

# GEOPOLYMER COMPOSITE MADE THROUGH PARTIAL REPLACING FLY ASH AND SLAG WITH CHEAPER AND LESS USED WASTE PRECURSORS

Lucian Paunescu<sup>1</sup>, Enikö Volceanov<sup>2</sup> and Bogdan Valentin Paunescu<sup>3</sup>

<sup>1</sup> Daily Sourcing & Research SRL Bucharest, Romania, *Corresponding author*, ORCID No. 0000-0002-2467-5120  
lucianpaunescu16@gmail.com

<sup>2</sup> National University of Science and Technology POLITEHNICA, Faculty of Engineering in Foreign Language, Bucharest, Romania, ORCID No. 0000-0002-2020-476X [evolceanov@yahoo.com](mailto:evolceanov@yahoo.com)

<sup>3</sup> Consitrans SA Bucharest, Romania [pnsbogdan@yahoo.com](mailto:pnsbogdan@yahoo.com)

**ABSTRACT:** The research presented in this paper was focused on making a geopolymer composite characterized by the large replacement of the most commonly used alumina-silicate precursors (carbon ash and processed metallurgical slag) with cheaper and less commonly utilized wastes. Thus, clay brick waste, residual building concrete, and flat glass waste resulted from building demolition were introduced in manufacturing mixture after reducing the carbon ash and slag content. Many previous works in the literature have confirmed that carbon ash and metallurgical slag are the most suitable industrial secondary products usable in the preparing process of geopolymer composites, but their intense demand has contributed to the trend of increasing their price. Numerous alternative materials with cementitious and pozzolanic properties available in the world offer the possibility of using them for similar purposes. Even if applying these wastes does not result in reaching the qualitative level of carbon ash/slag-based geopolymer, their appropriate combination is beneficial and the current work used different experimental versions including clay brick, residual concrete, and flat glass resulted from building demolition, associated with significantly reduced consumption of ash and slag.

**KEYWORDS:** geopolymer composite, waste, alumina-silicate, clay brick, building concrete, flat glass.

## 1. INTRODUCTION

An attractive material researched and developed in the last decades, having abilities of mechanical strength and durability at a high level, is the geopolymer composite. Several residual materials adequate for making different geopolymer composite types, such as secondary products from various industries (coal ash from energy industry and granulated metallurgical slag from metallurgy) as well as ash of rice husk, residual granite in powder state, or ash-volcanic material are already known, used or experimental tested as partial substitutes for blast furnace slag or carbon ash [1, 2].

At the beginning of this millennium, research activities in the field of geopolymer composites carried out worldwide led to making composites based on cement having great tensile resistance and brittleness resistance performances compared to traditional cementitious materials. However, a high-performance mixture of cementitious composites requires considerably higher cement quantities than those needed to manufacture conventional concrete.

On the other hand, it is well known that the industrial production of ordinary cement contributes approximately 8 % of greenhouse gas emissions (CO<sub>2</sub>) to total global emissions, making the total elimination of Portland cement necessary [3].

Granulated blast furnace slag and coal fly ash are practically inert materials due to their high silica and

alumina content, their chemical activation being possible in an alkaline environment based on sodium/potassium hydroxide dissolved in deionized water (with molarities between 6M-14M) and an aqueous solution of sodium/potassium silicate, in accordance with the discovery of the researcher J. Davidovits at the end of the 20<sup>th</sup> century. Through activating alumina-silicate wastes in the alkaline environment, the geopolymerization reaction is initiated and developed forming the new material called geopolymer. This has comparable properties with that of Portland cement, having cementitious and pozzolanic abilities [4]. Coming from metallurgical and energy generating industries respectively, precursor materials of geopolymer are cheap, widely available worldwide, and environmentally friendly, being viable replacements for traditional Portland cement.

Various methods focused on significantly growing the strength of concrete composites aim at including the addition of reinforcing fibers (steel, polypropylene, polyethylene, glass, and natural materials [5, 6]) as well as nanomaterials (based on SiO<sub>2</sub>, TiO<sub>2</sub>, Fe<sub>2</sub>O<sub>3</sub>, Cr<sub>2</sub>O<sub>3</sub>, and Al<sub>2</sub>O<sub>3</sub> [7-9]) in the manufacturing mixture, but the necessary expenses are quite high. Various fiber alternatives (vegetable or animal) have been recently tested, inclusive by members of the Romanian research team who made the current work [10-13]. These additional materials

are already applied in the preparation process of some high-performance concretes.

Given the high level of mechanical and durability performances experimentally obtained in the world, the production of geopolymer composites has gradually gained more and more appreciation in competition with traditional concrete composites. The wide availability of materials representing the precursors of the geopolymer composite, their reduced price, low energy consumption, and the very small level of CO<sub>2</sub> emissions during the preparation process were extremely attractive elements for traditional construction concrete manufacturers [14].

