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Effect of Glass Powder Substitution on Compressive Strength and Sorptivity of GGBFS Based Geopolymer Concrete

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Keywords

Geopolymer Concrete, Ground Granulated Blast Furnace Slag, Glass Powder, Compressive Strength, Sorptivity.

Abstract

In this study, the effect of glass powder substitution on the compressive strength and sorptivity values of ground granulated blast furnace slag (GGBFS) based geopolymer concretes was investigated. In geopolymer concrete mixtures, 5, 10, 15 and 20% by weight glass powder was substituted for GGBFS. Geopolymer concrete samples prepared by using sodium hydroxide as alkali activator were subjected to ambient curing for 28 days. The compressive strengths of the samples were between 39.54 MPa and 30.67 MPa. As the glass powder substitution increased, the compressive strength decreased. The sorptivity values of 5, 15, 30, 60 and 1440 minutes of the samples were determined. The cumulative sorptivity values of the samples, in which 0, 5, 10, 15, and 20% glass powder was substituted, were 1.14, 1.18, 1.38, 1.46 and 1.73 mm/min$^{1/2}$, respectively. As the glass powder substitution ratio in the samples increased, the sorptivity value increased. An exponential relationship was found between compressive strength and sorptivity values, and the correlation coefficient of this relationship was 0.95.

1.Introduction

Portland cement is the main material used in the production of concrete, which is the second most used material after water in the world. CO_2 emission in Portland cement production constitutes 10% of global CO_2 emissions and the increasing demand for Portland cement also increases the amount of CO_2 emissions. For this reason, efforts to find an alternative binder in concrete production continue (Zakka et al., 2021) [1].

The term geopolymer was introduced by Davidovits in 1978. Mediums such as alkaline medium (Na^+, K^+, Li^+, Ca^+, etc.), phosphoric or humic acid can be used to synthesize geopolymers with a three-dimensional amorphous microstructure. The geopolymerization process in an alkaline environment occurs with polymeric Si-O-Al bonds formed by the reaction of Al and Si minerals with alkaline solution [2].

Alkali activation of waste materials containing alumino silicate such as fly ash, ground granulated blast furnace slag (GGBFS), clay is used in the production of geopolymer, which is a new alternative binder material. Geopolymer concretes are expected to be green binding materials and consume less energy (Singh et al., 2019) [3].

It is estimated that approximately 200 million tons of glass waste is stored in storage yards every year in the world. The recycling rate of waste glass in European Union countries is 73% on average and it is the leader in the world with this rate. Non-biodegradable waste glass poses a problem due to the search for new storage yards and low recycling rate [4]. The use of recycled waste glass in Portland cement and concrete has received worldwide attention due to rising disposal costs and environmental concerns (Shi et al., 2007)[5]. Glass can be recycled endlessly, as there is no loss of quality and value [6]. The use of waste glass in construction materials is important in terms of saving waste glass storage areas and recycling waste glass. The use of waste glass as a substitute for aggregate or cement can both reduce the consumption of natural resources and reduce the energy use in cement production (Si vd., 2020) [7].

Sethi et al. (2019) [8] investigated the effect of adding 5, 10 and 15% glass powder on the compressive strength of the geopolymer concretes. Sevinç and Durgun (2020) [9] determined the properties of high calcium fly ash-based geopolymer concretes produced by replacing 5, 15, 20, 25 and 50% glass powder. Zhang et al (2020) [10] investigated the compressive strength of waste glass based geopolymer concrete at different curing temperatures (20, 50, 80 and 100 °C). Xiao et al. (2020) [11] investigated the compressive strength of fly ash-based geopolymer pastes cured at ambient temperature. Glass powder was substituted for fly ash from 0% to 100% with a 25% increase rate. At the same time, geopolymer series were produced by using sodium hydroxide in different molarities (0, 2.5, 5, 7.5 and 10M) in the production of geopolymers. As the waste glass ratio increased, the compressive strength of the samples decreased. When the 60-day compressive strengths were compared, the highest strengths were obtained in the samples containing 10M sodium hydroxide.

Bellum et al. (2020) [12] stated that the sorptivity values of the fly ash based geopolymer concretes decreased as the GGBFS substitution ratio increased. Topal et al. (2021) [13] reported that the sorptivity values of the samples increased as the binder content decreased in GGBFS based geopolymer concretes. Khan et al. (2021) [14] studied the effect of 10, 20, 30 and 40% glass powder substitution on alkali-activated fly ash mortars on the sorptivity values of the samples.

