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Mortar strength of Low calcium Flyashbased Geopolymer

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Abstract: *Development of an alternative to conventional cement binder has become the essential need in the construction industries. Production of the conventional constituents of concrete particularly Portland cement exploits significant amount of natural resources and emits equivalent amountof carbon dioxide to the atmosphere. Research made on making binder without cement has come to a viable level of developing geopolymers.Industrial wastes and by products that are pozzolanic in nature are being used as source material and activated using alkaline solutions to use as binder. Considerable research has been carried out to study about the performance of geopolymer concrete with steam curing or hot curing which are feasible for precast concrete and practically not viable for conventional construction activities. However, there is not much data available on themortar strength.Abasic study on the strength characteristicsof low calcium flyash based geopolymer with 8-16M molar concentration of Sodium hydroxide and 1.5-3.0 liquid ratios of sodium silicate to sodium hydroxide. Both hot oven curingat 65^oC and ambient curing at room temperature aremade. The results are compared and the optimum molarity for maximum strength is reported.*

Keywords: *Geopolymer, low calcium flyash, ambient curing, hot curing, mortar strength*

I. Introduction

The demand for concrete is increasing day by day and at the same time, the environmental aspects of concrete are being discussed to develop an eco-friendly binder. As the CO_2emission and the exploitation of natural resources in producing cement and hence the concrete, lead to environmental degradation, there is a need to arrive an alternative to cement binder. Cement is an important ingredient of the conventional concrete used in centuries and responsible for binding property cannot be simply ignored. However, in 1980s, Joseph Davidovits, a French scientist initiated research on linear organic polymers and later the alumino-silicate solid state chemistry resulting in the development of new binder by polymerization called geopolymer.

Geopolymers are mineral substances obtained synthetically by chemical processes but are actually also found in nature, which take millions of years (Davidovits and Morris, 1988) to form. A hypothesis formulated about the use of geopolymer binders during the Egyptian construction of 4000 years old ancient monuments is the synthetic stones of reagglomerated materials.A mineral substance such as disintegrated or naturally disaggregated rock and giving it a compact structure using a binder, a geological glue that will agglomerate (or re-agglomerate) the mineral particles is involved. The same concrete technology was used during the erection of Egyptian pyramids by laying geopolymer mixes (with a limestone aggregate) into formwork; individual blocks were thus produced step by step. Thus, Geopolymer is basically an inorganic alumino-silicate compound, synthesized from certain source materials. Joseph Davidovits (2011) explained his pioneer works of geopolymers based on, kaolinite/hydrosodalite, metakaolin, calcium, rock, silica, flyash, phosphate and organic minerals.

The source material and the blend of sodium hydroxide (or potassium hydroxide) solution and sodium silicate (or potassium silicate) solution termed as alkaline solutionare the two important constituents of GP.Source materials like low calcium flyash (Djwantoro et al., 2003 and Rangan, 2008), GGBS (Parthiban and Saravanaraja Mohan, 2014), Metakaolin,calcium, rock, silica, flyash, phosphate and organic minerals (Joseph Davidovits, 2011), mineral powder (Huihong Liu et al, 2014), red mud with flyash and micro silica (Abhishek and Aswath, 2012) and high calciumflyash (Shankar and Khadiranaikar, 2012: Ashley Russell et al, 2015 and Prinya Chindaprasirt et al,2013) have been used in the development of GPC.Mostly used flyash that is rich in silica and alumina reacts with alkaline solution and forms aluminosilicate gel that acts as the binder and by thermal activation produces GPC.

Flyash is abundantly available, but to date its utilization is limited inspite of the specifications (IS: 3812-1981).The source material is mixed with an activating solution which liberate the Si and Al and possibly with the additional source of silica (sodium silicate). The various parameters that influence include, ratio of alkaline liquid/flyash (by mass), molarity of sodium hydroxide, liquid ratio sodium silicate to sodium hydroxide, water content of mixture, dosage of super plasticiser, mixing time, rest period prior to curing, handling time, curing temperature, curing time, curing method and age of concrete.

Joseph Davidovits (1994) reported that, Geopolymer cement hardens rapidly at room temperature and provides compressive strength of 20MPa after only 4 hours at 20^{o}C and the 28 day strength in the range of 70-100MPa. Mallikarjuna and Gunneswara (2015) investigated that combination of flyash and GGBS resulted in decreased final setting time and increased mortar compressive strength.Ubolluk and Chindaprasirt (2009) reported that mixing sequence had some effects on geopolymerisation and strength of mortar. SEM studies suggested that geopolymerisation started with gel formation in colloidal form varying in sizes from less than 1μm to about 20μm. As more gel was formed, it overwhelmed remaining flyash particles and formed a continuous mass of gel resulting in relatively dense geopolymer matrix.Mallikarjuna Rao and Gunneswara Rao (2015) observed that increase in sodium hydroxide increases compressive strength of geopolymer mortar made of combination of flyash and GGBS.

