

Effect of waste glass addition on mechanical properties of slag based geopolymers

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Abstract. Slag is one of the by-products of energy industry which is suitable for secondary industrial processing. Although the slag has been successfully used in industrial production for several decades its use does not achieve the level of its potential. The Slags can be used as alkali activated materials and utilized in synthesis of geopolymers. This work describes an improvement of mechanical properties of alkali activated binders – geopolymers made of blast furnace slag. The effect of addition of waste glass on mechanical properties of geopolymers was examined. The Waste glass was added in a form of broken and crushed glass particles. Samples were tested after 7, 28 and 90 days.

1. Introduction

The Ground granulated blast-furnace slag (GGBFS) is a by-product of the steel industry by adding limestone to ore for the purpose of removing non-ferrous contaminants, and it consists of four major chemical components: CaO, SiO₂, Al₂O₃ and MgO [1]. As one of the main by-products during the process of iron and steel making, the blast furnace slag is discharged in a super-high temperature of 1450–1650°C [2]. These components are highly reactive with alkaline solutions to form alkali-activated GGBS [3].

The slag can be used as an alkali activated material and utilized in synthesis of geopolymers. The term geopolymer was first used by Joseph Davidovits. He defined the material that is formed in inorganic polycondensation called geopolymerization. In the geopolymerization reaction, three-dimensional structures of AlO₄ and SiO₄ tetrahedra are created. Later the term geopolymer was used for all alkali activated aluminosilicates [4, 5].

The geopolymers now represent a new group of inorganic substances, because they have a significant environmental and energy potential. They belong to a group of the inorganic polymer covalently bound macromolecules with the chain consisting of -Si-O-Al-O-. Geopolymers are obtained from the chemical reaction of alumino-silicate oxides with sodium silicate solutions in a highly alkaline environment. As an alkali activating solution, a strongly alkaline aqueous solution of sodium or potassium hydroxide is most commonly used [5, 6].

The geopolymers find a broad range of applications in the field of transportation, emergency repairs, metallurgy, coating, membrane materials, and nuclear waste disposal. Despite a significant commercial and technological potential geopolymers' easy-brittle character limits their extensive applications where great efforts are made to overcome such a disadvantage. Numerous studies are dedicated to optimize



the strength of geopolymer products and to understand the mechanism of the geopolymerization [7, 8, 9, 10].

In the last years, different studies have investigated the possibility of using different types of wastes mixed with fly ash or slag as raw materials. The selection of the materials to create the geopolymers depends on influences such as availability, disposal urgency, difficulty for recycling and final applications [11].

The primary aim of this paper is to demonstrate that a mechanical activation of GGBFS improve mechanical properties of all geopolymers made in our research.

2. Materials and methods

The material used for the alkali activation was the blast furnace slag (BFS) after the mechanical activation in a ball mill. Milling was performed in the laboratory ball mill with steel balls with different diameters. A chemical analysis of the material is in Table 1. After grinding stage d80 was 120 μm . The material was homogenized before the alkali activation. No other treatment was applied to the material. SEM pictures of the materials after grinding are in Figure 1. As shown, slag after mechanical activation in ball mill has plate-like and needle-like structures. SEM images have been taken at different magnification. The SEM images of GGBFS display rough and angular shape.

