Factors Influencing Compressive Strength of Fly Ash-based Geopolymer Concrete

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ABSTRACT

In recent years, geopolymer has been introduced as a novel and green alternative to the Portland cement. Compressive strength is considered as one of the important characteristics of concrete. In geopolymer concretes, according to the ingredients, several factors have been identified as important parameters affecting the compressive strength. Hence, in this experimental research, several factors affecting the compressive strength of fly ash-based geopolymer concrete including: the type of alkaline activator solution, the weight ratio of water to solid material participated in geopolymerization, sodium hydroxide concentration, the weight ratio of alkaline activator solution to aluminosilicate source, sodium silicate to sodium hydroxide weight ratio and time and temperature of curing, were studied. The obtained results indicated that using potassium hydroxide and potassium silicate as an alkaline activator solution, result in higher 28-day compressive strength compare to sodium-based alkaline activator solution. On the other hand, using sodium hydroxide and sodium silicate as an alkaline activator solution, result in higher 3- and 7-day compressive strengths and also, faster hardening. Furthermore, increasing the weight ratio of water to solid material result in significant decreasing geopolymer concrete compressive strength. Also, compressive strength is increases with increase in concentration of sodium hydroxide up to 14 M, but for 16 M, there is no remarkable changes in compressive strength. The optimum ratio of alkaline activator solution to fly ash and sodium silicate to sodium hydroxide was measured 0.5 and 1.5, respectively. Increasing the time and temperature of curing result in significant increasing 3-and 7-day compressive strengths.

KEYWORDS

Geopolymer Concrete, Fly Ash, Compressive Strength, Alkaline Activator Solution, Factors Influencing Compressive Strength.

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1. Introduction

Concrete due to its special features is the most widely used construction material after water [1], but the production process of Ordinary Portland Cement (OPC) as a main component of Portland cement concrete (PCC), has major environmental disadvantages, most notably, carbon dioxide (CO_2) emissions [2]. In recent years, geopolymer concrete (GPC) has been introduced as a novel and green alternative to the PCC capable of reducing the negative environmental impacts associated with OPC [3].

In term of technical properties, compressive strength is considered as one of the important characteristics of concrete. In geopolymer concretes, according to the ingredients, several factors have been identified as important parameters affecting the compressive strength. Therefore, it seems necessary to study the effect of these parameters on the compressive strength of GPC. Hence, in this experimental research, several factors affecting the compressive strength of fly ash-based GPC including: the type of alkaline activator solution, the weight ratio of water to solid material participated in geopolymerization, sodium hydroxide concentration, the weight ratio of alkaline activator solution to aluminosilicate source, sodium silicate to sodium hydroxide weight ratio and time and temperature of curing, were studied.

2. Methodology

The low-calcium Fly ash was used as alominosilsicate source. Sodium hydroxide (NaOH) with 98% purity, potassium hydroxide (KOH) with 90% purity, and liquid sodium silicate (Na_2SiO_3) and potassium silicate (K_2SiO_3) with SiO_2/Na_2O molar ratio of 2 and 2.1, were used to prepare the alkaline activator solution. Aggregates with granular sizes of 7-10 mm was used as coarse aggregate. The fineness modulus and sand equivalent values of the fine aggregates were measured equal to 3.0113 and 73, respectively. To study the effect of mentioned parameters on compressive strength, 28 mix designs were set. Subsequently, GPC specimens were made and subjected to compressive testing (according to BS1881: Part116 [4]).

3. Discussion and Results

The obtained results indicated that using KOH and K_2SiO_3 as alkaline activator solution, result in higher 28-day compressive strength compare to Na-based alkaline activator. On the other hand, using NaOH and Na_2SiO_3 as an alkaline activator solution, result in higher 3- and 7-day compressive strengths and also, faster hardening. This can be attributed to the distinct role of Na and K during the geopolymerization process. The effect of extra water on compressive strength is presented in Figure 1. Adding 10 kg/m^3 of extra water to the GPC mixture resulted in the highest compressive strength. By adding more extra water, the compressive strength decreased, so that in the case of 30 kg/m^3, the 3-, 7-, and 28-day compressive strengths decreased by approximately 17, 16, and 14%, respectively. This can be related to the weight ratio of water-to-solid material participated in geopolymerization. By increasing this ratio (more than the optimal ratio) the compressive strength of the GPC is significantly reduced.

Figure 2 illustrates the effect of NaOH concentration on GPC compressive strength. For NaOH concentration between 10M and 14M, the compressive strengths increase. At higher NaOH concentrations, a higher content of Al_2O_3 and SiO_2 in the raw material is dissolved in the active alkali solution, resulting in higher compressive strength. Increasing the NaOH concentration from 14M to 16M showed no significant improvement in GPC compressive strength. Increase of NaOH solution concentration above the optimal level (14M here), more hydroxide ions will be precipitated in the aluminosilicate gel immediately after initiation of the geopolymerization process. This results in lower compressive strength growth or even its decline.