Numerous attempts have been made, especially after 2000, to test the manufacturing conditions of geopolymer composite concrete aiming to achieve very good performances. Not all potential precursors for geopolymer manufacturing have shown to be adequate for this technical objective. Thus, the use of residual concrete and fine sand recycled from building demolition, as alumina-silicate precursors, had contradictory consequences: the residual concrete slightly improving the fluidity, while the sand reduced the geopolymer fluidity. Tests carried out under conditions of the combine use of the two waste types showed that fluidity is not practically affected [15].

The impact of adding reinforcing fibres to the geopolymer mass on tensile properties and microstructural appearance of the geopolymer composite was analyzed under conditions of geopolymer curing at ambient temperature [16]. It was experimentally found that while the compression strength, bending resistance, and density of traditional composites increased within steel fibres added, breaking and bending distortion were clearly decreased. Supplementary, micro- or nano-silica materials added allowed an obvious reduction of cracking and bending ductility of geopolymer composites.

Members of authors' team of the current paper conducted tests in 2023 on making a polymer concrete composite using metallurgical slag and carbon ash, with addition of small amounts of nano-silica (between 3.8-6.5 kg·m<sup>-3</sup>) and steel dust recovered from steelmaking in electric arc furnaces (between 3.5-6.0 kg·m<sup>-3</sup>) [17]. Results were remarkable in terms of mechanical strength performances. Thus, compression strength values reached up to 73.0 MPa and flexure resistance up to 12.1 MPa in case of using the highest contents of nano-silica and steel dust as well as adopting 180 days-curing process at ambient temperature.

The role of metallurgical slag content on mechanical strength peculiarities and on the bond resistance of geopolymer composites based on coal fly ash was highlighted by authors of the paper [18]. Partial replacement of the cementitious binder represented by fly ash with metallurgical slag (between 10-30 wt. %) was tested under experimental conditions. Geopolymer composites including slag in the starting mixture had improved compression strength, elastic modulus, cracking and stress resistance (using reinforcing fibres). All specimens of geopolymer composites (without and with slag) showed several small cracks. By increasing the slag content in the range mentioned above, the density of cracks decreased.

The work [19] researched the influence of slag and alkaline solution amounts on operability and mechanical resistance geopolymer made based on carbon ash. The investigations showed that for all cured geopolymer times below 180 days, the compression resistance has increased through the slag content growing.

Preparing process of a geopolymer composite, in which the slag was replaced in different ratios with ground residual brick recovered from building demolition [20]. As a result of applying this technique, water uptake gradually increased, reaching a huge value (304 %) in the case of completed replacement of slag.

Other recycled alumina-silicate wastes from building demolition (ground residual concrete and recycled paste powder) as replacements for carbon ash and slag in manufacturing process of geopolymer composite were tested in the work [21]. Carbon ash and slag replacement up to 100 % with ground residual concrete led to increasing water-permeable porosity and water uptake. It has been observed that water uptake does not reach a very high level when the ash and slag are replaced in ratios within the limits of 50-100 % with recycled paste powder.

With the development of making the geopolymer composites based on metallurgical slag, the slag as a precursor has become a much more requested industrial by-product and, consequently, its price has increased. Rice husk ash has become an interesting alternative for researchers, knowing that its use in cement composites has increased mechanical properties and has reduced the water uptake [22]. The high content of rice husk ash (in the range of 60-80 %) had a favourable consequence on the compression and flexure resistance of concretes. The conclusion of the work mentioned above has been that the combination of 60 % rice husk ash with 40 % slag can constitute an optimal technical solution to obtain very

good mechanical peculiarities of geopolymer composites.

Another industrial by-product that can be used as an alumina-silicate precursor in the manufacture of geopolymer composites is the residual granite powder, recycled from granite stone processing. Previous research has shown that this powder could be suitable as a binder in the manufacturing process of cement-based composites [23].

Volcanic rock powder, as a natural, porous, and lightweight material, is also a potential alumina-silicate precursor for the manufacture of geopolymer composites for ecological construction [24].

Another industrial waste with cementitious and pozzolanic role tested according to the literature is the so-called „red mud”. It is a very alkaline residual material originating from the Bayer procedure of refining bauxite for obtaining alumina [25, 26]. Despite the very large available quantities, the use of this residue in the manufacture technique of geopolymers requires combination with carbon ash or processed metallurgical slag. The high alkalinity of red mud favours the geopolymerization method, but the consequence on resistance characteristics of this construction material type was not at the expected level.