Fernando et al (2007) reported that the mud based binders possess extremely high tensile strength in 7days of curing. Heah et al (2012) studied the kaolin-based geopolymers and concluded that kaolin geopolymers showed good volume stability with no crack and disintegration in water which proved the existence of bonding.Zhu Pan and et al (2009) reported that the strength of mortars after the exposure to elevated temperature (800^{o}C), some times decreased but other times increased. It is believed that the two opposing processes occur in mortars that (i) further geopolymerisation and/or sintering at elevated temperatures leading to strength gain and (ii) the damage to the mortar due to thermal incompatibility arising from non-uniform temperature distribution.The economic benefits and contribution of geopolymer concrete to sustainable development have been outlined (Sourav et al, 2014) and it is realised that no Indian Standards are available and so a detailed study on the chemistry behind the polymerization is needed.

II. Experimental Investigation

Low calcium flyash (ASTM Class F) collected from Mettur Thermal power station (Coal based) is used as the source material. The composition of the flyash and cement (OPC 43) is shown in Table 1.For its wide availability and less expensive, the sodium based solution is used as the alkaline activator shown in figure 1. The 8M, 10M, 12M, 14M and 16M molar concentration of Sodium hydroxide with liquid ratios 1.5, 2.0, 2.5 and 3.0 are considered for the preparation of alkaline solution. For each mix of the alkaline solution, the solution is mixed 24 hours prior to use. The mass of NaOH solids is 262 gms/kg of NaOH solution.Knowing the molecular weight of NaOH (40) and with the decided molar concentration (8M, etc.,), the weight of NaOH solids required per liter of solution is $Mole \times Molecular\ \ weight = 8 \times 40 = 320\ gm$. Similarly, the details for other molarities are given in Table 2 (Rangan, 2008). Based on the liquid ratio, the quantity of sodium silicate is also calculated.

Table 1 Chemical Composition of low calcium flyash and cement

Material	Mass (%) of various elements									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	Na_2O	K_2O	TiO_2	MgO	SO_3	LOI
Flyash	54.40	25.64	11.32	02.03	00.41	00.73	01.53	00.92	01.70	01.32
Cement	22.60	04.30	02.30	64.30	00.05	00.04	-	02.20	02.10	02.10

Fig. 1 The constituents of alkaline solution

Table 2 Mass of NAOH solids in various molar solutions

No	**Molarity of NaOH**	**Mass of NaOH solids per kg of NaOH solution(gm)**	**Mass of NaOH solids per litre of solution (gm)**
1	8M	262	320
2	10M	314	400
3	12M	361	480
4	14M	404	560
5	16M	444	640

The determination of the consistency of the flyash based geopolymer paste is first considered as per IS:4031-1988(Part-4), using Vicat's apparatus. The cement with water and flyash with alkaline solutions are separately dealt respectively. The standard consistency for various molar concentrations and liquid ratios are presented in Table 3.

Table 3 Consistency of paste

No	Molarity of NaOH	Consistency of paste				
		GP with various liquid ratios of alkaline solution				Cement
		1.5	2.0	2.5	3.0	29%
1	8M	30%	30%	30%	30%	
2	10M	31%	31%	31%	31%	
3	12M	32%	32%	32%	32%	
4	14M					
5	16M	33%	33%	33%	33%	

Samples of flyash and sand used are shown in figure 2. Standard mortar (1:3) is prepared by taking about 555gm of standard sand and 185gm of flyash and mixing with alkaline solution (one fourth of the consistency plus 3% by combined weight of sand and flyash). The mortar is then filled into the standard cube moulds (70.7mm size) and compacted well in vibrator. In the next day, after 24 hours of casting, a set of specimens are kept in an oven for hot curing at 65^{o}C for 24 hours and another set specimens of same batch under ambient curing at room temperature. Totally about twenty different mixes of GPC and one mix of conventional 43 grade cement are considered.

The mortar cubes are tested (figure 3) in 3 and 28 days of casting for hot curing and on 28 days for ambient curing appropriately after rest period. In parallel, mortar compressive strength based on conventional 43grade OPC is also obtained. The test results of ambient curing is presented in figure 4 and that of hot cured is given in figure 5. The comparison of mortar compressive strength of ambient cured and hot cured samples is presented in figure 6.

