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Original Research Paper

Ecofriendly Geopolymer: An Alternative Construction Material

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ABSTRACT

Geopolymer is an inorganic alumina silicate polymer synthesized from predominantly silicon and aluminium materials of geological origin or byproduct materials like fly ash. The use of geopolymer technology substantially reduces the CO_2 emissions by the cement industries and utilizes the waste materials such as fly ash. The fresh geopolymer concrete has stiff consistency and high viscosity. The chemical reaction period is substantially fast. To evaluate the performance of geopolymer mortar, the tests conducted are cube compressive strength, cylinder compressive strength and split tensile strength. Strength tests revealed that the compressive strength of geopolymer mortar cubes increases 2 to 2.5 times the compression strength of the control mortar. The main advantages of the present investigation are 100% fly ash utilization, complete elimination of cement, no water/autoclave curing, low water absorption and high compressive strength.

INTRODUCTION

The production of geopolymeric cement does not require any calcination of calcium carbonate, unlike ordinary Portland cement, which results from the calcination of limestone (calcium carbonate) and silico-aluminious materials. The geopolymer mortar is widely used in different fields, for example, it is used to immobilize toxic metal wastes such as arsenic, antimony, lead, copper, zinc, mercury, etc. (Van Deventer & Lorenzen 1977). It is inexpensive and used in durable encapsulation of hazardous wastes such as asbestos and radioactive wastes (Davidovits 2002a). It is also used for building components such as bricks, ceramic tiles, etc. (Davidovits 1994). Further, it is also used in industrial pavements, highways, and pavement blocks. Even for repairing runways made of concrete, geopolymer mortar is used. In addition to concrete products such as railway sleepers, sewer pipes, prefabricated units for the housing market, etc., the geopolymer mortar has more advantages than other mortars (Djwantoro et al. 2004a). It is economical and eco-friendly. It increases compressive strength (Djwantoro et al. 2004b) and water absorption is proved to be very less. The green house gases do not have any effect on this material. With regard to the properties, it has got excellent chemical, acid and fire resistance. Autoclave curing is completely eliminated. Besides, it is more durable when compared with other mortars. The manufacturing of geopolymer concrete is carried out using the usual concrete technology methods. The worldwide production of fly ash up to December 2008 is listed in Table 1.

GEOPOLYMERIC BINDER REACTION AND PRECURSOR STEPS

Thermal activation: The first step to obtain a certain reactivity of clay minerals is the thermal activation process in which the dehydroxylation of the clay minerals leads to an unstable and nearly amorphous state of the solid.

Alkali activation: Secondly, alkali hydroxide solutions disintegrate this solid network to produce reactable silicate and aluminate monomers (Lee 2003).

Reactive setting: The third step can be characterized as the real setting period in which the silicate and aluminate monomers (Matthew & Brian 2003) condense to a stable polymer as shown in the flowchart (Fig. 1).

FLY ASH BASED GEOPOLYMER MORTAR

As powdered coal passes through the high temperature zone in the furnace, the volatile matter and carbon are burnt off. But most of the mineral impurities such as clays, quartz and feldspar will melt at high temperature (Lee & Van Deventer 2004). At present the fly ash production amounts to approximately 80-120 million tonnes per year in India, which is likely to exceed 200 million tonnes by the end of 2010 and therefore, will pose a serious problem as far as space and pollution hazards are concerned. It is to be noted that fly ash, one of the possible sources for making geopolymer binders, is available abundantly worldwide, and yet its usage to date is very limited (Davidovits 2002b). Composition of fly ash used in the study as determined by X-Ray fluorescence (mass %) is given in Table 2.

The geopolymer mortar consists of fly ash, sand and fly ash binder ratio. The geopolymer mortar is produced by totally replacing the ordinary Portland cement (OPC). Therefore, the use of geopolymer technology not only reduces the CO_2 emissions substantially in the cement industries, but also utilizes the waste materials such as fly ash. Use of fly ash in the manufacture of geopolymers is an important strategy in making mortar.

MATERIALS AND METHODS

The cube and cylinder specimens (total 216 specimens) were cast using fly ash, sand 1:3 mix ratios and binder to fly ash ratio of 0.45. The binders used were sodium hydroxide and sodium silicate. The

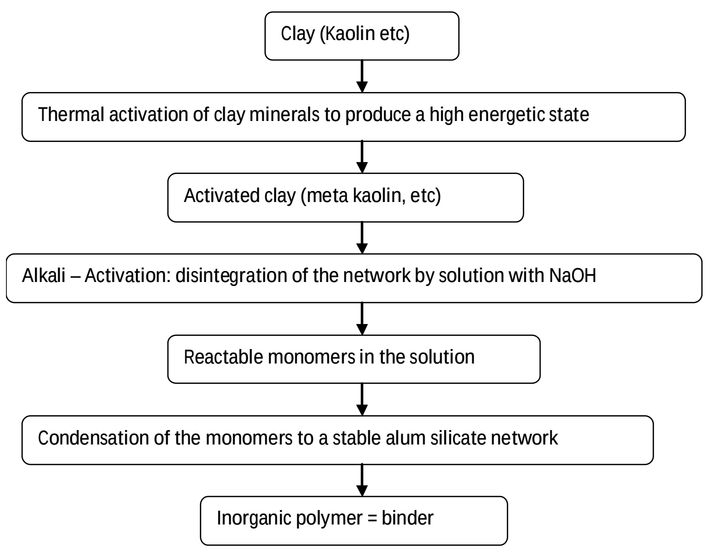

Fig 1: Polymer network flowchart.

