

The Effect of Amount of Alkaline Solution on Fly ash and Metakaolin based Geopolymer Mortar Properties

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Abstract— This study investigated the effect of four different amounts of alkaline solution (240, 270, 390 and 435 ml) used in the production of metakaolin and fly ash-based geopolymer mortar on sample properties. In the preparation of geopolymer mortars, metakaolin obtained by the sintering at 1000 °C of kaolin clay and fly ash obtained from Kütahya Seyit Ömer (Turkey) thermal power plant was used. Geopolymer mortars were cast into 40x40x160 mm molds and cured for 5 h at 80 °C in a laboratory-type oven. The curing process of the samples was completed, and they were subjected to physical and mechanical tests at the end of the 7th day following their production. Consequently, it was determined that the ideal amount of alkaline solution in the preparation of the geopolymer mortar samples was 270 ml. In addition, the flexural and compressive strength values of the geopolymer mortars produced using 270 ml alkaline solution were 4.9 MPa and 21.8 MPa, respectively.

Keywords— fly ash, metakaolin, alkaline solution, geopolymer, mortar.

I. Introduction

There has been an increase in the demand for concrete as a building material. However, the production of cement used in the production of concrete leads to environmental pollution and limestone raw material is reduced. Approximately one ton of CO₂ is released for the production of one ton of normal Portland cement [1]. Another negative aspect of cementitious composites is that they do not show sufficient resistance to many external influences [2].

One of the studies on the production of binding agents without the use of Portland cement is uses the activation of industrial waste, such as blast furnace slag and fly ash, and pozzolans such as zeolite and metakaolin with alkalis. With a network of inorganic molecules called geopolymer, a wide range of material characterization can be accomplished through these activations [3].

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Geopolymerization is composed of amorphous, Si-O-Al and Si-O-Si bonds with a semi-crystalline polymeric structure of solid aluminosilicate oxides and alkali metal silicate solutions in a high alkaline environment and at a mild temperature [4]. However, the geopolymer reaction mechanism is not fully understood. Most recommended mechanisms include the steps of a dissolution, transport or orientation, as well as polycondensation [5].

The literature contains some scientific data from previous studies regarding the evaluation of the chemical and physical properties of geopolymer. However, extensive research is needed to determine the fracture strength of this material, the effect of different curing regimes on the hardening rate, and the concentration and dosage of alkaline [6].

This study investigated the effect of different amounts of alkaline solution used in the production of metakaolin and fly ash-based geopolymer mortar activated with 12M NaOH on the samples.

II. Material and Method

A. Materials

Fly ash from Kütahya Seyit Ömer (Turkey) thermal power plant and kaolin clay from the Kale Mine were used in the preparation of geopolymer mortar samples. Prior to use in the production of geopolymer mortar, kaolin clay was calcined in a laboratory-type electric arc furnace for 1 h at 1000 °C and at the final temperature and converted to metakaolin. Prior to the addition to the mixture, the metakaolin material was milled in a laboratory-type ball into a mill fineness of -250 µm and then sieved. Table 1 shows d₁₀, d₅₀ and d₉₀ values of laser particle size analysis of the fly ash and metakaolin.

According to the XRF analysis of the fly ash, its total values of SiO₂+Al₂O₃+Fe₂O₃ is 81.71% and the value of CaO is 4.31%. The fly ash used in line with this data is class F fly ash according to ASTM C 618-08a [7]. Silica / alumina ratio (SiO₂/Al₂O₃) by mass of the fly ash is 2.69 (Table 2). According to the data obtained from the XRD analysis of the fly ash and metakaolin, fly ash contains minerals such as quartz, magnetite, hematite and albite while metakaolin contains minerals such as quartz and mullite.