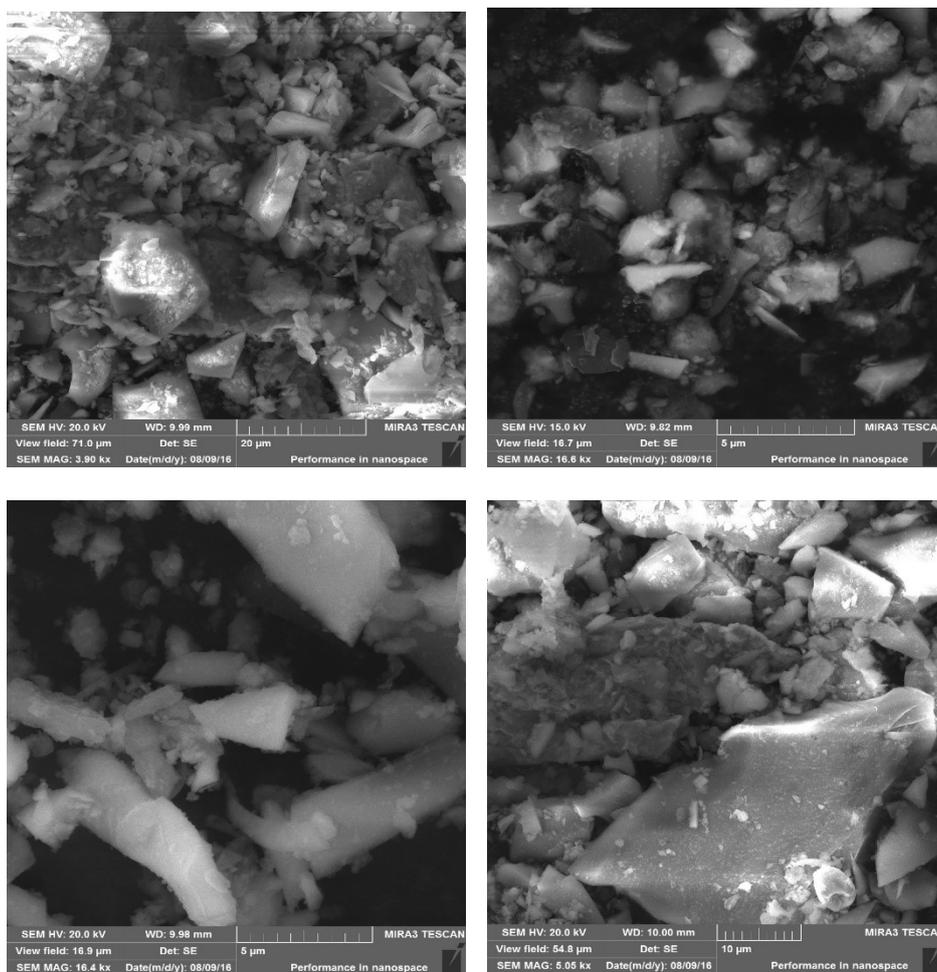


Figure 1: SEM pictures of GGBFS.

The activation solution was prepared by mixing solid NaOH pellets with Na-water glass and water. The sodium water glass from the Kittfort Praha Co. with the density of 1.328–1.378 g/cm^3 was used. It

contains 36–38% Na_2SiO_3 and the molar ratio of $\text{SiO}_2/\text{Na}_2\text{O}$ is 3.2–3.5. The solid NaOH with the density of 2.13 g/cm^3 was obtained from Kittfort Praha Co. containing at least 97% – 99.5% of NaOH.

Table 1. Chemical composition of GGBFS.

Material	SiO_2	CaO	MgO	Al_2O_3	Fe_2O_3	Other
BFS [%]	40.3	37.01	12.1	8.51	0.3	1.78
WG [%]	71.3	9.2	1.2	1.9		

The slag mixture samples with different amount of waste glass (WG) were prepared. WG came from old colorless glassy waste such as old bottles. The samples with 10%, 20%, and 30% by weight and also a reference sample which was created only from GGBFS were prepared. Two different particle sizes of the waste glass were used. In the first set of experiments the particle size of the waste glass was below 1mm. In the second set it was between 1–4 mm.

GGBFS was first mixed with WG and after their homogenization, the activation solution was added. The value of the Ms modulus in the activation solution was adjusted to 1.3. An overall concentration of the alkaline activation agent was adjusted to 7% Na_2O in the binder mass. The water-to-fly ash ratio was adjusted to 0.23. GGBFS and WG mixture was stirred with the activation solution for 10 minutes, until a creation of a homogenous mixture. The mixture was then filled into prismatic molds with the dimensions $40 \times 40 \times 160 \text{ mm}$ and compacted on the vibration table VSB-40. The pastes were cured in a hot air drying chamber at 80°C for 6 hours. Thereafter, the samples were removed from the molds, marked, and stored in laboratory conditions till the moment of the strength test. The values of compressive strength were determined after 7, 28 and 90 days according to the Slovak Standard STN EN 12390-3. A part of the samples was kept for 28 days at laboratory temperature, then a water absorption test according to the Slovak Standard STN 73 1316 was performed.

The compressive strength of the hardened samples was determined after 7, 28 and 90 days using the hydraulic machine Form+Test MEGA 100-200-10D.

3. Results and discussion

Properties and a composition of material play an important role in the alkali activation. The samples were synthesized from GGBFS with addition of WG by several proportions and in different particle sizes. The effect of WG addition on final compressive strength and flexural strength as a function of time was examined. The resulting strengths are shown in Figures 2 and 3 for the particle size below 1 mm.

