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Mechanical properties of geopolymer concrete containing polyvinyl alcohol fiber exposed to high temperature

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HIGHLIGHTS

- The high-temperature resistance of geopolymer concrete with PVA was investigated.
- Geopolymer concretes were exposed to 20 °C, 400 °C, 600 °C and 800 °C.
- The mechanical properties of geopolymer concrete decreased with the increase of temperature.
- The use of PVA increased the mechanical properties of geopolymer concrete.

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ABSTRACT

The objective of the study is to scrutinize the high-temperature resistance of geopolymer concrete with polyvinyl alcohol fiber (PVA). F-class fly ash was used for the production of geopolymer. Polyvinyl alcohol fiber was used in 0%, 1%, and 2% by mass of the fly ash. Sodium silicate solution and sodium hydroxide were used as alkali activators. 100 × 100 × 100 mm cube and 75 × 75 × 300 mm beam samples were produced using the geopolymer concrete. The all mix was produced by curing these samples at 60, 80, and 100 °C. Then the samples were air-cured for 28 days at 20 ± 2 °C. At the end of the curing period, the samples were exposed to high temperatures at 20 °C, 400 °C, 600 °C and 800 °C. Compressive strength and flexural strength tests were conducted on the samples. The findings demonstrated that as the PVA fiber ratio increased, compressive strength and flexural strength of the geopolymer concrete increased. Furthermore, compressive strength and flexural strength of the samples that were exposed to high temperatures demonstrated reductions which samples.

1. Introduction

Cement industry faces problems due to the inability to satisfy Portland cement demand and global warming because of CO_2 emissions. Thus, alkali activated cement was developed as an alternative to Portland by the researchers [1]. Utilization of geopolymer technology would decrease the environmental damage by decreasing CO_2 emissions, and would cause less waste substance emissions to the environment by utilizing the fly ash in production [2,3]. There are two geopolymer production methods. The first method utilizes fly ash directly. In this method, it is mixed with a specific activator and then this mixture is hardened under a certain temperature to satisfy solid substance specifications. In the other indirect method, the mixture of fly ash and activators is first transformed into cement clinker and then the cement could be used for concrete production. The first method is easier for its simple technique and its applicability under low temperatures [4]. Resistance and durability of the geopolymer mortar and cement that are produced by using an adhesive obtained by the activation of fly ash are quite good [5–19]. Sarker and Mcbeath [8] investigated the resistance of geopolymer concrete elements produced with steel fiber reinforced fly ash against fire. Geopolymer concrete panels exposed to fire displayed less cracks and flaking when compared to regular cement panels. Duan et al. [9] examined the acidity and temperature effects of the geopolymer concrete that contains fly ash and metakaolin. They concluded that under acidity and high temperatures, geopolymer concrete was more durable than regular concrete. Castel and Foster [10] analyzed the adherence strength of geopolymer cement. Their study showed that the compressive and adherence strengths of geopolymer concrete that contains F-class fly ash were dependent on curing conditions. Furthermore, they reported that the performance of geopolymer concrete cured at 80 °C was similar to the regular concrete. Albitar et al. [11] researched the effects of lead slag on the strength properties of fly ash geopolymer concrete. It was found that the

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mechanical properties of the optimized geopolymer concrete mixture that contained 25% fly ash and 75% lead slag were similar to that of the geopolymer concrete that contained 100% fly ash. Martin et al. [12] scrutinized the behavior of geopolymer concrete activated with alkali in high temperatures. They observed that the strength of geopolymer concrete increased between 25 and 600 °C.

The use of fibers in geopolymer concrete increases everyday. Sanjayaan et al. [13] examined the fracture toughness of steel fiber reinforced geopolymer cement and proposed a model. They reported that the model proposed could predict fracture toughness of steel fiber reinforced geopolymer concrete. Alomayri and Low [14] investigated the mechanical properties of cotton fiber reinforced geopolymer composites. Geopolymer concrete with 0.5% cotton fiber demonstrated the best strength properties. PVA fiber ceramic composite is one of the most frequently used reinforcing material elements [15]. Ohio and Li [16] researched the compressive and tensile strengths of PVA fiber geopolymer concrete. Their study demonstrated that PVA fiber increased the strength of the geopolymer concrete. Masi et al. investigated the mechanical and thermal properties of basalt and PVA fiber geopolymer concrete. The findings of this study stressed that PVA fibers increased the flexural strength and toughness of the geopolymer composite [17]. Behzad et al. [18] researched the compressive and flexural strengths of geopolymer concrete with 2% PVA fiber. They found that the use of three activators were beneficial for high compressive strength and flexural behavior. Shaikh analyzed the mechanical properties of short fiber geopolymer composites. The study demonstrated that the fracture strength of fiber reinforced geopolymer composites were higher than the cement-based system [19]. Yunsheng et al. [20] developed a PVA short fiber reinforced fly ash geopolymer composite using extrusion technique. They have exposed this composite to freeze–thaw cycles and sulfuric acid attack. Geopolymer concrete that was exposed to sulfuric acid and freeze–thaw cycles for 1 month demonstrated only 1% strength loss.

