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Influence of Processing Temperature and Molarity on the Strength Development of Geopolymer Mortars

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ABSTRACT
Geopolymer is a new group of materials produced by the alkaline activation of alumino-silicate compounds. The interest of this project is to investigate the influences of synthesis parameters such as processing temperature, molarity of NaOH and ratio of Na_2SiO_3/NaOH on compressive strength of a geopolymer mortars. Geopolymer samples are prepared using varying concentrations of alkaline activators along with varying precursors such as silica fume, ground granulated blast furnace slag (GGBS) and fly ash. With sol/solid = 0.2 (as arbitrary), Na_2SiO_3/NaOH = 2.5 (as arbitrary) and NaOH molarity of 7M and 11M geopolymer samples are prepared and cured at different curing conditions. Compressive strength of these samples is found out and the optimum mix proportion is found out. Finally, an early strength development in geopolymer concrete could be achieved by the proper selection of curing temperature and the period of curing.
Keywords - About five key words in alphabetical order, separated by comma

I. INTRODUCTION

Geopolymers also referred to as Aluminosilicate Inorganic Polymers (AIP) and Alkali Activated Cement (AAC) are based on alkali soluble aluminium and silicon precursors (aluminosilicates). Structural differences and resulting properties of geopolymers can be explained by variation in the source silicon to aluminium amorphous molar ratio, alkali metal cation type and concentration, water content and curing regime amongst other variables in the geopolymer synthesis.

Geopolymers to be part of the alkali activated family of cementitious materials, characterised by low calcium content. Early work by Purdon (1940) using sodium hydroxide solutions to activate ground blast furnace slags (GBFS) produced cementitious materials suitable for concrete production. Later workers showed that these materials were basically a calcium silicate hydrate based gel (Roy 1999; Wang and Scrivener 1995) with silicon present mainly in one dimensional chains and some substitution of aluminium for silicon and magnesium for calcium whereas the geopolymer gel is a three dimensional alkali alumina-silicate framework structure (Duxson et al. 2007). Calcium (~3 wt%) in geopolymers acts as an accelerator for setting enabling ambient temperature curing of geopolymers to take place (Temuujin et al. 2009).

The defending characteristic of a geopolymer is that the binding phase consists of an alkali alumina silicate gel, with aluminium and silicon linked in a three dimensional tetrahedral gel frame framework of silicate and aluminate groups that is relatively resistant to dissolution in water. Charge balancing of the aluminate group is by alkali metal cations typically sodium and potassium.

Geopolymer may be considered a composite of partially reacted precursor, typically metakaolin or fly ash, sodium reaction products, and pore space. Some of the pore space is filled with aqueous alkaline solution. The pore volume can be in the order of 1-40 %. The solid reaction product is amorphous and is the inorganic polymer component (Maitland et al. 2011).

The hardened geopolymer has an amorphous glass-like structure which is capable of modification by aggregates, reinforcing agents and process aids during the mixing and shaping process. Potential applications include concretes and mortars (in competition with OPC), specialised high temperature applications such as fire and heat resistant products (with superior durability to OPC), binders for encapsulation of toxic chemicals and nuclear waste and chemically resistant products (Rostami and Brendley 2003; Nugteren et al. 2011).

There are many occasions where concrete is exposed to elevated temperatures like fire exposure, exposure from thermal processes, exposure from furnaces, nuclear exposure, etc.. In such cases, understanding of the behaviour of concrete and structural members exposed to elevated temperatures

is vital. Even though many research reports are available about the behaviour of OPC concrete at ambient temperatures, only limited information available is about the behaviour of geopolymer concrete after exposure to elevated temperatures.

The present research work focuses on the influence of different precursors and moilarity variables on the compressive strength of the geopolymer mortars. The project also explores the influence of processing temperature on the compressive strength of the geopolymers.

II. EXPERIMENTAL INVESTIGATION
2.1Materials
The following materials were chosen for the foregoing investigation i) Ennore sand ii) Ground granulated blast furnace slag iii) silica fume and iv) rice husk ash. The materials were collected from the local commercial market Vijayawada, India.

2.2 Preparation of Alkaline solution
The compressive strength of geo-polymer concrete is examined for the mixes of varying molarities of Sodium hydroxide (8M and 11M). The molecular weight of sodium hydroxide is 40. To prepare 14M i.e. 14 molar sodium hydroxide solution, 560g of sodium hydroxide flakes are weighed and they can be dissolved in distilled water to form 1 liter solution. For this, volumetric flask of 1 liter capacity is taken, sodium hydroxide flakes are added slowly to distilled water to prepare 1liter solution. The weights to be added to get required molarity

2.3 Manufacturing and casting of geopolymer mortar
The conventional method used in the making of normal concrete is adopted to prepare geo-polymer mortar. First, the ennor sand, GGBS and silica fume are mixed in dry condition for 3-4 minutes as aforementioned proportions and then the alkaline solution which is a combination of Sodium hydroxide solution and Sodium silicate solution is added to the dry mix. The mixing is done about 6-8 minutes for proper bonding of all the materials. After the mixing, the cubes are casted with the mixes A1 to A9 by giving proper compaction. The sizes of the cubes used are of size 75mmX75mmX75mm.

2.4 Compressive strength
The compressive strength of all the mixes was examined at the age of 28 days ambient curing and also for 30mins, 1hour, 7hours and 24hours in oven curing by maintain temperature 105°C or the various replacement levels of precursors contents and prepared with different molarity of alkaline activator. the values of average compressive strength

for different replacement levels of precursors such as GGBS, silica fume and rice husk ash and prepared with different concentration of alkaline activator (8M and 11M) at the end of the different processing temperatures as mentioned.