The design of geopolymer composite concrete within this work aimed at choosing and testing an original combination of cheaper and less applied precursors (according to literature data) as partial substitutes (generally between 35-50 %) of frequently used basic materials (such as carbon ash and slag from the cast iron production).

The adopted materials were building demolition wastes (old clay brick, old concrete waste, and residual clear flat glass), low amounts of carbon ash and processed slag from cast iron making as well as mix solution including 12M NaOH and Na<sub>2</sub>SiO<sub>3</sub> as an alkaline activator.

## 2. MATERIALS AND PROCEDURES

### 2.1 Materials

In the experiment presented below, have been selected wastes from building demolition (such as old clay brick scrap, old concrete waste, and residual clear flat glass), low quantities of carbon ash and cast iron-slag from metallurgy as well as a common alkaline activator containing 12M-molarity NaOH solution and Na<sub>2</sub>SiO<sub>3</sub> solution.

In the first years after the end of World War II, a good opportunity arose in some European countries seriously affected by the war (especially Germany and the United Kingdom) of technical capitalization

of masonry waste from buildings. Of course, the manufacturing techniques were not at all similar to those developed by J. Davidovits at the end of 20<sup>th</sup> century using the alkaline activator of alumina-silicate wastes for preparing geopolymer composites [4, 27]. The clay brick scrap was subjected to breaking, ball mill-grinding, and sieving, so that selected grain size was in the range of 30-80 µm. The chemical composition of clay brick measured by authors in Metallurgical Research Institute indicated the following situation: 53.9 % SiO<sub>2</sub>, 15.6 % CaO, 14.5 % Al<sub>2</sub>O<sub>3</sub>, 7.7 % Fe<sub>2</sub>O<sub>3</sub>, 2.0 % MgO, 1.8 % K<sub>2</sub>O, 0.8 % Na<sub>2</sub>O.

If the initiation of the residual construction concrete reuse in manufacturing process of new construction materials was almost similar to that of clay brick waste, shortly after the war, currently there is a trend of recycling the concrete from building demolition based on modern manufacturing methods such as sintering and expanding waste mixtures [28] or alkaline activation of silica-alumina residues for making novel polymers usable in building. End-of-life construction concrete resulting from building demolition is a typical silica-alumina waste, rich in silica and alumina, containing 68.9 % SiO<sub>2</sub>, 18.7 % Al<sub>2</sub>O<sub>3</sub>, 6.5 % Fe<sub>2</sub>O<sub>3</sub>, 1.6 % CaO, 1.5 % K<sub>2</sub>O, 1.3 % TiO<sub>2</sub>, etc. [28]. As with the recycled clay brick, the broken concrete pieces were repeatedly ground (after removing the steel reinforcement) until the concrete grain size was reduced under 100 µm.

End-of-life building flat glass resulting from the building demolition has also constituted a very useful raw material for the solid mixture designed in view of producing the geopolymer composite. According to data from [29] including some of authors of the current paper, residual flat glass is mainly composed of SiO<sub>2</sub> (between 70-73 %). Among the other components of the chemical composition, Na<sub>2</sub>O and K<sub>2</sub>O together represent 13.4-14.6 %, CaO is in the range of 8-9.7 %, MgO is within the limits of 3.5-4.5 %, while Al<sub>2</sub>O<sub>3</sub> has a maximum value of 1.5 %. Generally, during the demolition process, the available quantity of flat glass waste is very high. The mechanical processing of this waste was performed by sorting and cleaning, followed by ball mill-grinding and finally, sieving and the flat glass-particle size was accepted below 80 µm.

Fly ash experimentally used here had been procured from Paroseni-Thermal Power Plant (Romania) and stored for different subsequent experiments 9 years ago, under the conditions that anthracite was the used fuel. The oxide components of recycled carbon ash were determined and included: 53.9 % SiO<sub>2</sub>, 26.7 % Al<sub>2</sub>O<sub>3</sub>, 4.2 % Fe<sub>2</sub>O<sub>3</sub>, 3.4 % CaO, 2.6 % MgO, 1.4 %

TiO<sub>2</sub>, 0.5 % Na<sub>2</sub>O, 0.5 % K<sub>2</sub>O, 1.7 % SO<sub>3</sub>. The initial grain dimension of the ash (under 250 μm) was reduced through mechanical processing methods under 80 μm.

Ground cast iron-slag has also been utilized into material mix for preparing the geopolymer composite. The slag was supplied to the authors' team about 10 years ago by the company ArcelorMittal Galati (Romania). The industrially granulated slag as spheres with relative diameters in the range of 2-6 mm required ball mill-grinding, the obtained powder having the grain size below 90 μm.

Alkaline solution used as an activator included NaOH in form of solid pellets dissolved in deionized water (12M-molarity) and Na<sub>2</sub>SiO<sub>3</sub> with 38 % concentration. The weight report Na<sub>2</sub>SiO<sub>3</sub>/NaOH was about 2.5.