Fig.2 Samples of flyash and sieved sand

Fig.3 Testing of cubes

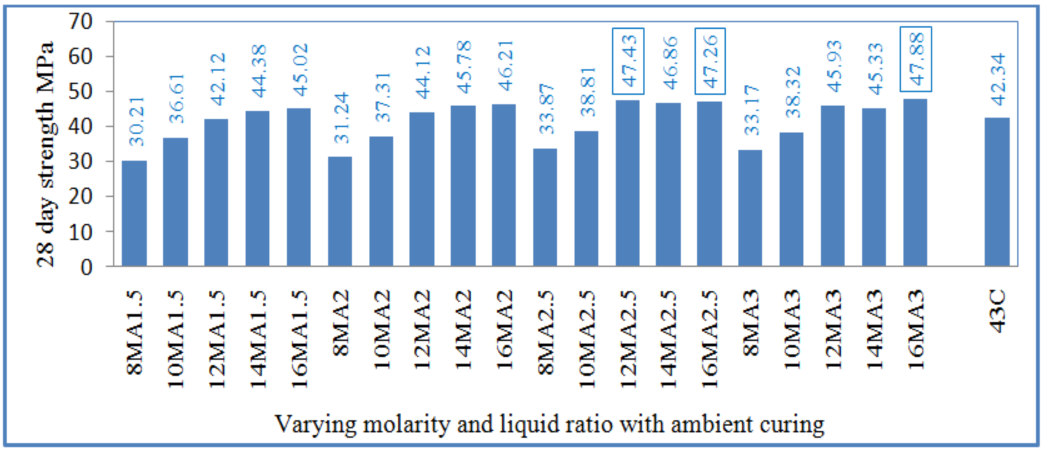

Fig.4 Comparison of strength for ambient cured mortar

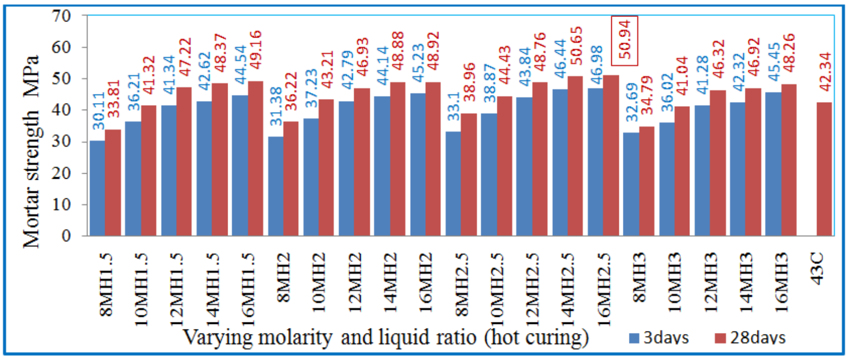

Fig.5 Comparison of strength for hot cured mortar

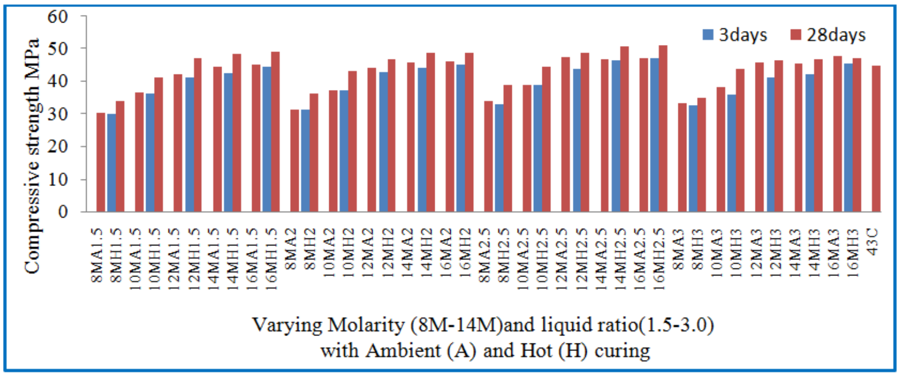

Fig.6 Comparison of strength for hot and ambient cured mortars

III. Discussion Of Results

- The calculated amount of activator is sufficient for making a paste and no extra water is added for all the ten different concentrations of activating solution.
- For hot curing both the 3day strength and 28 day strength increase with the increase in the molarity of NaOH for all the four liquid ratios considered. The difference between the 3day and 28 day strength is a variant. The variation is a minimum of 6.2% to a maximum of 17.7%.
- The maximum 3day compressive strength is achieved by hot curing for 16M NaOH with liquid ratio 2.5 as 46.98MPa for which the corresponding 28day strength is 50.94MPa. The increase is only about 8.4%.
- The 28 day mortar strength is exceeded from 12M and above concentration of sodium hydroxide for liquid ratio 1.5 and 10M and above for liquid ratios 2.0-3.0 considered for hot curing.
- In case of ambient curing, the three day strength is not achieved for all the 10 cases and the 28 day strength is always less compared to corresponding hot cured specimen strength. The maximum 28 day compressive strength is achieved from the ambient cured samples for 16M NaOH with liquid ratio 3 as 47.88MPa. This is 6% less than the 28day strength of hot cured mortar.
- The 28 day mortar strength is exceeded from 14M and above concentration of sodium hydroxide for liquid ratio 1.5 and 12M and above for liquid ratios 2.0-3.0 considered for ambient curing.

IV. Conclusion

- The consistency of geopolymer is proportional to the molarity of NaOH but independent of the alkaline liquid ratio considered.
- In case of ambient curing, the 3day strength is not achieved for all the 10 cases and the 28 day strength is always less compared to that corresponding to hot cured specimens.
- By hot curing, the equivalent mortar strength can be achieved using activator having 12M sodium hydroxide with liquid ratio 1.5.
- Equivalent mortar strength of geopolymer can be obtained using activator having 14M sodium hydroxide with liquid ratio 1.5 by ambient curing.

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