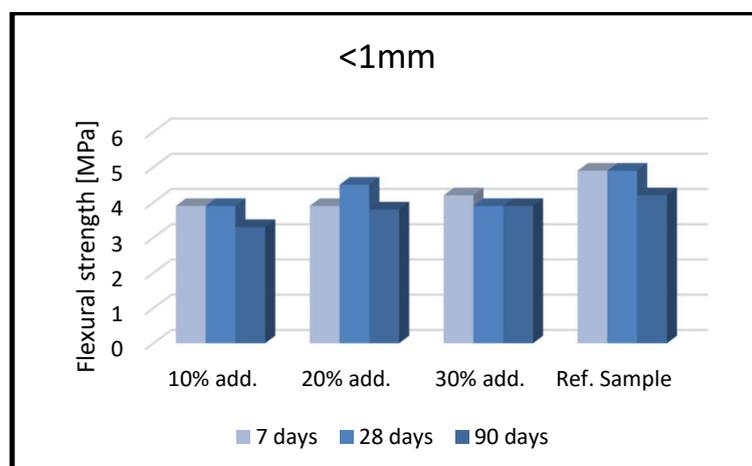


Figure 2. Effect of WG addition on flexural strength.

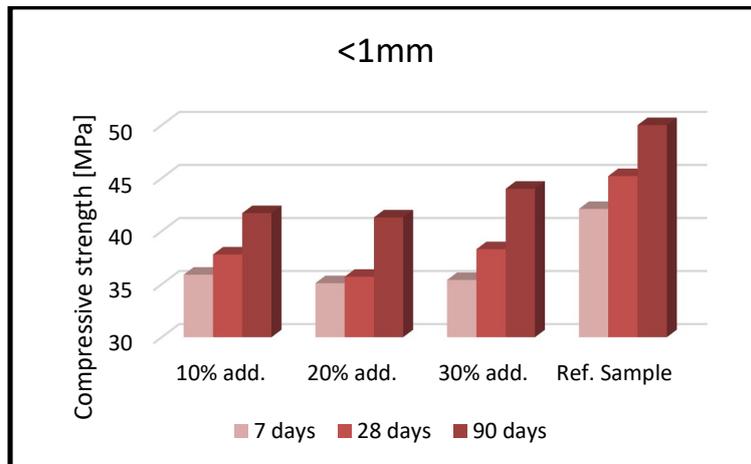


Figure 3. Effect of WG addition on compressive strength.

The flexural strength results shows that maximum strength of all samples is not achieved on 90th day, but the slag addition in the samples proves that these strengths were lower than the flexural strength of the reference sample. The flexural strength of all samples was decreasing over the time.

The same tendency showed results of the compressive strength tests. The addition of WG with particle size below 1mm did not improve the compressive strengths of the mixtures over the reference sample. The highest strengths were achieved for the samples with 30% addition of WG. Results also showed that on 90th day, all the strengths were about the same, which means that the added portion of WG have no significant effect on the compressive strength of the hardened material, but when compared to the reference sample, the compressive strength of all the samples is lower.

The water absorption was examined over 24 hours and was measured after 10, 40, 90, 360 and 1440 minutes. The measured water absorption in the prepared geopolymeric materials is shown in Figure 4. The results show that 20% addition of WG in the sample decreases the water absorption. The highest water absorption was measured for the sample with 10% addition of WG.

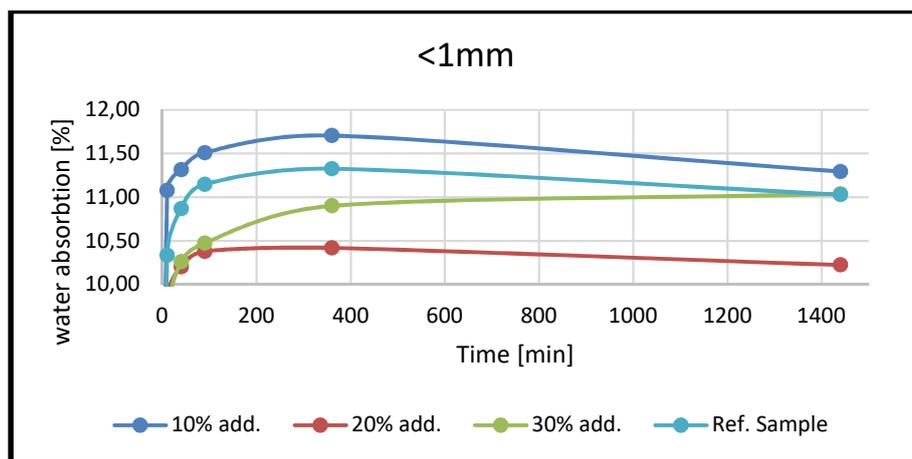


Figure 4. Water absorption of GGBFS geopolymers with <1mm WG addition.