## 2.2 Procedures

Preparing the alkaline activator was made 24 hours before the preparation of the solid mixture, in a separate container, its mixing being obtained by stirring for 3-4 min. The homogeneous fluid mix was casted over the solid component mixture. Final mixing was performed with an electrically driven stirrer for 5-6 min until a paste was formed and this was poured into a metal mould. The mould containing the geopolymer paste was placed in a laboratory electric oven and heated at 70 °C for 24 hours. After hot-hardening the geopolymer paste, the composite specimen was removed from the mould and subjected to the curing process at ambient thermal conditions (under controlled low humidity conditions) for 7, 28, and 56 days respectively, before investigating the characteristics of the final product.

## 2.3 Methods for investigating the features of geopolymer composite features

Characterization methods of geopolymer composite specimens are presented further. The fresh geopolymer composite workability was analyzed according to ASTM C 143-10 with the slump test equipment. Water-absorbing was measured through the immersion procedure of the specimen under water for 24 hours (ASTM C948) at the end of the curing process (56 days) and the sample mass was identified through weighing. The geopolymer

composite denseness was determined by Archimedes' method through the liquid intrusion technique (ASTM D792-20). The compression strength was measured with 2000 kN-compression fixture Wyoming Test Fixture [30] and the flexure resistance was determined by carrying out the three-point bend test on the specimen (SR EN ISO 14125: 2000). The structural appearance of composite specimens was analyzed with the Biological Microscope model MT5000, 1000 x magnification.

## 3. OUTCOMES AND COMMENTS

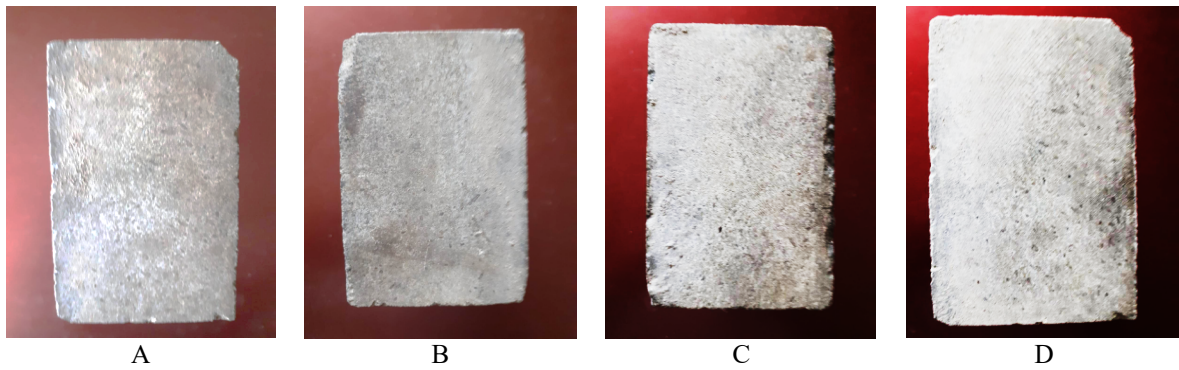
### 3.1 Outcomes

Several experimental versions were adopted aiming to create a type of geopolymer composite based on the choice of cheaper and less used precursors, which would partially replace coal ash and cast iron-slag as the most frequently utilized in such manufacturing processes. Materials that compose the mixture variants are indicated in Table 1.

**Table 1.** Composition of variants for testing

Component	Variant (kg·m <sup>-3</sup> )			
	No. 1	No. 2	No. 3	No. 4
Clay brick scrap	81	84	88	92
Residual building concrete	55	57	60	63
Clear flat glass waste	20	22	24	26
Coal fly ash	182	176	168	160
Ground granulated blast furnace slag	79	75	70	65
12M NaOH solution	45	45	45	45
Na <sub>2</sub> SiO <sub>3</sub> solution	112	112	112	112
Water addition	25	25	25	25

According to the data in Table 1, the total consumption of common solid precursors (fly ash and granulated blast furnace slag) had much lower values (between 225-261 kg·m<sup>-3</sup>), being replaced by less used and cheaper precursors (clay brick waste, residual building concrete, and flat glass waste) summing between 156-181 kg·m<sup>-3</sup>. Images of the four specimens obtained through the use of making recipes exposed in Table 1, are presented in Figure 1.