Table 1: Worldwide production of fly ash.

Country	Production (Million tonnes)	Utilization (Million tonnes)
Australia	19	<3
China	>110	16
Germany	38	14
India	>90	4
Japan	15	5
Russia	72	7
South Africa	38	27.9
Spain	18	3
U.K.	20	8
U.S.	70	10

Table 2: Composition of fly ash.

Composition	Percentage
SiO_2	53.36
Al_2O_3	26.49
Fe_2O_3	10.86
CaO	1.36
Na_2O	0.37
K_2O	0.80
TiO_2	1.47
MgO	0.77
SO_3	1.70
Loss on Ignition	1.39

cube specimen size was 100mm × 100mm × 100mm. The cylinder and split tensile specimen size was 50 mm diameter and 100 mm height. The 5M solution mortar specimens were cast using activated fly ash and unactivated fly ash. The details of test specimens are shown in Table 3. Before utilizing the binder solutions in the mortar, the chemicals and the solutions were mixed and kept 24 hours in room temperature. Only after this process, the mixture was used so that it gives the correct binding action. During moulding, the specimens were mechanically vibrated. The control specimen cubes were cast using cement, sand with 1:3 mix ratio and water cement ratio of 0.5. After 24 hours, the geopolymer specimens and control specimens were removed from the mould. The geopolymer specimens were cured by air for 7 days, 14 days and 28 days. The control specimens are cured by water for 7 days, 14 days and 28 days. After specified period of curing, the tests for cube compressive strength, cylinder compressive strength and split tensile strength were conducted on specimens cast with fly ash with heating and without heating.

RESULTS AND DISCUSSION

The comparison of cube compressive strength is shown in Fig. 2. An average of 6 values for control mortar and 9 values for geopolymer mortar have been considered for plotting these diagrams. The comparison of cylinder compressive strength is shown in Fig. 3, and comparison of split tensile strength in Fig. 4. Comparison of compression strength of cubes and cylinders cast with fly ash with and without heating is shown in Fig 5. Based on the experimental results following observations were made:

1. The strength of FLY ASH BASED geopolymer mortar is more than 2 to 2.5 times the strength of control mortar cubes.
2. The compressive strength of fly ash mortar with heating is more than 10 to 20% to that of without heating.
3. The compressive strength of geopolymer mortar does not vary much with age. This clearly shows that the geopolymer precast products can be made available swiftly to meet any emergency situation.

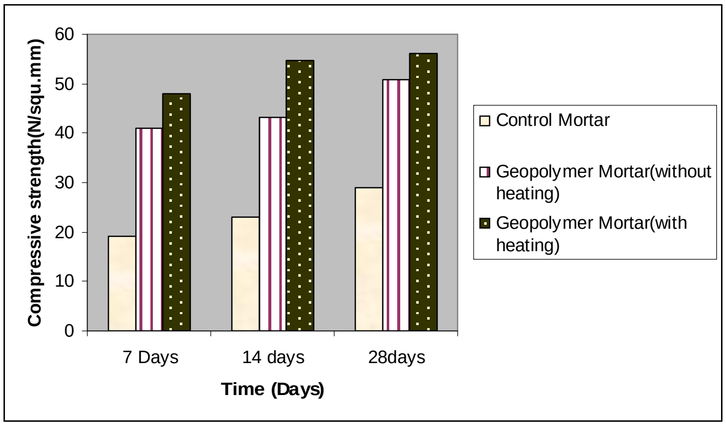

Fig. 2: Comparison of cube compressive strength.

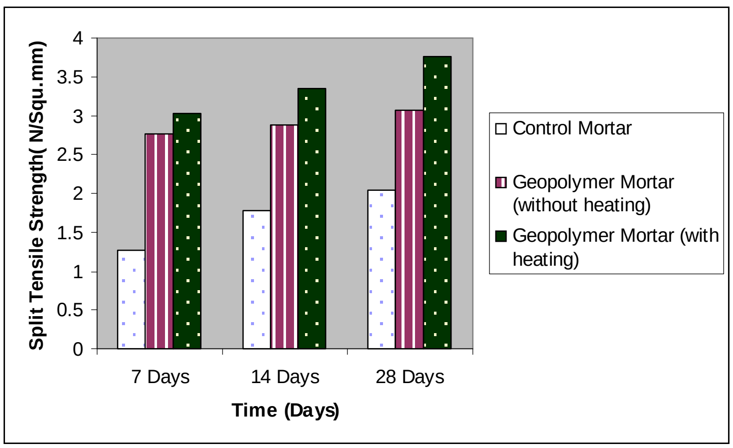

Fig. 3: Comparison of cylinder strength.

