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NOTE

Strength Study on Fly Ash-Based Geopolymer Mortar

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Geopolymer is a novel binding material produced from the reaction of fly ash with an alkaline solution. In geopolymer mortar, portland cement is not utilized at all. In this research, the influence of various parameters on the short term engineering properties of fresh and hardened low-calcium fly ash-based geopolymer mortar were studied. Tests were carried out on 70.71 × 70.71 × 70.71 mm cube geopolymer mortar specimens. The test results revealed that as the concentration of alkaline activator increases, the compressive strength of geopolymer mortar also increases. Study showed that higher mixing temperature and higher curing temperature exhibited higher compressive strength in early stages and still develop with longer curing. When the samples were mixed at room temperature, the compressive strength was low at an early stage, but gradually increased and finally, had as high strength.The mass ratio of activator/fly ash of 0.416 produced the highest 28 days compressive strength for the specimen.

Key Words: Carbon dioxide, Compressive strength, Flyash, Geopolymer mortar, Global warming.

The manufacture of ordinary Portland cement (OPC) releases large amount of carbon dioxide (CO_2) to the atmosphere that significantly contributes to greenhouse gas emissions. One ton of carbon dioxide gas is released into the atmosphere for every ton of ordinary portland cement produced. Currently, the world annual ordinary Portland cement production is about 1.6 billion tons or about 7 % of the global loading of carbondioxide into the atmosphere. By the coming years, the global cement consumption is expected to reach 2 billion tons, meaning that approximately 2 billion tons of CO_2 will be released into the atmosphere. Production of 1 ton ordinary portland cement requires approximately 1.5 tons of limestone and considerable amount of both fossil fuel and electrical energy. Therefore there is a need to find alternative type of binders to produce more environmentally friendly concrete. A promising alternative is to target reduction in CO_2 emissions from cement manufacture through the substitution with fly ash (a coal combustion waste product). The use of fly ash may reduce the total energy demand for producing concrete, lower the emissions of greenhouse gasses into the atmosphere from the concrete industry and recycle the fly ash that otherwise only disposed in landfill. In this view, the use of fly ash can make valuable contribution to the reduction of environmental impact from concrete industry.

In 1978, Davidovits *et al.*[1] developed Inorganic polymeric materials and coined the term geopolymer for it. Geopolymer has the potential to replace ordinary portland cement concrete and produce fly ash-based geopolymer concrete with excellent physical and mechanical properties. Geopolymer is used as the binder to completely replace ordinary portland cement in producing geopolymer concrete. In order to produce geopolymer, low-calcium fly ash needs to be activated by an alkaline solution to produce polymeric Si-O-Al bonds. Geopolymer concrete has the potential to reduce greenhouse emissions[2] from the concrete industry by 80 %. The objective of this research was to study the engineering properties and mix design of fly ash-based geopolymer mortar with sodium-based alkaline solution as the reactor.

Fly ash is the aluminosilicate source material used for the synthesis of geopolymeric binder in this research. In this study, low calcium fly ash (Class F) from Mettur Thermal Power Plant from Mettur, India was utilized as the source material. The breakdown of the chemical composition of the fly ash is shown in Table-1. Davidovits[3] suggested the molar ratio of Si to Al of about 2 for producing cement and concrete. The fly ash is dark in colour, which is primarily due to the presence of iron oxide (Fe_2O_3). A combination of sodium hydroxide solution and sodium silicate solution was used as the alkaline activator. Analytical grade sodium hydroxide in pellets form with 98 % purity and sodium silicate with Na_2O = 12 %, SiO_2 = 30 % and water = 58 % by mass was used in this research. Sodium hydroxide solution was used as alkaline activator because it is widely available and is less expensive than potassium hydroxide solution.

TABLE-1
CHEMICAL COMPOSITION OF FLY ASH

Components	IS:3812 (1981) specifications	Fly ash used (%)
$SiO_2 + Al_2O_3 + Fe_2O_3$	70 % Min	84.71
SiO_2 (alone)	35 % Min	37.70
MgO	5.0 % Max	0.02
Total sulphur as SO_3	2.75 % Max	0.01
Alkalies as Na_2O	1.5 % Max	0.43
LOI	12 % Max	2.00
CaO	Nil	7.60
K_2O	Nil	0.05

The alkaline activator was prepared in the laboratory. In order to avoid the effect of unknown contaminants, distilled water was used to dissolve the sodium hydroxide pellets. The alkaline activator was prepared by mixing the sodium hydroxide solution with sodium silicate solution together just before the mixing of mortar to ensure the reactivity of solution. Locally available fine aggregate (river sand) in saturated surface dry condition was used.

The fly ash and the fine aggregate were first dry mixed together in for 2 min to ensure homogeneity of the mixture. The mixture was activated by adding activator solution containing sodium hydroxide and sodium silicate according to the required concentration range of 16 M and mixed for a further 10 min. Then, the geopolymer paste was cast into 70.71 × 70.71 × 70.71 mm cube moulds immediately after mixing in two layers. Each layer was tamped 25 times with a rod. All the cast specimens were vibrated on a vibrating table for 2 min to remove air voids.

Each of the test data points corresponds to the mean value of the compressive strengths of the three test cubes in a series. The standard deviations are plotted on the test data points as the error bar. A total of 14 mixtures were made to study the influence of various parameters on the compressive strength. The details of these mixtures are presented in Table-2. The ratio of sodium silicate to sodium hydroxide solution by mass was 2.5 for all mixture proportion. This ratio was fixed at 2.5 for all mixture because the sodium hydroxide solution is more expensive than the sodium silicate solution. The mass ratio of fine aggregate to fly ash was 2.5 for all mixture. The activator-to-fly ash ratio is varied from 0.376, 0.386, 0.396 and 0.416. The test results on the setting time of geopolymer paste shows that the fresh fly ash based geopolymer mortar could be handled up to 2 h without any sign of setting for curing temperature ranging from 65 ºC to 80 ºC. Similar results were obtained by previous research conducted by Hardjito *et al.*[4]. Furthermore, it was observed that fresh fly ash-based geopolymer paste did not harden at room temperature for at least one day.

TABLE-2
COMPRESSIVE STRENGTH RESULTS

W/b ratio	Days of curing	Compressive strength	
		Conventional mix	Geo-polymer mix
0.376	7 days	11 MPa	10 MPa
	14 days	12 MPa	13 MPa
	28 days	14 MPa	15 MPa
0.386	7 days	13 MPa	12 MPa
	14 days	15 MPa	15 MPa
	28 days	16 MPa	17 MPa
0.396	7 days	15 MPa	16 MPa
	14 days	17 MPa	18 MPa
	28 days	19 MPa	20 MPa
0.416	7 days	19 MPa	20 MPa
	14 days	22 MPa	23 MPa
	28 days	24 MPa	26 MPa

Conclusion

This paper presented the study of geopolymer mortar cured in elevated temperature. From the experimental results reported in this paper, the following conclusions are drawn:

(a) Higher concentration of sodium hydroxide solution results in a higher compressive strength of geopolymer mortar.

(b) The activator-to-fly ash ratio, by mass of 0.40 produced the highest compressive strength.

(c) Curing temperature plays an important role in the geopolymerization process.

(d) As the ratio of water-to-geopolymer solids by mass increases, the compressive strength of geopolymer mortar decreases.

(e) By replacing cement with fly ash the emission of CO_2 is reduced considerably which in turn reduces the effect of global warming.

(f) Thus the Geo-polymer mix has a higher compressive strength than conventional mix which is 8 % to be accurate. As similar to earlier studies the fly ash based geo-polymer mortar gains more strength on time.

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