**Figure 1.** Surface appearance of geopolymer composites  
A – variant 1; B – variant 2; C – variant 3; D – variant 4.

The workability of the four geopolymer composite specimens was determined by slump testing of fresh geopolymer taken immediately after mixing and forming the paste. Abram's cone test for determining the slump flow [31, 32] showed a decreasing value level of the composite workability with the decrease of the ratios of carbon ash (mainly) and cast iron-slag through replacement with clay brick, building concrete, and clear flat glass waste. Measurements made through the Abram's cone test indicated that the flow diameter values slowly decreased from 208 to 195 mm. Workability slump test values also tended to decrease from 72 to 57 mm. According to the data in Table 2, the workability level corresponding to versions 1-4 falls within the limits of medium values.

**Table 2.** Workability characteristics

Version	No. 1	No. 2	No. 3	No. 4
Slump flow (mm)	208	204	201	195
Workability slump test (mm)	72	68	61	57

In general, geopolymer composite fresh mixtures had satisfactory viscosity and cohesion peculiarities. Under conditions in which slag amount in the mix was relatively small and was also reduced from variant 1 ( $79 \text{ kg}\cdot\text{m}^{-3}$ ) to variant 4 ( $65 \text{ kg}\cdot\text{m}^{-3}$ ), the amount of liquefied calcium ions of the slag reacted more slowly with alkaline solution to form C-S-H phase, contributing to diminishing the workability [33].

The investigation of physio-mechanical characteristics carried out after the completion of 7-56 day-curing process led to the results shown in Table 3.

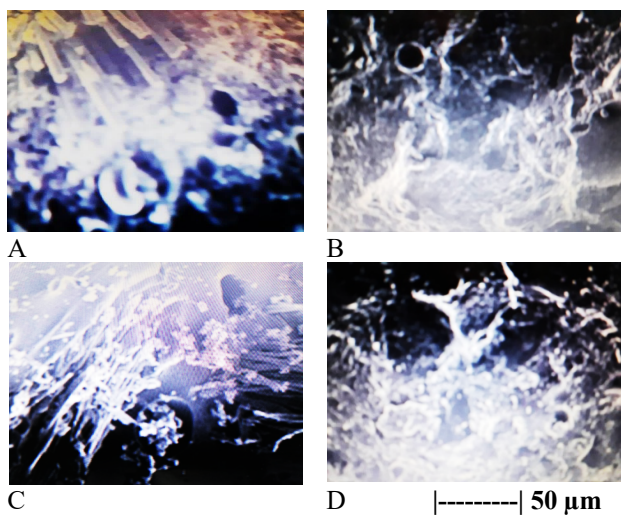
**Table 3.** Physio-mechanical features of samples

Peculiarity	Variant 1	Variant 2	Variant 3	Variant 4
Denseness ( $\text{kg}\cdot\text{m}^{-3}$ )	2180	2166	2145	2130

Peculiarity	Variant 1	Variant 2	Variant 3	Variant 4
Compression resistance (MPa)				
-7 curing days	25.9	25.6	25.0	24.5
- 28 days	38.7	38.3	37.8	37.0
- 56 days	39.5	39.2	38.6	38.1
Flexure resistance (MPa)				
-7 curing days	5.3	5.4	5.3	5.1
- 28 days	6.0	5.9	5.8	5.4
- 56 days	6.3	6.1	6.0	5.7
Water uptake (vol. %)	6.4	6.8	6.6	7.5

Examining the data in Table 3 led to the conclusion that the reduction of the carbon ash amount (between  $182\text{-}160 \text{ kg}\cdot\text{m}^{-3}$ ) and slag (from  $79$  to  $65 \text{ kg}\cdot\text{m}^{-3}$ ), compensated by the addition of clay brick, concrete, and flat glass waste summing an additional  $25 \text{ kg}\cdot\text{m}^{-3}$ , allowed obtaining more than satisfactory values of compression and flexure resistance, although their level was lower compared to that of composites produced with carbon ash or carbon ash and metallurgical slag (without considering the option of adding reinforcing fibres). According to experimental data, decreasing the weight ratio between fly ash and slag mix and less used waste including brick, concrete, and glass, negatively influenced the composite mechanical strength, but to an acceptable extent. On the other hand, the strength level reached at early age (after 7 days of curing process) is high compared to the final resistance values (after 56 days).

The microscopic appearance of the four geopolymer composite specimens was also analyzed after the finish of 56 hardening days at ambient temperature. Pictures representing the microscopic structure of the samples are exposed in Figure 2.



**Figure 2.** Microstructural appearance of geopolymer specimens

A – version 1; B – version 2; C – version 3; D – version 4.

In conformity with images in Figure 2, by decreasing fly ash amount and increasing the clay brick powder content, the Si/Al and at the same time, Na/Al ratios increase. By decreasing carbon ash amount, the share of un-reacted carbon ash grains also is diminished. By mainly increasing the clay brick powder content, the larger un-reacted crystals brought by the powder also grow. The influence of un-reacted crystals on the geopolymer is negative in terms of its mechanical strength, which is reduced [34].

