Turkish Journal of Engineering

https://dergipark.org.tr/en/pub/tuje

e-ISSN 2587-1366

Freeze-thaw resistance of blast furnace slag alkali activated mortars

Şinasi Bingöl*[1], Cahit Bilim [2], Cengiz Duran Atiş [3], Uğur Durak [3]

[1] Tokat Gaziosmanpasa University, Engineering and Architecture Faculty, Civil Eng. Department, Tokat, Turkey
[2]Mersin University, Engineering Faculty, Civil Engineering Department, Mersin, Turkey
[3]Erciyes University, Engineering Faculty, Civil Engineering Department, Kayseri, Turkey

Keywords
Blast Furnace Slag
Geopolymer mortars
Freeze-Thaw Cycle

ABSTRACT

In this study, blast furnace slag geopolymer mortars were prepared in prism molds with the size of 4 x 4 x 16 cm by alkali activating powdered sodium meta silicate (Na_2SiO_3). The mortar mixtures prepared to contain sodium in different proportions were cured with 3 different curing methods, and 300 cycles of freeze-thaw were applied, and strength and weight losses were examined. Control samples prepared with PC were also exposed to freeze-thaw cycles and the results were compared with each other. It was observed that 8% sodium added geopolymer mortars significantly preserved their compressive strength and weight. Especially, the compressive strength of the samples produced with 8% sodium and exposed to freeze-thaw cycle after 28 days of air curing increased by around 32%.

1. INTRODUCTION

Geopolymers are defined as binders that reduce CO_2 emission, provide recycling of waste materials, and have the potential to be an alternative to Portland Cement (PC)(Atabey et al., 2020). Waste materials with high silica and alumina content such as fly ash (FA) and blast furnace slag (BFS) are used in the production of geopolymer mortar. FA and BFS are activated with some alkaline materials to gain strength (Çelikten et al., 2019).

Portland cement is the most widely used hydraulic binder in the construction industry. This hydraulic binder has a composite structure made of materials such as limestone and gypsum. PC has high strength and high freeze-thaw resistance. However, excessive amount of energy need during production and causing high CO_2 emission are among its disadvantages. Researchers state that it is responsible for 5-7% of the world's CO_2, with around 0.66-0.82 kg CO_2 emission per 1 kg of PC (Lämmlein et al., 2019; Peng et al., 2012; Xie et al., 2019; Zhang et al., 2018, 2020)

On the other hand, thanks to geopolymer material technology, it has been revealed that greenhouse gas emissions and energy consumption were reduced by 73% and 43%, respectively (Meyer, 2009). This makes it attractive to investigate geopolymer binders as an alternative binder instead of Portland cement in concrete production (Juenger et al., 2011).

Frost resistance is an important property for concrete durability (Zhuang et al., 2016). Fu et al. (2011). determined that geopolymer concrete can withstand the freeze-thaw effect more than 300 cycles. It has been determined by researchers that F class fly ash based geopolymer concretes have poor frost resistance but can withstand up to 225 cycles with the addition of 50% slag (Zhao et al., 2019). It is also among the determined features that the freezing resistance of normal Portland cement concretes increases with the addition of air entraining admixture, but the air additive decreases the strength in geopolymer concretes (Brooks et al., 2010; Sun and Wu, 2013; Yuan et al., 2020).

In this study, the freeze-thaw resistance of blast furnace slag was investigated by activating alkali to contain different amounts of sodium. After the mortar mixes were kept under different curing conditions, they were subjected to freezing-thawing for 300 cycles and Flexural, compressive strength and mass losses were investigated. The results obtained were compared with the control samples prepared with Portland cement. The aim of the study is to contribute to the literature by conducting research on new binder materials in order to

* **Corresponding Author**

*(sinasi.bingol@gop.edu.tr) ORCID ID 0000-0002-3708-3079
(cbilim@mersin.edu.tr) ORCID ID 0000-0002-0975-1391
(cdatis@erciyes.edu.tr) ORCID ID 0000-0003-3459-329X
(ugurdurak@erciyes.edu.tr) ORCID ID 0000-0003-2731-3886

Cite this article

Bingöl Ş, Bilim C, Atiş C D & Durak U (2022). Freeze-thaw resistance of blast furnace slag alkali activated mortars. Turkish Journal of Engineering, 6(1), 63-66

Research Article / DOI: 10.31127/tuje.810937

Received: 15/10/2020; Accepted: 21/12/2020

reduce the economic and ecological damage of Portland cement.

2. MATERIALS AND METHOD

2.1. Cement

Normal Portland cement (CEM I 42.5 R) was used for the control samples in the study. The material supplied from Tokat Adoçim Cement Factory conforms to the standards (TS EN 197-1, 2012). The chemical properties of cement was given in Table 1.

2.2. Blast Furnace Slag

The blast furnace slag used in the study is the slag waste of İskenderun Iron and Steel Factory. The slag was supplied and used as ground powder. The specific surface area of the slag was determined as approximately 6000 cm^2/g, and the specific gravity was determined as 2.90 g/cm^3. The chemical properties of slag was given in Table 1.