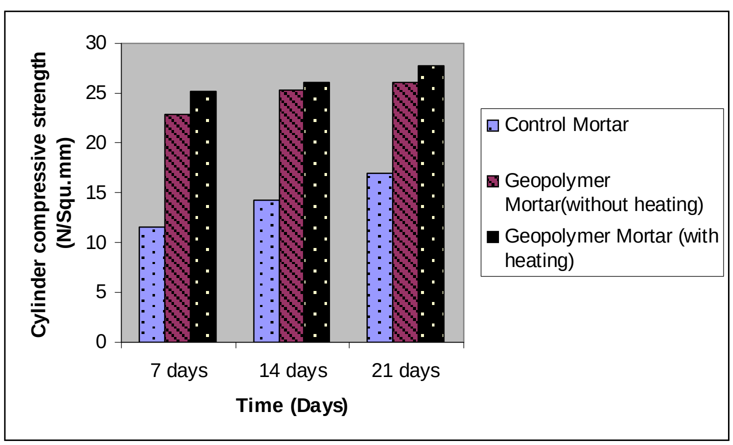

Fig. 4: Comparison of split tensile strength.

Table 3: Details of test specimens.

Sl. No	Type of test	No. of specimens	Details
1.	a. Cube compression test	18	Control mortar specimen
	b. Cylinder compression test	18	
	c. Split tension test	18	
2.	a. Cube compression test	27	Geopolymer mortar specimen (without heating of fly ash)
	b. Cylinder compression test	27	
	c. Split tension test	27	
3.	a. Cube compression test	27	Geopolymer mortar specimen (with heating of fly ash)
	b. Cylinder compression test	27	
	c. Split tension test	27	

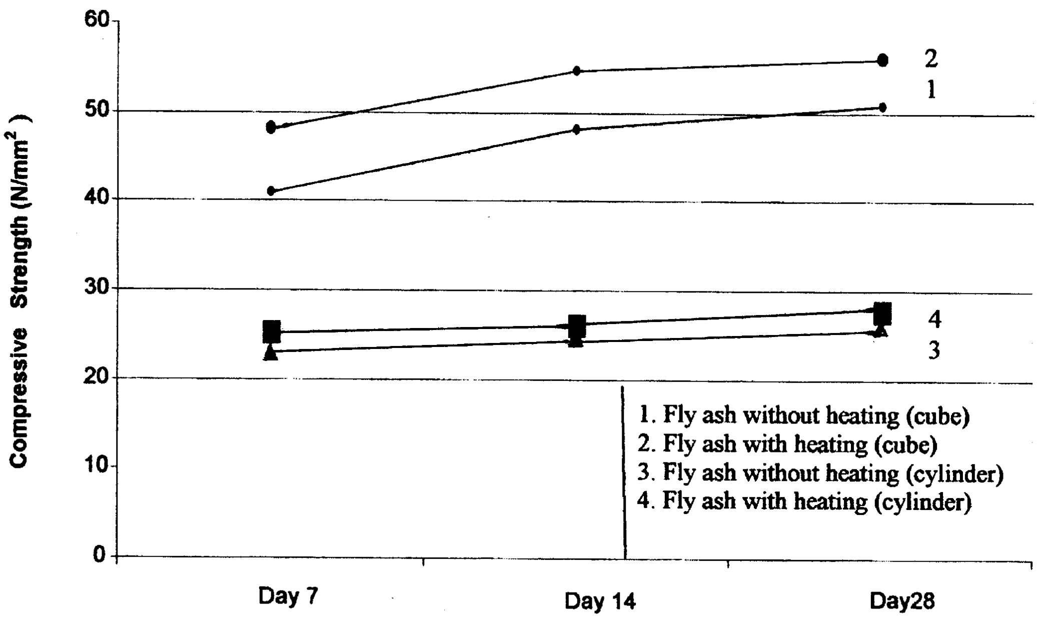

Fig. 5: Comparison of cube and cylinder strength.

4. An increase in the curing temperature increase the concrete compressive strength, especially at temperature up to 60°C

From the application and engineering point of view, research into the utilization of wastes/materials and in particular those from the mineral industries requires immediate attention. This paper has focused on chemically and structurally durable formula and using easily available bonding material.

Although fundamental research would provide a better understanding of the bonding mechanism and subsequent leaching behaviour of immobilized metals from these structures, there is a dire need for immediate application oriented research in order to consolidate and practically evaluate the progress made hitherto in this field.

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