In this study, the effect of glass powder substitution at different ratios on the compressive strength and sorptivity values of GGBFS based geopolymer concretes was investigated. In geopolymer concrete mixtures, glass powder was substituted at 5, 10, 15 and 20% by weight instead of GGBFS. The compressive strength and sorptivity values of the samples were determined after the geopolymer mixtures prepared using sodium hydroxide as alkali activator and river aggregate as aggregate were subjected to ambient curing for 28 days.

2. Materials And Experimental Procedures

2.1. Materials

GGBFS was used as raw material in the production of geopolymer concrete. The specific gravity of GGBFS was 2.86 g/cm^3, and the Blaine fineness was 3996 cm^2/g. The specific gravity of the glass powder were 2.58 g/cm^3. The chemical compositions of GGBFS and glass powder are given in Table 1. 12M sodium hydroxide solution was used as alkali activator. River aggregate was used as both fine aggregate (0-4mm) and coarse aggregate (4-8mm).

Table 1. Chemical composition of GGBFS and glass powder

Component (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3
GGBFS	32.5	9.94	1.25	32.45	9.31	0.82
Glass powder	69.4	1.09	0.48	8.27	4.25	_
Component (%)	Na_2O	K_2O	TiO_2	Mn_2O_3	S^{-2}	LOI
GGBFS	0.31	0.85	1.16	3.51	0.3	_
Glass powder	12.3	_	_	_	_	16.2

2.2. Mix design and experiment procedures

In the production of geopolymer concrete, after first preparing 12M sodium hydroxide solution, GGBFS and glass powder were added and mixed. Then, fine and coarse aggregates were added to the mixture, respectively, and mixed. The prepared geopolymer concrete mixture was placed in steel molds measuring 50×50×50 mm^3. After being kept in the mold for 24 hours, the samples removed from the mold were subjected to ambient curing for 28 days. The amounts of materials used in the geopolymer concrete mixtures are given in Table 2.

Table 2. Amounts of materials used in geopolymer concrete mixes (kg/m^3)

Mixtures	C0	C5	C10	C15	C20
GGBFS	400	380	360	340	320
Glass powder	-	20	40	60	80
NaOH solution	200	200	200	200	200
Fine aggregate	1102.8	1102	1100.2	1099	1097.7
Coarse aggregate	605.35	604.7	604.96	603.26	602.56

ASTM C109 (2020) [15] and ASTM (2004) C1585 [16] standards were used to determine the compressive strength and sorptivity values of the samples that completed curing periods, respectively. The equation in Equation 1 was used to determine the compressive strength.

$$f_m = \frac{P}{A} \quad (1)$$

In order to determine the sorptivity values of the samples, they were kept in an oven at 105±5°C for 24 hours. Then, the side surfaces of the sample were wrapped with a waterproof tape and the sample was immersed in water so that it contacted 5 mm of water from the bottom surface (Figure 1). The weights of the samples at the end of 5, 15, 30, 60 and 1440 minutes were measured and the sorptivity values of the samples were determined with the equations given in Equations 2 and 3.

$$S = \frac{I}{t^{1/2}} \quad (2)$$

$$I = \frac{m_t}{a \times d} \quad (3)$$

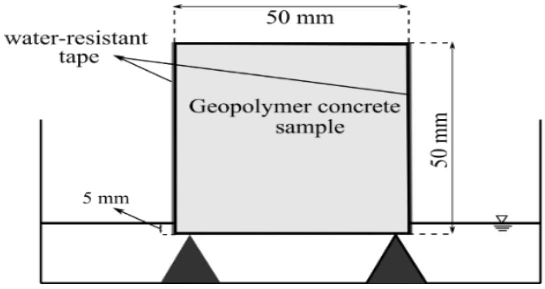

Figure 1. Schematic of the sorptivity test procedure applied to samples

3. Results and discussion

The compressive strengths of the samples that completed curing time are given in Figure 2. The compressive strength of the control sample without glass powder was 39.54 MPa. The compressive strengths of C5, C10, C15 and C20 coded samples were 37.81, 35.13, 32.49 and 30.67 MPa, respectively. With the increasing glass powder substitution in the samples, the compressive strength decreased. These reduction rates were between 4.6% and 28.9%. Sethi et al. (2019) [8] reported that the compressive strength of geopolymer concretes activated using sodium hydroxide with three different molarities (4, 8 and 12 M) decreased as the glass powder replacement ratio increased. Khan et al. (2021) [14] stated that the compressive strength of alkali activated mortars decreased as glass powder substitution increased.