Table 1. Chemical properties of cement and slag

Oxide	Cement	Slag
SiO_2 (%)	18.87	38.89
CaO (%)	62.78	28.94
Na_2O (%)	0.4	0.36
K_2O (%)	0.9	0.78
Al_2O_3 (%)	5.62	13.48
SO_3 (%)	2.82	1.51
MgO (%)	2.63	5.53
Fe_2O_3 (%)	2.54	1.36
MnO (%)	-	1.16
Others (LOI etc.)	3.44	6.50

2.3. Sand

For the mortar mixes, river sand from Tokat region was used. Maximum grain size was 4 mm, density of sand was approximately 2.3 g/cm^3.

2.4. Water

Normal drinking water was used in the production of mortars (TS EN 1008, 2003).

2.5. Activator

For the alkaline activation of the mortars, Na_2SiO_3 in powder form supplied from Tekkim Chemical Industry was used.

2.6 Mix proportions

Mixing ratios of mortars were specified as follows; binder / aggregate ratio 1:3, water / binder ratio 1: 2, aggregate amount 1350 g sand (TS EN 196-1, 2016). 3 different activator ratios were used in the production of blast furnace slag geopolymer mortars. Na_2SiO_3 was added to the mortar mixture in a way to contain 4%, 8% and 12% sodium by weight of the slag. The mix proportion of mortars was given in Table 2. The prepared mortars were placed in prism molds of 4×4×16 cm^3 dimensions. The mortars prepared with 3 different activators were subjected to 3 different cures. These curing methods were determined as 1 day in oven (DO) at 75 °C, 28 days at 20±2 °C room temperature (DA) and 28 days in water at 21±2 °C (DW). Portland cement mortars that are the control samples were also cured at 21±2 °C in water for 28 days. Geopolymer mortars and control mortars that completed their curing time were subjected to 300 cycles of freezing-thawing. After the cycle is completed, the weight changes, flexural and compressive strength changes of the mortars were determined.

Table 2. Mix proportions

Mixture	Cement (g)	Slag (g)	Activator (%)	Water (g)	Sand (g)
Cement	450	0	0	225	1350
Slag	0	450	4-8-12	225	1350

3. RESULTS

Weight, flexural strength and compressive strength changes at the end of 300 cycles are given in Table 3.

Table 3. Physical and mechanical changes after the freeze-thaw test

Sodium Ratio	Curing type	Loss of flexural strenght (%)	Loss of compressive strenght (%)	Loss of weigth (%)
CEM I 42.5 R	28 DW	0.67	-4.29	0.86
4%	1 DO	28.94	20.95	7.28
	28 DA	100.00	100	4.86
	28 DW	90.84	-29.67	0.67
8%	1 DO	43.78	-2.04	-2.66
	28 DA	16.50	-31.91	1.58
	28 DW	28.97	3.67	-0.23
12%	1 DO	100.00	100	100
	28 DA	30.96	59.69	5.18
	28 DW	67.49	40.91	7.34

According to the weight and strength results obtained; It is observed that the weight and flexural strength of the control samples are preserved and the compressive strength increased by about 4.3%. In slag geopolymer mortars, it is seen that 4% 28 GH and 12% 1 GE samples are completely dispersed. However, it was determined that the weight was preserved and the compressive strength significantly increased in the 8% sodium added mortars. Although the flexural strength of the 8% 28 DA sample decreased by 16%, the compressive strength increased by 32% and reached the value of 76.39 MPa. The compressive strength of the 8% 1 DO sample increased by 2% and reached 58.60 MPa. Although the compressive strength of the 8% 28 DW sample decreased by 3.6%, it shows a compressive strength of 72.68 MPa.

Figure 1. Images of mortars after freeze-thaw test

In 4% sodium added geopolymer mortars; although the flexural strength of the 28 DW sample decreased significantly, the compressive strength increased around 30% and reached the value of 58.13 MPa. Even though the compressive strength of the 1 DO sample reduced by 21%, it decreased to 44.23 MPa.

An overall decrease was observed in 12% sodium added mortars. It was detected that the 1 DO sample was completely dispersed. In addition, the compressive strengths of the 28 DA and 28 DW samples decreased to 24.85 and 33.35 MPa, respectively.

Generally, at the end of the freeze-thaw cycle, it was observed that 8% sodium added geopolymer mortars maintained themselves in terms of both weight and strength. It was detected that 12% sodium added mortars were more affected.

4. DISCUSSION

Strength and weight changes of slag geopolymer mortars and control mortars after 300 cycles of freeze-thaw were investigated. It was observed that 8% sodium added mortars were the least affected samples by the freeze-thaw cycle. These mortars are thought to be less damaged because of the fact that they gain their strengths very well.

It was determined that the strength and weight losses are high in mortars containing 4% and 12% sodium. Although the initial strengths of these mortars are high, it has been observed that they are more damaged during the freeze-thaw cycles. In this study, it can be said that 8% sodium meta-silicate addition gives the optimum results.

