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Setting time and 7-day strength of geopolymer mortar with various binders

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HIGHLIGHTS

- Setting time, 7-day compressive strength, 7-day flexural strength were evaluated.
- Effect of curing temperature, NaOH molarity on 7-day strength were studied.
- Increasing GGBS content in the mixture leads to decrease setting time.
- Increasing curing temperature and molarity improves compressive and flexural strength.
- Binder type has a significant effect on 7-day strength, setting time and microstructure.
- Addition of GGBS and silica fume achieves better properties compared to fly ash only.

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ABSTRACT

Concrete is considered one of the most vital materials used in construction all over the world which ordinary portland cement (OPC) is used as the binder to produce it. The harmful effect of OPC production on environment is well known. Therefore, geopolymer concrete is considered an important alternative material in construction field due to its acceptable mechanical and durability properties as well as being environmentally friendly product. The main objective of this study is to investigate setting time and 7-day properties of geopolymer mortar considering several parameters as curing temperature, sodium hydroxide solution molarity, alkaline solution to binder ratio and binder type. The evaluated properties in this study were setting time, 7- day compressive strength, 7- day flexural strength and microstructure of mortar specimens. Results indicated that binder type has a significant effect on the mentioned properties. Mixes contained 50% fly ash, 35% ground granulated slag (GGBS) and 15% silica fume yield the best properties. Also increasing curing temperature, sodium hydroxide solution molarity and decreasing alkaline solution to binder ratio improved mechanical properties of geopolymer mortar with various binders.

1. Introduction

Portland cement concrete industry has rapidly increased in recent years as a result of continuous urban development. Portland cement has harmful effect on the environment due to high amount of greenhouse gas, resulting from the high volume of carbon dioxide emitted during its production, which represents about 65% of global warming [1] where the production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere [2]. In addition, the production of ordinary portland consumes a lot of energy. Therefore, several attempts have been reported to find good alternative binders able to achieve high mechanical and durability characteristics and at the same time don't have negative effects on environment. As a result, geopolymer concrete became one of the promising alternative materials used in construction in recent years as it reduces the use of ordinary Portland cement (OPC) in the concrete industry. The term of "geopolymer concrete" was first to be known by Joseph Davidovits in 1978.

According to Davidovits, using alkaline liquid could be appropriate to react with the silicon (Si) and the aluminum (Al) in a source material of geological origin or in by product materials such as fly ash, blast furnace slag, and rice husk ash to produce binders. The most common alkaline liquid used to achieve effective geopolymerization process is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate.

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Geopolymer concrete showed high compressive strength, excellent resistance to sulfate attack, good acid resistance, low creep and drying shrinkage [3]. The strength of geopolymer depends on several factors. One of the most important factors is the nature of source materials. Geopolymers synthesised from calcined source materials, such as metakaolin (calcined kaolin), fly ash, slag etc., yield higher compressive strength when they were compared to those made from non-calcined materials, such as kaolin clay. The source material used for geopolymerization can be a single material or a combination of various types of materials [4]. Heat-cured fly ash based geopolymer concrete achieved good properties in terms of strength and durability because of its high alumina and silica content which form the precursor of geopolymer gel [5,6].

Hardjito and Rangan [7] investigated that increasing fly ash content increases workability of fly ash based geopolymer concrete with constant solution to fly ash ratio and decreases water absorption and porosity. In addition, increasing curing period even with low curing temperature enhances compressive strength, tensile strength, and modulus of elasticity [8].

Ranganath [9] reported the effect of fly ash, water content, sodium silicate-to-sodium hydroxide ratio and the duration of elevated curing temperature on the properties of geopolymer concrete while Jamkar et al. [10] observed the increase in workability and compressive strength with the increase in fineness of fly ash. The water absorption capacity of geopolymer concrete is much lesser than OPC concrete which confirms that geopolymer concrete is more durable [11].

Pradip Nath et al. [12] indicated that inclusion of additives such as slag or OPC with fly ash mixtures obviously improved early age properties. Also, increasing binder content resulted in compressive strength increase. Another study [13] investigated the effect of adding slag (GGBS) to fly ash based geopolymer concrete up to 20% of the total binder and results revealed that considerable increase in strength and a decrease in the workability were noticed in geopolymer concretes with higher GGBS. Moreover, it was reported that adding a small amount of hydrated lime provided a significant increase in the early-age strength but slightly reduced the later-age strength of the activated slag/fly ash blends [14]. In addition, it has been proved that in case of slag and fly ash blended geopolymer concrete cured at ambient temperature, slag reacts almost completely and the fly ash is partially dissolved and contributes in the occurred reaction. The principal reaction product in these pastes is a hydrated calcium silicate, like CSH gel [15].