The second set of experiments had the same parameters, but the particle size of WG was different. Results are in Figures 5 and 6.

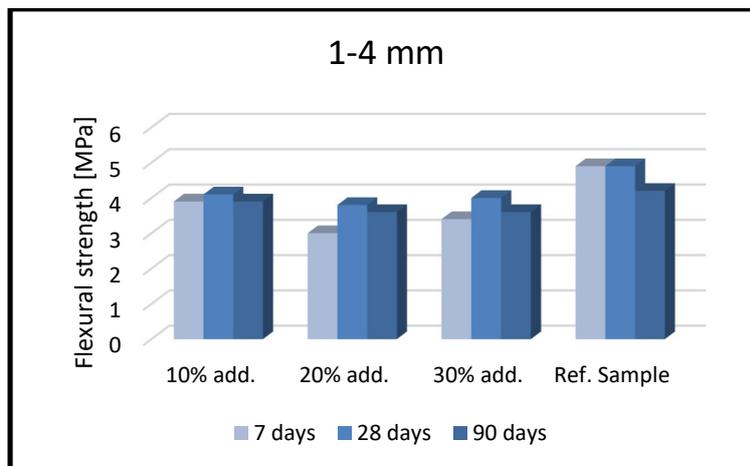


Figure 5. Effect of WG addition on flexural strength.

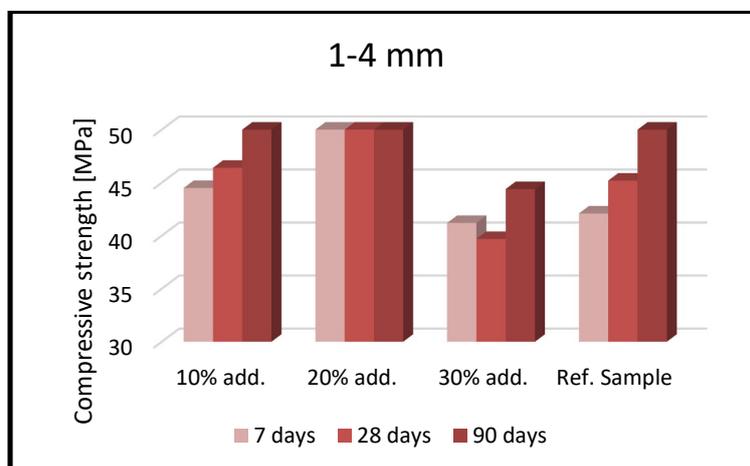


Figure 6. Effect of WG addition on compressive strength.

The flexural strength results show very similar results than results with WG with smaller particle size. Also not only they did not improve the flexural strengths but strengths were decreasing over time. The highest strengths were achieved by the reference sample.

The compressive strengths results with 1–4 mm particle size WG finally showed an improvement. 10 and 20% of WG in the mixture showed a little bit higher strengths than the reference sample in each day of testing. 20% addition of WG also showed that the strengths were almost the same from 7th to 90th day of measuring. On the contrary 30% addition of WG on the contrary showed decreasing in strengths.

WG shows similar strengths as in [12, 13], we can compare the high of compressive strengths. Compressive strength values are comparable to Portland cement, close to 45 and 50 MPa, were achieved for samples produced with 7 M solution in contrary to [12] where highest strengths were achieved with 6 M solution. Similar results were also obtained in [13], where highest strengths were achieved in mixture containing 20% addition of ground container glass. Optimum addition levels of WG are in 10 to 20% range.