III. RESULTS AND DISCUSSION
The compressive strength of all the mixes was examined at the age of 28 days ambient curing and also for 30mins, 1hour, 7hours and 24hours in oven curing by maintain temperature 105°C or the various replacement levels of precursors contents and prepared with different molarity of alkaline activator. The values of average compressive strength for different replacement levels of precursors such as GGBS, silica fume and rice husk ash (as aforementioned) and prepared with different concentration of alkaline activator (8M and11M).

Table 3.1. Test data on oven curing at 105°C for 8M

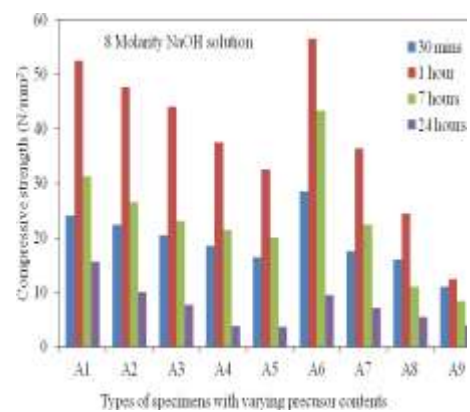| Samples	Compressive strength (N/mm²)			
	30mins	1hr	7hr	24hr
A1	24.08	52.45	31.24	15.55
A2	22.45	47.64	26.55	10.05
A3	20.41	44.05	23.05	7.65
A4	18.45	37.45	21.45	3.88
A5	16.44	32.45	20.05	3.65
A6	28.45	56.45	43.35	9.55
A7	17.54	36.4	22.45	7.12
A8	16.05	24.45	11.05	5.45
A9	11.05	12.4	8.45	4

Figure 3.1 Compressive strength of mortars prepared with different precursor content and 8M alkaline activator

Table 3.2. Test data on oven curing at 105°C for 11M

Samples	Compressive strength (N/mm^2)			
	30mins	1hr	7hr	24hr
A1	27.5	59.18	34.61	18.4
A2	25.25	50.61	28.98	11.43
A3	24.08	48.51	26.53	6.94
A4	22.45	39.55	24.49	4.89
A5	18.77	36.75	20.25	4.05
A6	30.05	63.88	48.4	10.05
A7	23.27	40.65	24.49	9.45
A8	16.33	38.85	13.06	6.1
A9	13.06	21.45	10.45	4.08

Table 3.3. Test data on Ambient curing for 8M and 11M

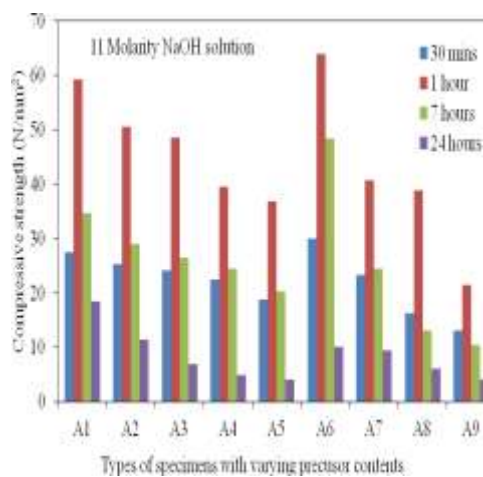| Samples	Compressive strength for 28days at ambient curing	
	8M	11M
A1	49.85	52.44
A2	45.55	46.94
A3	40.45	43.18
A4	30.75	34.53
A5	28.42	30.54
A6	26.34	29.34
A7	24.22	26.12
A8	20.48	24.81
A9	7.24	8.57

Figure 3.2 Compressive strength of mortars prepared with different precursor content and 11M alkaline activator

Fig 3.1 shows the variation of compressive strength of mortar prepared with different precursor content as mentioned in the Table 4.2. Increasing the GGBS content increases the compressive strength of the GGBS based geopolymer blends. It can be that the compressive strength of geopolymer matrix increase with increase in the GGBS content. This can attributed due to the higher alumina content dissolved in the alkaline solution. Significant differences were noted in the compressive strength development of the geopolymers with various precursors' contents. The figure 3.2 shows that the maximum compressive strength was obtained when the partial replacement of RHA (as 5%) in blends.

Figure 3.1 also shows that the compressive strength was influenced by the processing temperature. By comparison, higher strength was obtained in the case of 1hour curing in the oven by maintaining 100°C than the curing period of 30mins, 7hours and 24hours (by maintaining temperature of 100°C). This can be attributed to the effective and efficient geopolymerization in the geopolymer matrix takes place. For higher curing period greater than 1hour, there is a chance of formation of etched holes or micro cracks in the blends which effects the strength. Similar trend was observed in geopolymer mortar contains different molarity of alkaline activators 11M.

IV. CONCLUSIONS

From the experimental investigation on strength development of geopolymer mortars with varying precursor content, curing conditions and alkali-activator concentration, the following broad conclusions can be drawn.

Geopolymer mortars can prepared without conventional cement and curing at ambient or thermal conditions.

The compressive strength of geopolymer mortars increased with increase in the GGBS content. This can attributed due to the higher alumina content dissolved in the alkaline solution.

Significant differences were noted in the compressive strength development of the geopolymers with various precursor contents.

The maximum compressive strength was found in the case of combination of GGBS and RHA (A6 mix), this is due to the presence of higher alumina content in GGBS and higher Silica content in the RHA. However, higher percentage replacement of RHA leads to reduce the denseness of the geopolymer matrix which leads to reduction in strength.

There was increase in compressive strength with the increase in the molar concentration of alkaline activator. This increase may be attributed to high dissolution of precursor content (alumina and

silica) which is prompted by higher concentration of sodium hydroxide.

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