, in particular by 24%. The absorption capacity of the geopolymers deteriorated with the presence of plastic in the matrix. The residual strength after heating of geopolymer composites containing plastic has a decreasing tendency. [12]

Table 1. *Overview of research dealing with the synthesis of municipal solid waste and geopolymers [13],[14],[15]*

Authors	**Types of Additives**	**Curing Regime**	**Primary Findings**
Jin et al.	MSWI ash CaO and Cl rich	20 ± 3°C a 60 ± 3% relative humidity for 28 days	• Strength reached 36.1 MPa after leaching 2 000 ml of simulated acid rain at pH 3.0 • excellent stability in acidic and alkaline environments without secondary contamination
Wongs et al.	MSWI ash CaO and SiO_2 rich	60°C for 24 h, subsequently for 7 to 28 days at 25 °C and 50% relative humidity	• the highest strength of 52.8 and 53 Mpa was achieved after 7 and 28 days by a sample containing 20% of ash • the sample with 20% ash has a higher hydrate phase of calcium silicate than the reference sample as the XRD analysis indicated
Tian et al.	MSWI ash CaO rich and coal ash with SiO_2 a Al_2O_3 content	60 °C for 6 h, then 7 days at room temperature	• during solidification of samples containing MSWI fly ash, it reacts with alkali to form H2 and subsequently creates cracks and causes low strength. This effect can be mitigated by optimizing the sodium hydroxide synthesis process

Xiao et al.	Glass powder from municipal waste containers	20 °C for 24 h; 3, 7, 14, 28 days afterwards at room temperature	• the highest strength of 34.5 MPa was achieved by a sample containing waste glass powder together with class C fly ash in a ratio of 1: 3 • samples activated with solutions with high or low base content reduced reactivity due to electrostatic shielding of ions
Hajimohammadi et al.	Fine separated waste glass powder	7, 14, 28 and 56 days at room temperature	• fine glass powder increases the alkalinity of the matrix, which helps a higher range of dissolution and responds better near the aggregates • the amorphous portion of the glass in the later stages forms a strong compact matrix
Toniolo et al.	Fine waste sodium-calcium powder	60 °C for 48 h, then 7 to 28 days	• sodium-calcium glass shards are a viable substitute for commercial sodium silicate solutions • leaching of heavy metals meets the criteria despite the non-traditional composition of the geopolymer matrix
Aly et al.	Recycled crushed rubber from tires	28 to 60 days in water at room temperature	• the compressive strength was increasing up to 10% of the crushed rubber content limit • A significant improvement occurred in impact resistance due to the low stiffness of the rubber particles
Long et al.	Recycled crushed rubber from tires	20 ± 2 °C and above 95% relative humidity for 3, 7 and 28 days	• crushed rubber has a negative effect on the static mechanical properties • compressive strength decreased with increasing crumb volume by 31.3%, 32.6%, 35% • flexural strength decreased by 23.6%, 13.4% and 7.3% as well
Luhar et al.	Rubber fibres derived from tires	90 °C for 48 h, followed by 3, 7, 28, 90, 365 days at room temperature	• the compressive strength decreases by increasing the percentage of rubber fibres • flexural and tensile strength increases with the percentage of rubber fibres due

			to better bridging between enlarged cracks
Ganesh et al.	Fine powder from crushed PET bottles	Room temperature and before testing 1h at 200, 400, 600 and 800 °C	• compressive strength increased by 5.8% using 10% plastic powder • the absorption capacity decreases with the presence of plastic powder in the geopolymer matrix • the residual strength decreases after heating the samples
Posi et al.	Recycled packaging foam from household electrical appliances	25 °C for 1 h and then cured at 25, 40 and 60 °C for 48 h	• foam volumes had significant effects on the strength, density and thermal properties of the geopolymer • maximum strength was achieved at a solution concentration of 10M and a temperature of 40 °C

According to the overview of scientific studies presented in the table, the conclusion of several facts related to the properties of geopolymer composites can be done. Ash from the municipal solid waste incineration has a positive effect on mechanical and physical properties. However, there are many differences between them due to the composition of the waste from which the ash originates. Siliceous waste glass also had a positive effect on the properties of geopolymers, but the main importance is in what form and amount it is added to the matrix. Recycled rubber granulates added to geopolymer composites in larger quantities had a negative effect on properties in most studies. The maximum amount of rubber crumb, with positive effect on the geopolymer composite, is approximately 10%. The addition of plastic waste powder also has a positive effect on the geopolymer only up to this percentage limit. Possibility of combining individual types of municipal waste in the formation of geopolymers and how these variations would affect the resulting geopolymer is worth consideration. In summary, it can be stated that municipal solid waste can be used in production of geopolymer composites. The usage of this waste will not only reduce costs but also allow the reuse of raw waste material that would be landfilled. Synthesized geopolymers together with municipal solid waste can be considered as a way to improve and create a circular economy in individual countries of the world.

CONCLUSION

Geopolymers are gaining more and more attention around the world thanks to their excellent properties, low energy consumption and CO2 production when compared to conventional concrete. The present overview study is contained in several research dealing with the synthesis of geopolymers and municipal solid waste such as fly ash from municipal waste incineration, glass waste material, recycled rubber granulate and plastic waste. The use of waste materials promotes recycling and reduces their amount which leads to creating new sustainable green materials. However, there are some limitations that can occur when synthesizing municipal waste due to their different chemical, physical and mineralogical properties, treatment and curing methods. Therefore, establishing a standard that would help to use geopolymer composites on a commercial scale would be necessary. Clearly, creating such a standard for certain types of municipal waste is not easy due to their very different chemical composition; hence it is necessary to focus on the given issue and seek solutions. Another important step is the creation of a cost-effective precursor geopolymer mixture, which would enable the greater use of municipal solid waste and thus reduce the environmental impact on the environment. The search for specific application possibilities of geopolymer composites created by using municipal solid waste will also help the future direction and use of geopolymer composites.

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