### 3.2 Comments

Comparing the obtained results regarding the compression and flexure resistance of the four samples, it is observable that they are quite close in value, with the specification that the first experimental version is the best, but all the others are acceptable for applications in construction.

Given that the less commonly used precursors according to the literature (such as clay brick, construction concrete, and window glass) represented in this experiment between 37.4 % (version 1) and 44.6 % (version 4) and each nominated precursor represented 50.8-51.9 % (clay brick), 34.8-35.3 % (construction concrete) and 12.8-14.4 % (flat glass) of the total of these additional precursors, it can be accepted that this distribution between brick, concrete, and glass constitutes approximately the optimal technical solution for the association between quality and low costs.

Physio-mechanical features of geopolymer composite specimens were: denseness between 2130-2180 kg·m<sup>-3</sup>, compression strength at early age in the range of 24.5-25.9 MPa and after 56 days within the limits of 38.1-39.5 MPa, flexural strength at early age between 5.1-5.4 MPa and after 56 days in the range of 5.7-6.3 MPa. Water uptake had values between

6.4-7.5 vol. %, the greatest value being reached in version 4.

## 4. CONCLUSION

This paper aimed at making a geopolymer composite type through advanced replacing the most commonly used alumina-silicate raw materials (such as carbon ash and ground cast iron-slag) with some cheaper and less usually utilized wastes (such as clay brick scrap, old building concrete, and residual flat (window) glass from demolition activity of old construction. The common components as silico-alumina precursors (carbon ash and slag) were diminished to values between 62.6 % (version 1) and 55.4 % (version 4), being replaced with old clay brick, residual building concrete, and flat glass recovered from construction demolition. Of the total materials added as replacements for fly ash and slag, clay brick waste represented 50.8-51.9 %, residual concrete was 34.8-35.3 %, and flat glass represented between 12.8-14.4 %. Results showed the possibility of creating geopolymer composite specimens with adequate mechanical strength (compression and flexural) and durability properties, viable for use as high-performance construction materials. Despite replacing the most suitable alumina-silicate precursors for the manufacture of geopolymers (fly ash and slag) with cementitious materials with weaker properties, the strength performances were close to those of ash and slag-based polymers.

## 5. REFERENCES

1. Tahwia, A.M., Abdulaimi, D.S., Abdellatief, M., Youssf, O., Physical, mechanical and durability properties of eco-friendly engineered geopolymer composites, *Infrastructures*, MDPI, De Maeijer, P.K., Arias-Sanchez, P. (eds.), Vol. 9, No. 11, (2024).  
<https://doi.org/10.3390/infrastructures9110191>
2. Alawi, A., Milad, A., Barbieri, D., Alost, M., Alaneme, G.U., Bux, Q., Eco-friendly geopolymer composites prepared from agro-industrial wastes: A state-of-the-art review, *CivilEng*, MDPI, Luongo, A., D'Annibale, F. (acad. eds.), Vol. 4, No. 2, pp. 433-453, (2023).  
<https://doi.org/10.3390/civileng4020025>
3. Andrew, R.M., Global CO<sub>2</sub> emissions from cement production, *Journal of Earth System Science*, Springer Link Publishing, Vol. 10, No. 1, pp. 195-217, (2018).  
<https://doi.org/10.5194/essd-2017-77>
4. Davidovits, J., Geopolymers: Inorganic polymeric new materials, *Journal of Thermal Analysis Calorimetry*, Springer Link Publishing,