TABLE I. PARTICLE SIZE ANALYSIS OF THE MATERIALS

Sample	Particle size		
	d ₁₀ (µm)	d ₅₀ (µm)	d ₉₀ (µm)
Fly ash	15.96	84.75	231.33
Metakaolin	1.18	11.69	56.34

TABLE II. CHEMICAL COMPOSITION (XRF) OF THE FLY ASH AND METAKAOLIN

Oxide (%)	Materials	
	Metakaolin	Fly ash
SiO ₂	61.61	49.81
Al ₂ O ₃	35.02	18.50
Fe ₂ O ₃	0.89	13.40
MgO	0.06	4.56
Na ₂ O	0.03	0.55
K ₂ O	0.50	1.84
SO ₃	0.08	1.45
CaO	0.15	4.31
LOI	0.27	3.52
Total	98.61	97.94

NaOH and sodium silicate solution (Na₂SiO₃) were used as the alkaline activator in the preparation of the geopolymer mortars. The properties of these materials are presented in Table 3.

TABLE III. ALKALINE ACTIVATORS AND THEIR PROPERTIES

Sodium silicate solution (Na ₂ SiO ₃) (SS)	Sodium hydroxide (NaOH)
Na ₂ O: 26.98 (%)	M: 40 g/mol
SiO ₂ : 8.77 (%)	NaOH ≥ 99,0 (%)

B. Procedure

Liquid at four different rates was used in order to observe the effect of alkaline solutions in geopolymer mortars. NaOH which was in a pellet state during the preparation of alkaline solutions, was dissolved in purified water and made into a 12M concentration. The SS/NaOH ratio by volume of the alkaline solutions, in which sodium silicate solution and NaOH were used together was 2. Geopolymer mortars were prepared by adding alkaline solution and standard sand to the fly ash and metakaolin materials and mixed in an automatically programmable cement mixer. Afterwards, the geopolymer mortar was cast in steel molds (size 40x40x160 mm) and vibrated. Later on, the samples were placed in a laboratory type oven in order to perform a thermal curing process and they were subjected to thermal curing for 5 h at 80 °C. Table 4 shows the materials and mixture ratios used in the preparation of the geopolymer mortars.

TABLE IV. MIXTURE RATIOS OF THE MORTARS

Materials	Mixtures			
	1	2	3	4
Alkaline solution (ml)	240	270	390	435
Fly ash (gr)	270	270	270	270
Metakaolin (gr)	180	180	180	180
Standard sand (gr)	1350	1350	1350	1350

C. Tests

After the completion of the thermal curing, the samples were stored in the laboratory environment until the day of the tests. 7-day geopolymer mortars were used in the tests. The mean values of three samples from each of the sample groups were taken for the physical tests and the compressive strength tests. The apparent porosity, unit weight and apparent density values of the samples were determined according to TS EN 772-4 [8] and their water absorption values were determined according to TS EN 771-1 [9]. The mechanical properties of the geopolymer mortar were determined according to TS EN 196-1 [10].

III. Result and Discussion

The data obtained from the geopolymer mortars as physical and mechanical properties are separately presented and discussed in this section.

The apparent porosity and water absorption values (Figure 1) of the geopolymer mortars showed variations depending on the amount of the alkaline solution used. The alkaline solution led to a decrease in the apparent porosity and water absorption rates up to a certain value, while these values increased again with higher amounts of alkaline solution. Of all the samples, the lowest water absorption rate and apparent porosity values were obtained from the mortar samples with 270 ml alkaline solution. From the second mixture onwards, the apparent porosity and water absorption rates of the samples increased with an increase in the amount of alkaline solution used in the production of the geopolymer mortars. It is believed that the porosity rate of the samples increased with an increase in the amount of the solution used in the production and led to an increase in the values of the apparent porosity and water absorption. It is also believed that the apparent porosity and water absorption values of the samples produced with 240 ml alkaline solution, were the highest due to the fact that the materials could not be sufficiently compressed to the molds.