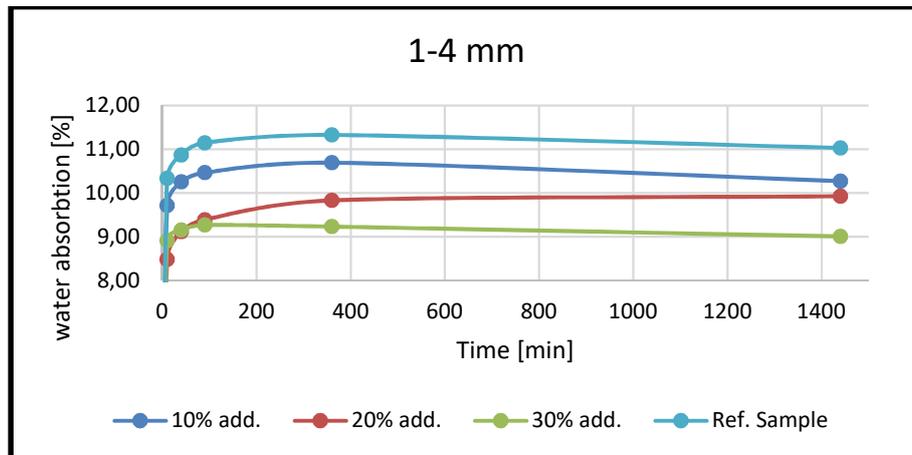


Figure 7. Water absorption of GGBFS geopolymers with 1–4 mm WG addition.

The water absorption test with these geopolymers mixtures showed that an increase in the portion of WG in the sample decreases the water absorption. The highest water absorption was measured for the reference sample, the lowest was measured for the sample with 30% addition of WG. WG has a positive effect to reduce the water absorption in these geopolymers.

4. Conclusions

The alkali activated materials – geopolymers, are a new generation of inorganic binders. Any aluminosilicate materials can be used to prepare the geopolymers, including the slag. This paper describes possibilities of preparation of the geopolymers from GGBFS with the addition of a different amount of the waste glass. The results showed, that WG has not always a positive effect on strengths of the produced material. With smaller particle size there is very small positive effect and only in the water absorption. Bigger particle size has achieved an improvement in the compressive strengths and also in the water absorption.

Acknowledgments

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References

- [1] Snellings R., Mertens G and Elsen J 2012 Supplementary cementitious materials *Rev. Mineral. Geochem.* **74** pp 211–278
- [2] Wang H, Ding B, Liu X, Zhu X, He X and Liao Q 2017 Solidification behaviors of a molten blast furnace slag droplet cooled by air *Applied Thermal Engineering* **127** pp 915–924
- [3] Arai Y, Powell B A and Kaplan D I 2017 Sulfur speciation in untreated and alkali treated ground-granulated blast furnace slag *Science of The Total Environment* **589** pp 117–121
- [4] Davidovits J 1991 Geopolymers: Inorganic Polymeric new materials *Journal of thermal analysis* **37** pp 1633–1656
- [5] Skvara F 2007 Alkali activated materials or geopolymers *Ceramics – Silikáty* 51/3 pp 173–177
- [6] Xu H and van Deventer J S J 2000 The geopolymerisation of alumina-silicate materials. *Int. J. Miner. Process* **59** pp 257–266
- [7] van Deventer J S J, Provis J L, Duxson P and Lukey G C 2007 Reaction mechanisms in the geopolymeric conversion of inorganic waste to useful products *Journal of Hazardous Materials* **139** pp 506–513
- [8] Zhang H Y, Kodur V, Qi S L and Wu B 2015 Characterizing the bond strength of geopolymers at ambient and elevated temperatures *Cement and Concrete Composites* **58** pp 40–49
- [9] He J, Jie Y, Zhang J, Yu Y and Zhang G 2013 Synthesis and characterization of red mud and rice

- husk ash-based geopolymer composites *Cement and Concrete Composites* **37** pp 108–118
- [10] Zhang J, He Y, Wang Y, Mao J and Cui X 2014 Synthesis of a self-supporting faujasite zeolite membrane using geopolymer gel for separation of alcohol/water mixture *Materials Letters* **116** pp 167–170
- [11] Toniolo N and Boccaccini A R 2017 Fly ash-based geopolymers containing added silicate waste *Ceramics International* **43** pp 14545–14551
- [12] Toniolo N, Rincón A, Avadhut Y S, Hartmann M, Bernardo E and Boccaccini A R 2018 Novel geopolymers incorporating red mud and waste glass cullet *Materials Letters* **219** pp 152–154
- [13] Tho-In T, Sata V, Boonserm K and Chindapasirt P 2018 Compressive strength and microstructure analysis of geopolymer paste using waste glass powder and fly ash *Journal of Cleaner Production* **172** pp 2892–2898