- Vol. 37, No. 8, pp. 1633-1656, (2008).  
<https://doi.org/10.1007/BF01912193>
5. Telrandhe, S., Fiber reinforced concrete-types, properties and advantages, Sakshi Chem Science Pvt. Ltd., Nagpur, Maharashtra, India, (2025).  
<https://www.sakshichemsciences.com/fiber-reinforced-concrete/>
  6. Afroughsabet, V., Biotzi, L., Ozbakkaloglu, T., High-performance fiber-reinforced concrete: a review, *Journal of Materials Science*, Springer Science-Business Publishing (on-line), New York, the United States, (2016).  
<https://doi.org/10.1007/s10853-016-9917-4>
  7. Goel, G., Sachdeva, P., Kumar Chaudhary, A., Singh, Y., The use of nanomaterials in concrete: A review, *Materials Today: Proceedings*, Elsevier, Vol. 69, Part 2, pp. 365-371, (2022).  
<https://doi.org/10.1016/j.matpr.2022.09.051>
  8. Paunescu, L., Axinte, S.M., Volceanov, E., Nonconventional geopolymerization and densification method of alumina-silicate waste solids for producing extremely high-strength geopolymers, *Nonconventional Technologies Review*, Vol. 28, No. 4, pp. 22-27, (2024).  
<https://www.revtn.ro/index.php/revtn/article/view/488/436>
  9. Paunescu, L., Paunescu, B.V., Volceanov, E., Nonconventional procedure of more intense valorization of alumina-silicate waste for preparing new geopolymeric materials suitable in construction, *Nonconventional Technologies Review*, Vol. 28, No. 3, pp. 18-23, (2024).  
<https://www.revtn.ro/index.php/revtn/article/view/488/436>
  10. Paunescu, L., Volceanov, E., Paunescu, B.V., Ioana A., Fly ash-based aerogel reinforced with polyester fibres for remarkable thermal and acoustic properties, *Nonconventional Technologies Review*, Vol. 27, No. 1, pp. 27-31, (2023).  
<https://www.revtn.ro/index.php/revtn/article/view/406>
  11. Paunescu, L., Volceanov, E., Paunescu, B.V., Reinforced concrete composite with vegetable fibre, *Academic Journal of Manufacturing Engineering*, Vol. 21, No. 1, pp. 120-125, (2023).  
[https://ajme.ro/PDF\\_AJME\\_2023\\_1/L15.pdf](https://ajme.ro/PDF_AJME_2023_1/L15.pdf)
  12. Paunescu, L., Ioana, A., Volceanov, E., Paunescu, B.V., The use of keratin protein as animal fibers to make a geopolymer based on alumino-silicate industrial by-products, *Bulletin of Polytechnic Institute from Iasi, Chemistry and Chemical Engineering Section*, Vol. 69 (73), No. 4, pp. 33-46, (2023), ISSN: 2537-2947.
  13. Paunescu, L., Ioana, A., Paunescu, B.V., Environmentally friendly technique for making high-strength geopolymer concrete reinforced with animal fibers as food industry waste, *Romanian Journal of Civil Engineering*, Matrix Rom Publishing, Vol. 15, No. 1, pp. 88-97, (2024).
  14. Almutairi, A.L., Tayeh, B.A., Adesina, A., Isleem, H.F., Zeyad, A.M., Potential applications of geopolymer concrete in construction: A review, *Case Studies in Construction Materials*, Elsevier, Vol. 15, (2021).  
<https://doi.org/10.1016/j.cscm.2021.e00733>
  15. Wang, F., Ding, Y., Nishiwaki, T., Zhang, Z., Yu, K., Fully recycled engineered geopolymer composite, mechanical properties and sustainability assessment, *Journal of Cleaner Production*, Elsevier, Vol. 471, (2024).  
<https://doi.org/10.1016/j.jclepro.2024.143382>
  16. Alrefaei, Y., Dai, J.G., Tensile behavior and microstructure of hybrid fiber ambient cured one-part engineered geopolymer composites, *Construction and Building Materials*, Elsevier, Vol. 184, pp. 419-431, (2018).  
<https://doi.org/10.1016/j.conbuildmat.2018.07.012>
  17. Paunescu, B.V., Paunescu, L., Volceanov, E., Microsilica and steel dust as nano- and micro particles addition for increasing the mechanical strength of fly ash and blast furnace slag-geopolymer concrete, *Romanian Journal of Civil Engineering*, Matrix Rom Publishing, Vol. 14, No. 2, pp. 120-129, (2023).
  18. Ling, Y., Wang, K., Li, W., Shi, G., Liu, P., Effect of slag on the mechanical properties and bond strength of fly ash-based engineered geopolymer composites, *Composites Part B: Engineering*, Elsevier, Vol. 164, pp. 747-757, (2019).  
<https://doi.org/10.1016/j.compositesb.2019.01.092>
  19. Deb, P.S., Nath, P., Sarker, P.K., The effects of ground granulated blast-furnace slag blending with fly ash and activator content on the workability and strength properties of geopolymer concrete cured at ambient temperature, *Materials & Design (1980-2015)*, Elsevier, Vol. 62, pp. 32-39, (2014).  
<https://doi.org/10.1016/j.matdes.2014.05.001>
  20. Ahmed, J.K., Atmaca, N., Khoshnaw, G.J., Exploring flexural performance and abrasion resistance in recycled brick powder-based engineered geopolymer composites, *Beni-Suef University Journal of Basic Application Science*, Springer Open, Vol. 13, (2024).