This study examined the resistance of the geopolymer concrete produced by adding 0%, 1%, and 2% polyvinyl alcohol fiber against high-temperatures.

2. Experimental study

2.1. Materials

F-class fly ash procured from Seyit Ömer Thermal Power Plant in TURKEY was used in this study. Chemical composition and physical properties of the fly ash was presented in Table 1. River aggregate with a maximum particle diameter of 16 mm was used in the experiments. "Visco Crete Hi-Tech 36" series, high performance 3rd generation super plasticizer concrete admixture, produced by Sika corporation was used in the mixtures. As a result of test mixtures, plasticizer admixture was used in the ratio of 1.5%. Elazığ province tap water was used in all experimental studies. In the study, sodium hydroxide and sodium silicate were used to activate the alkali. The properties of sodium hydroxide and sodium silicate were presented in Tables 2 and 3.

Table 1
Physical and chemical properties of the fly ash.

Chemical composition (%)	Fly ash
$S(SiO_2)$	54.49
$A(Al_2O_3)$	20.58
$F(Fe_2O_3)$	9.27
S + A + F	84.34
CaO	4.26
MgO	4.48
SO_3	0.52
K_2O	2.01
Na_2O	0.65
KK	3.001

Table 2
Chemical properties of sodium hydroxide.

Name of the chemical	Sodium hydroxide, caustic
Chemical formula	NaOH
Molecular weight	39.9971 g/mol
CAS registration number	[1310-73-2]
Density	2.1 g/cm^3
Melting point	318 °C (591 K)
Boiling point	1.390 °C (1.663 K)

Table 3
Chemical properties of sodium silicate.

Acidity, %	0.05
Density (kg/L)	0.933–0.936
Boiling point, °C	101
Freezing point, °C	−48
Purity, %	99.99
Water solubility (g/L)	15

2.2. Mixture ratio and preparation of specimens

The aggregate was used 0–8 mm and 8–16 mm river aggregate. In addition, PVA fiber with 0%, 1% and 2% of the cement was used. The mixture ratios for the geopolymer concrete specimens prepared were presented in Table 4. To distribute the PVA fibers evenly, the aggregate, fly ash and PVA fiber were dry-mixed for 3 min. Later, they were mixed for an additional 3 min after the addition of alkali solutions. 75 × 75 × 300 mm beam and 100 × 100 × 100 mm cube specimens were prepared using the mixture ratios displayed in Table 4.

2.3. High temperature tests

All geopolymer samples in the moulds were cured in the drying oven at 60 °C, 80 °C and 100 °C for 24 h. Then the samples were taken out of the drying oven and cured at 20 ± 2 °C room temperature for the second time for 28 days. In order to dry the moisture in the specimens, the specimens were dried in drying oven for 24 h at 105 ± 5 °C. The dried specimens were exposed to 20 °C, 400 °C, 600 °C and 800 °C temperatures. These temperatures were selected for electrical and hydrocarbon fires occur at these temperatures [21–23]. The samples were kept for 1 h under each temperature [24]. The heating rate of the oven was selected as 2.5 °C/min [25–28]. Compressive strength and flexural strength tests were conducted on the samples, which were left for cooling at room temperature for a day. These tests made according to TS EN 12390-3 and TS EN 12390-5. The three samples were used for each experiment. It used the average of the three samples for each test result. Flexural strength tests made according to the centre-point loading.

3. Experimental results

The all results for compressive strength were given in Fig. 1. The percentage changes in compressive strength of geopolymer concrete exposed to the different temperatures were presented in Fig. 2. In order to better analyze the test results in this study, compressive strength of the concrete that unexposed to high temperatures, cured at 60 °C, containing 0% polyvinyl alcohol (PVA) was