5. CONCLUSION

In line with the purpose of the study, it was investigated that slag geopolymer mortars could be an alternative binder to Portland cement. Experimental studies have been conducted for this purpose and some data have been obtained. It was determined that slag geopolymer mortars reached higher compressive strengths than control mortars for some samples at the end of 300 cycles. Especially slag mortars containing 8% Na_2SiO_3 significantly preserve their weight and compressive strength at the end of the freeze-thaw cycle. It has been concluded that this study will be a good reference for researches that will be conducted in this field.

Author contributions

Şinasi Bingöl: Investigation, Experimental study, Writing-Original draft preparation. **Cahit Bilim:** Writing-Reviewing and Editing. **Cengiz Duran Atiş:** Methodology. **Uğur Durak:** Experimental study.

Conflicts of interest

The authors declare no conflicts of interest.

REFERENCES

Atabey İ İ, Karahan O, Bilim C & Atiş C D (2020). The influence of activator type and quantity on the transport properties of class F fly ash geopolymer. *Construction and Building Materials*, *264*. https://doi.org/10.1016/j.conbuildmat.2020.120268

Çelikten S, Sarıdemir M & Deneme İ Ö (2019). Mechanical and microstructural properties of alkali-activated slag and slag + fly ash mortars exposed to high temperature. *Construction and Building Materials*, *217*, 50–61. https://doi.org/10.1016/j.conbuildmat.2019.05.055

Brooks R, Bahadory M, Tovia F & Rostami H (2010). Properties of alkali-activated fly ash: High performance to lightweight. International Journal of

Sustainable Engineering, 3(3), 211–218. https://doi.org/10.1080/19397038.2010.487162
Fu Y, Cai L & Yonggen W (2011). Freeze-thaw cycle test and damage mechanics models of alkali-activated slag concrete. Construction and Building Materials, 25(7), 3144–3148. https://doi.org/10.1016/j.conbuildmat.2010.12.006
Juenger M C G, Winnefeld F, Provis J L & Ideker J H (2011). Advances in alternative cementitious binders. Cement and Concrete Research, 41(12), 1232–1243. https://doi.org/10.1016/j.cemconres.2010.11.012
Lämmlein T D, Messina F, Wyrzykowski M, Terrasi G P & Lura P (2019). Low clinker high performance concretes and their potential in CFRP-prestressed structural elements. Cement and Concrete Composites, 100(February), 130–138. https://doi.org/10.1016/j.cemconcomp.2019.02.014
Meyer C (2009). The greening of the concrete industry. Cement and Concrete Composites, 31(8), 601–605. https://doi.org/10.1016/j.cemconcomp.2008.12.010
Peng J X, Huang L, Zhao Y B, Chen P, Zeng, L & Zheng W (2012). Modeling of Carbon Dioxide Measurement on Cement Plants. Advanced Materials Research, 610–613, 2120–2128.
Sun P & Wu H C (2013). Chemical and freeze-thaw resistance of fly ash-based inorganic mortars. Fuel, 111, 740–745. https://doi.org/10.1016/j.fuel.2013.04.070
TS EN 1008. (2003). Mixing water for concrete—Specifications for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete. TSI.
TS EN 196-1. (2016). Methods of testing cement—part 1: determination of strength. TSI.
TS EN 197-1. (2012). Cement–Part 1: compositions and conformity criteria for common cements. In Turkish Standard Institution. TSI.
Xie N, Dang Y & Shi X (2019). New insights into how MgCl 2 deteriorates Portland cement concrete. Cement and Concrete Research, 120(April), 244–255. https://doi.org/10.1016/j.cemconres.2019.03.026
Yuan Y, Zhao R, Li R, Wang Y, Cheng Z, Li F & John M Z (2020). Frost resistance of fiber-reinforced blended slag and Class F fly ash-based geopolymer concrete under the coupling effect of freeze-thaw cycling and axial compressive loading. Construction and Building Materials, 250, 118831. https://doi.org/10.1016/j.conbuildmat.2020.118831
Zhang P, Gao Z, Wang J, Guo J, Hu S & Ling Y (2020). Properties of fresh and hardened fly ash/slag based geopolymer concrete: A review. In Journal of Cleaner Production (Vol. 270). Elsevier Ltd. https://doi.org/10.1016/j.jclepro.2020.122389
Zhang P, Zheng Y, Wang K & Zhang J (2018). A review on properties of fresh and hardened geopolymer mortar. Composites Part B: Engineering, 152(April), 79–95. https://doi.org/10.1016/j.compositesb.2018.06.031
Zhao R, Yuan Y, Cheng Z, Wen T, Li J, Li F & Ma Z J (2019). Freeze-thaw resistance of Class F fly ash-based geopolymer concrete. Construction and Building Materials, 222, 474–483. https://doi.org/10.1016/j.conbuildmat.2019.06.166
Zhuang X Y, Chen L, Komarneni S, Zhou C H, Tong D S, Yang H M, Yu W H & Wang H (2016). Fly ash-based geopolymer: Clean production, properties and applications. Journal of Cleaner Production, 125, 253–267. https://doi.org/10.1016/j.jclepro.2016.03.019