- <https://bjbas.springeropen.com/articles/10.1186/s43088-024-00532-7>
21. Wu, H., Liu, X., Wang, C., Zhang, Y., Ma, Z., Micro-properties and mechanical behavior of high-ductility engineered geopolymer composites (EGC) with recycled concrete and paste powder as green precursor, *Cement and Concrete Composites*, Elsevier, Vol. 152, (2024). <https://doi.org/10.1016/j.cemconcomp.2024.105672>
  22. Zabihi, S.M., Tavakoli, H.R., Evaluation of monomer ratio on performance of GGBFS-RHA alkali-activated concretes, *Construction and Building Materials*, Vol. 28, pp. 326-332, (2019). <https://structurae.net/fr/litterature/article-de-revue/evaluation-of-monomer-ratio-on-performance-of-ggbfs-rha-alkali-activated-concretes/citations>
  23. Elyamany, H.E., Abd Elmoaty, A.E.M., Mohamed, B., Effect of filler types on physical, mechanical and microstructure of self compacting concrete and Flow-able concrete, *Alexandria Engineering Journal*, Elsevier, Vol. 53, No. 2, pp. 295-307, (2014). <https://doi.org/10.1016/j.aej.2014.03.010>
  24. Zeyad, A.M., Magbool, H.M., Tayeh, B.A., Garcez de Azevedo, A.R., Abutaleb, A., Hossain, Q., Production of geopolymer concrete by utilizing volcanic pumice dust, *Case Studies in Construction Materials*, Elsevier, Vol. 16, (2022). <https://doi.org/10.1016/j.cscm.2021.e00802>
  25. Wang, P., Liu, D.Y., Physical and chemical properties of sintering red mud and Bayer red mud and the implications for beneficial utilization, *Material (Basel)*, Elsevier, Vol. 5, No. 10, pp. 1800-1810, (2012). <https://doi.org/10.3390/ma5101800>
  26. Hu, W., Nie, Q., Huang, B., Shu, X., He, Q., Mechanical and microstructural characterization of geopolymers derived from red mud and fly ash, *Journal of Cleaner Production*, Elsevier, Vol. 186, pp. 799-806, (2018). <https://doi.org/10.1016/j.jclepro.2018.03.086>
  27. Youssef, N., Rabenantoandro, A.Z., Dakhli, Z., Chapiseau, C., Waendendries, F., Chehade, F.H., Lafhaj, Z., Reuse of waste bricks: a new generation of geopolymer bricks, *SN Applied Sciences*, Springer Link Publishing, Vol. 1, (2019). <https://link.springer.com/article/10.1007/s42452-019-1209-6>
  28. Paunescu, L., Dragoescu, M.F., Axinte, S.M., Sebe, A.C., Lightweight aggregate from recycled masonry rubble achieved in microwave field, *Nonconventional Technologies Review*, Vol. 23, No. 2, pp. 47-51, (2019).
  29. Ioana, A., Paunescu, L., Constantin, N., Pollifroni, M., Deonise, D., Petcu, F.S., Glass foam from flat glass waste produced by the microwave irradiation technique, *Micromachines*, MDPI, Vol. 13, (2022). <https://doi.org/10.3390/mi13040550>
  30. Dyg Siti Quraisyah, A.A., Kartini, K., Hamidah, M.S., Water absorption of incorporating sustainable quarry dust in self-compacting concrete, *4<sup>th</sup> International Symposium on Green and Sustainable Technology (ISGST)*, Kampar, Malaysia, October 3-6, 2021, IOP Conf. Series: Earth Environmental Science, Vol. 945, IOP Publishing Ltd., (2021). <https://doi.org/10.1088/1755-1315/945/1/012037>
  31. Waqas, R.M., Butt, F., Zhu, X., Jiang, T., Tufail, R.F., A comprehensive study on the factors affecting the workability and mechanical properties of ambient cured fly ash and slag based geopolymer concrete, *Applied Sciences*, MDPI, Lacidogna, G. (acad. ed.), Vol. 11, No. 18, (2021). <https://doi.org/10.3390/app11188722>
  32. Sankar Chanda, S., Guchhalt, S., A comprehensive review on the factors influencing engineering characteristics of lightweight geopolymer concrete, *Journal of Building Engineering*, Elsevier, Vol. 86, (2024). <https://doi.org/j.jobe.2024.108887>
  33. Thomas, B.S., Yang, J., Bahurudeen, A., Chinnu, S.N., Abdalla, J.A., Hawilch, R.A., Hamada, H.M., Geopolymer concrete incorporating recycled aggregates: A comprehensive review, *Cleaner Materials*, Elsevier, Vol. 3, (2022). <https://doi.org/10.1016/j.clema.2022.100056>
  34. Kugler, F., Fehn, T., Sandner, M., Kremar, W., Teipel, U., Microstructural and mechanical properties of geopolymers based on brick scrap and fly ash, *International Journal of Ceramic Engineering & Science*, The American Ceramic Society Publication Central, Vol. 4, No. 2, pp. 92-101, (2022). <https://doi.org/10.1002/ces2.10120>