Another research [16] carried out on fly ash/slag blended cement reported that compressive strength of 28 days of the mortar is up to 49 MPa and flexural strength is up to 8.4 MPa. The hydration products, investigated by SEM and X-ray diffraction, are mainly ettringite and C–S–H gel.

On the other hand, Rovnaník [17] evaluated the effect of curing temperature and curing time for metakaolin based geopolymer on the development of dense structure. Increasing temperature leads to accelerate formation of dense structure and accelerate geopolymerization reaction at early ages. Liew et al. [18] studied the effect of curing regimes on metakaolin geopolymer pastes. The results indicated that curing at room temperature was unfeasible therefore, heat curing is important in metakaolin geopolymer synthesis. Low curing temperature decreased the dissolution rate of metakaolin thus the geopolymerization process was slow. The chemical reaction was improved at higher temperature. Another research reported that increasing curing temperature from 30 °C to 90 °C leads to a decrease in water absorption and voids ratio of geopolymer mortar with different binders [19].

Most of studies proved that the common sodium hydroxide solution molarities used for producing geopolymer concrete ranging from 8 M to 16 M and optimum strength according to these investigations were observed at molarities between 12 M and 16 M [20,21,22]. Hamidi et al. evaluated flexural strength of geopolymer containing NaOH solution with concentrations ranging from 4 M to 18 M and it was concluded that the lowest value of strength was observed in case of using 4 M while the highest value was obtained by using 12 M [23].

Several previous investigations were carried out on heat-cured geopolymer concrete which is considered to be suitable for precast concrete members. However, the need of geopolymer concrete produced at ambient temperature will be essential to be suitable for site applications. So this work evaluates the effect of slag and silica fume addition with various percentages on fly ash based geopolymer mortar properties because researches about blended binders are limited.

The principal objective of this research is to determine setting time and 7-day properties of geopolymer mortar taking into account the effect of curing temperature, sodium hydroxide solution molarity, alkaline solution to binder ratio and binder type. The considered properties were evaluated in the terms of setting time, 7- day compressive strength, 7- day flexural strength and microstructure of geopolymer mortar. This study focused on investigating 7- day strength because several researches proved that 7-day strength represents 80–90% of the 28-day strength. [20,24].

2. Experimental program

2.1. Materials

In this study, various types of binder were used as the main silicon-alumina source materials for geopolymer mortar. These binders were class F fly ash according to ASTM C618, ground granulated blast furnace slag (GGBS) and silica fume. The used fly ash had a specific gravity of 2.2 and 95% of fly ash and slag were passing through the 45 μm sieve. The chemical composition of the used fly ash, GGBS, and silica fume is presented in Table 1. Natural siliceous sand with fineness modulus of 2.76 and specific gravity of 2.62 was used as a natural aggregate.

The used alkaline solution was a combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions which were used as alkali activators of binders. Sodium hydroxide (NaOH) in pellet form with 98% purity was dissolved in potable water to prepare the solution of the demanded concentration. Sodium silicate solution was obtained from a local commercial producer. It was colorless and had a chemical composition of Na_2O = 14.7%, SiO_2 = 29.4%, and H_2O = 55.9% and specific gravity of 1.52. In addition, high range water reducer naphthalene-based admixture (Type F) according to ASTM C494/C494M with specific gravity of 1.2 was used to improve workability of the mortar.

2.2. Test parameters and suggested tests

The parameters of this study were curing temperature, sodium hydroxide solution molarity, alkaline solution to binder ratio and

Table 1
Chemical composition of Fly ash, GGBFS, Silica fume and Portland cement.

Chemical composition	Fly ash(%)	GGBS (%)	Silica fume(%)
Silicon dioxide (SiO_2)	60	36.74	96.81
Iron oxide (Fe_2O_3)	2.50	0.40	0.45
Aluminum oxide (Al_2O_3)	28	10.78	0.25
Calcium oxide (CaO)	2.50	43.34	0.16
Magnesium oxide (MgO)	1.00	3.21	0.26
Sulfur trioxide (SO_3)	0.40	0.50	0.14
Na_2O	0.50	0.18	0.14
K_2O	1.00	0.17	0.28
Loss on ignition (LOI)	2.50	0.60	1.30