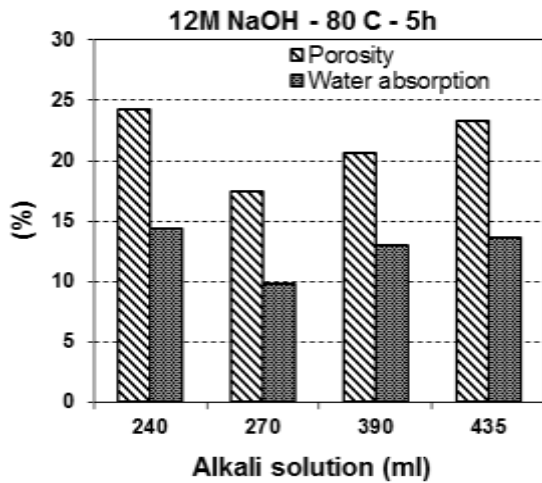


Figure 1. The apparent porosity and water absorption rates of the mortars.

It was determined that mixture sample No. 2 which had the lowest water absorption and porosity rates had the highest unite weight. In addition, the lowest bulk density values were obtained from mixture sample No. 3. On the whole, it was observed that the amounts of alkaline solution used in the production of the geopolymer mortars had no significant effect on the density values (Figure 2).

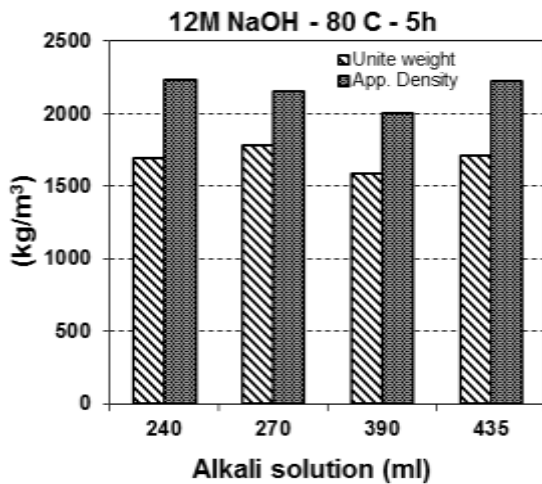


Figure 2. The bulk density and apparent porosity values of the mortars.

Figure 3 shows the flexural and compressive strength values of the mortars. According to the data obtained, it was observed that the use of alkali solution up to 270 ml, in the preparation of the geopolymer mortar samples, significantly increased the flexural and compressive strength values. On the other hand, when the amount of alkaline solution used was between 390 and 435 ml, it led to a significant reduction in the flexural and compressive strength values of the samples

It is believed that an excessive amount of alkaline solution used in the preparation of the geopolymer mortars prevents adequate geopolymerization in the matrix and therefore the mechanical properties do not fully develop.

When the amount of alkaline solution used in the preparation of the geopolymer mortars was 270 ml, the highest

flexural and compressive strength rates were 4.9 MPa and 21.8 MPa, respectively.

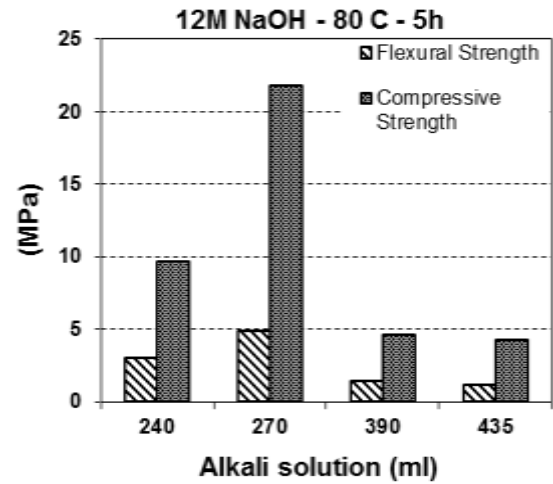


Figure 3. Flexural and compressive strength values of the mortars.

IV. Conclusion

According to the physical and mechanical properties obtained from the mortar samples produced using four different amounts of alkaline solution, 270 ml. alkaline solution was determined to be the most ideal amount for the preparation of the geopolymer mortar samples. In addition, the flexural and compressive strength rates of the geopolymer mortars produced using 270 ml alkaline solution were 4.9 MPa and 21.8 MPa, respectively.

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