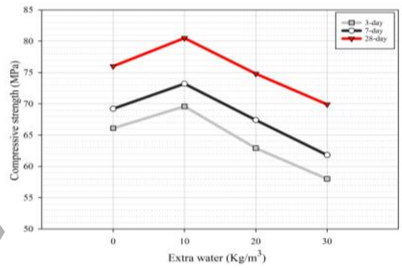

Figure 1. Effect of extra water on the compressive strength

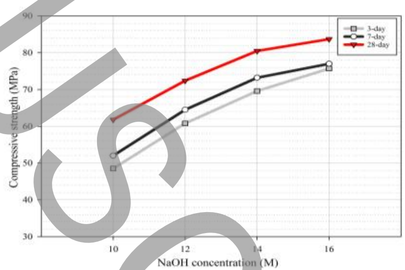

Figure 2. Effect of NaOH concentration on the compressive strength

Figure 3 shows the effect of alkaline activator solution/fly ash on GPC compressive strength. The maximum compressive strength was observed in ratio of 0.5, due to the increase in alkali content as this ratio increased. For higher alkaline activator solution/fly ash ratio, the compressive strength decreases, possibly due to water/solid ratio rise caused by increasing alkaline activator solution/fly ash ratio. Figure 4 represents the effect $Na_2SiO_3/NaOH$ on GPC compressive strength. By observing the compressive strength results, for $1<Na_2SiO_3/NaOH<1.5$, the compressive strength increase, yet when $1.5<Na_2SiO_3/NaOH<3$, the strength values decrease. Therefore, the optimal value of $Na_2SiO_3/NaOH$ ratio is considered equal to 1.5. This mainly attributed to SiO_4 (resulting from Na_2SiO_3) and Si/Al ratio changes with Na_2SiO_3 and NaOH concentrations and its effect on the geopolymerization process and consequently, compressive strength. Figure 5 and 6 illustrate the effect of curing condition on GPC compressive strength.

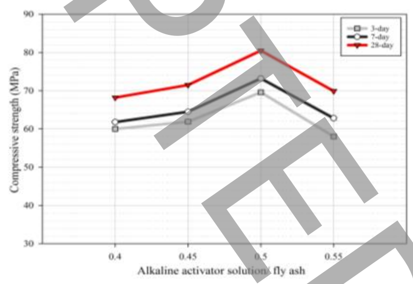

Figure 3. Effect of the weight ratio of alkaline activator/fly ash on the compressive strength

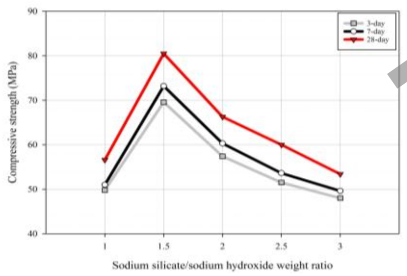

Figure 4. Effect of the weight ratio of $Na_2SiO_3/NaOH$ on the compressive strength

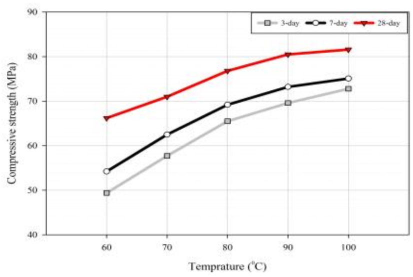

Figure 5. Effect of curing temperature on the compressive strength

The results showed that increasing the curing temperature from 60 to 90°C and similarly, increasing the curing time from 12 to 36 hours, results in faster hardening and increased GPC compressive strength. This can be attributed to the accelerating geopolymerization reaction and more dissolution of Si and Al by increasing curing time and temperature. But no remarkable changes in GPC compressive strength were observed with further increase in curing temperature to 100°C and curing time up to 48 hours.

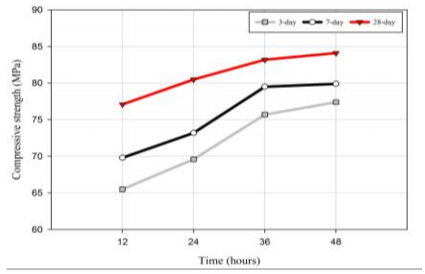

Figure 6. Effect of curing time on the compressive strength

4. Conclusions

1-Using K-based alkaline activator would result in higher 28-day compressive strength and the use of Na-based alkaline activator result in higher 3- and 7-day compressive strengths and also faster hardening.

2-Increasing the weight ratio of water to solid material result in significant decreasing compressive strength. Also, the compressive strength is increases with increase in concentration of sodium hydroxide up to 14 M, but for 16 M, there is no remarkable changes in compressive strength.

3-The optimum weight ratio of $Na_2SiO_3/NaOH$ and alkaline activator solution/fly ash in this study were 1.5 and 0.5, respectively, leading to the highest compressive strength.

4-Increasing the temperature of curing up to 90°C, result in significant increasing compressive strength. But with further increase in temperature to 100°C, no remarkable change in compressive strength was observed. Additionally, the compressive strength is increases with increase in time of curing up to 36 hours. But no significant change was measured with further increase in curing time.

5. References

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