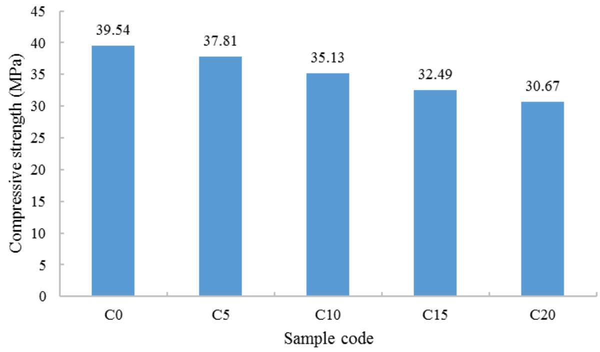

Figure 2. Compressive strength values of the samples

The sorptivity values of the samples depending on the time are given in Figure 3. After 5 minutes, the sorptivity values of the C0, C5, C10, C15 and C20 coded samples were 0.39, 0.41, 0.47, 0.48 and 0.55 mm/min$^{0.5}$, respectively. The large part of the total sorptivity values of the samples were reached in the first 60 minutes. The values at the end of 1440 minutes decreased considerably. The cumulative sorptivity values of the samples at 1440 minutes are given in Figure 4. As the glass powder substitution rate increased, the sorptivity values of the samples increased.

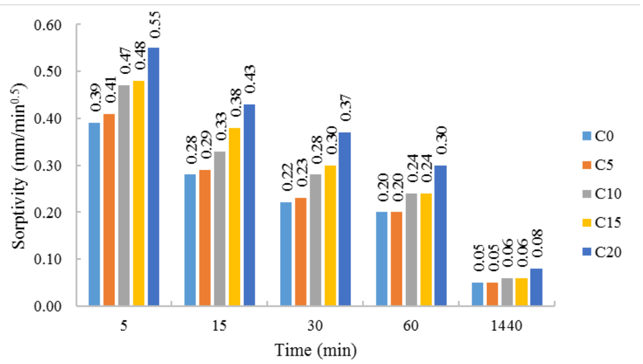

Figure 3. Sorptivity values of samples depending on time

There was an exponential relationship between the compressive strength and sorptivity values of the samples. This relationship is given in figure 5. The correlation coefficient of this relationship was 0.95. Similarly, Topal et al. (2021) [13], Siddique et al. (2016) [17], Mehta and Siddique (2017) [18] determined in their studies that there was a relationship between compressive strength and sorptivity values.

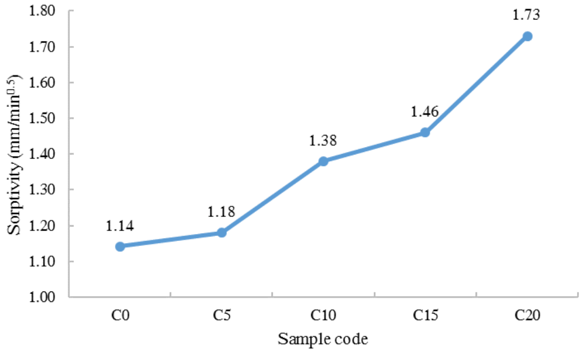

Figure 4. Cumulative sorptivity values of the samples

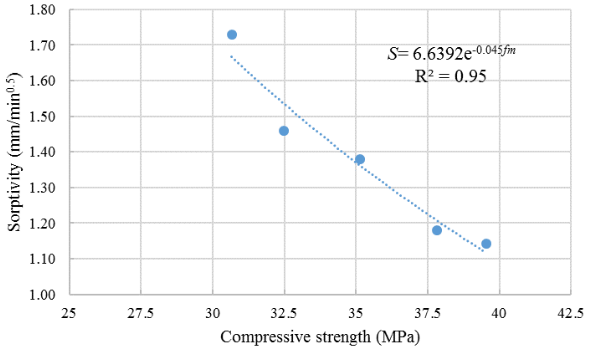

Figure 5. The relationship between the compressive strength of the samples and the sorptivity values

4. Conclusions

From the results obtained, the following conclusions can be drawn:

- As the glass powder substitution rate increased, the compressive strengths of geopolymer concretes decreased. These reduction rates were 4.6%, 12.6%, 21.7% and 28.9% for samples coded C5, C10, C15 and C20, respectively.
- The cumulative sorptivity values of the samples were between 1.14 mm/min$^{0.5}$ and 1.73 mm/min$^{0.5}$. With increasing glass powder substitution rate, the sorptivity values of the samples increased.
- There was an exponential relationship with a correlation coefficient of 0.95 between the compressive strength and sorptivity values of the samples.

Nomenclature

A : Area of loaded surface
a : Exposed surface area of the sample
d : Density of water
f_m : Compressive strength
I : Water absorption of samples
m_t : Weight change depending on the time t of the samples
P : Total maximum load
S : Sorptivity values of samples
t : Time

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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