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Study on the Properties of Alkaline Activated Flyash Based Geopolymer Composites

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Abstract : Cement and Concrete making not only consume significant amount of natural resources but also take responsibility of emitting considerable fraction of the totally generated carbon dioxide to the atmosphere through its cement production. Recent research is diverted to develop cement-free concrete from industrial waste and by products which are also quantitatively increasing day by day causing environmental and pollution problems. Geopolymer concrete is obtained by using an alkaline solution to activate the mixture of a source material like flyash with other constituents of like aggregates and admixtures, with a typical procedure slightly deviating from the conventional fabrication technology. In this study, the short term properties like consistency and setting time of geopolymer, strength of 1:3 mortars and concrete compressive and tensile strength of M40grade and long term properties like water absorption and acid resistance are considered. Low calcium flyash, sodium hydroxide/sodium silicate based alkaline solution, river sand, granite aggregates are used. Hot oven curing at 65^oC is adopted for GPC and pond curing for OPCC. It is observed by comparison with conventional concrete, the geopolymer technology can be a sustainable development in the concrete industries.
Keywords : Geopolymer, consistency, setting time, low calcium flyash, hot curing, compressive strength, durability.

Introduction

Geopolymer concrete (GPC) is obtained by alkali-activation of industrial waste of pozzolanicnature, having high in silica and Alumina contents. The geopolymers based on, kaolinite/hydrosodalite, metakaolin MK-750, Calcium, Rock, Silica, flyash, Phosphate and organic minerals is well explained[1]and also reported about the development of GPC from these source materials as the attempts of scientists from various origins. Of all these materials, flyash is available abundantly in India, but to date its utilization is limited inspite of the recommendations of Indian standards[2].Researchers tried to utilise the flyash for partial, high volume or total replacement of cement in concrete. As quantity of flyash available is high as waste, its utilization is limited and treating of flyash is a hectic problem. Therefore, there is a need for high volume utilization flyash for structural purpose. Geopolymer based mortar and concrete have high potentiality in the sustainable development of concrete through the waste management.

In the development of GPC, preparation of optimum fraction of alkaline combination and proposing the appropriate method of curing are typical when compared to the features of ordinary Portland cement concrete

(OPCC). In its earlier stage of development, typical formation of geopolymer required hot steam curing[3]but later reported, also for hot oven curing, exposed curing or ambient curing at room temperature under laboratory conditions[4]. The chemistry of Geopolymer formation is totally different from hydration process of cement[1].The normal consistency and setting time of geopolymers have been studied by many authors[5,6,7]and found varied with respect to parameters like molarity of the sodium/potassium hydroxide solutions, the liquid ratio between the components of the alkaline solution.

Mix design procedure for proportioning the constituents has also been developed for grades of GPC[8,9]. The method involved step by step procedure making certain basic assumptions that are also adopted for OPCC. Extensive studies conducted on flyash based GPC showed high early strength, low drying shrinkage and high freeze and thaw resistance[8](Rangan, 2008). Qualitative information is available and it is made possible to practically formulate the alkali activating solution for flyash to achieve required strength and other mechanical properties[10]. Durability studies have also been made by many authors[11,12]and found that GPC is comparatively more durable than OPCC.

There is a need to develop alternative binder systems that are less energy intensive and more ecofriendly in terms of consumption of natural resources and carbon dioxide emissions. The entire globe has been diverted to develop geopolymer binders to replace cement and make cement free products. While GPC has a history starting in the 1940s and has attributed significant academic research, it has yet to enter the mainstream of concrete construction.

Experimentation

The low calcium flyash with high SiO_2(54.40%), Al_2O_3(25.64%) and low CaO(2.03%) is used. The alkaline activator used is 12Molar Sodium hydroxide solution and Sodiumsilicate solution with liquid ratio 2.5. The 12 molarity Sodium hydroxide is prepared[8], one day prior to mixing with flyash or mortar or concrete to avoid the heating effect. The constituents of alkaline solution are shown in figure 1. The alkaline solution so prepared is only used for making geopolymer based paste, mortar and concrete. The type of specimens cast and tested is shown in figure 2.

(a) Sodium hydroxide flakes (b) Sodium silicate solution

Fig.1 Constituents of Alkaline solution

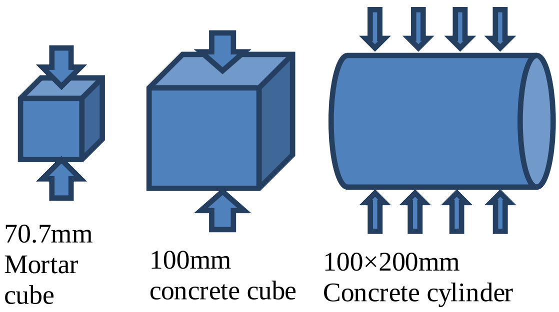

Fig.2 type of specimens for various tests

Consistency and Setting time

The short term properties like consistency and setting times are to be given prime importance as they become the fundamental properties to constitute the material in fresh as well as hardened states. The consistency of the flyash based geopolymer paste is determined as per Indian standards[13]using Vicat's apparatus with plunger and accessories. Geopolymer paste is prepared by mixing with alkaline solution and testing with varying percentage is done until the standard consistency value is obtained.

The setting times of the flyash based geopolymer paste is determined as per Indian standards applicable for cement paste[14]. Standard paste of Geopolymer is prepared with alkaline fluid binder of 85% of standard consistency and then filled into the Vicat's mould. The specimen is then placed into the oven for curing at an elevated temperature of 65^{o}C. Initially for every 15 minutes interval the specimen is taken out and placed on the Vicat's apparatus below the needle for observation to assess the initial setting time. Later, the interval is reduced to 10minutes and five minutes respectively. The specimen is taken back to the oven for curing continuity at the same elevated temperature. This procedure is repeated and the initial setting time is assessed satisfying the depth of penetration. In the same manner, the final setting time, is also determined in the same set up using a collared needle replacing the needle.

Geopolymer Mortar Strength

Standard mortar mix of ratio 1:3 is prepared by mixing 555gm of standard sand and 185gm of flyash with alkaline solution by quantity equal to one fourth of the consistency plus 3% by combined weight of sand and flyash as done for cement mortar. Mortar cubes of standard size (70.7mm size) are cast and after one day of casting, are kept in an oven for hot curing at 65^{o}C for 24 hours. The mortar cubes are tested in 3 days of casting for compressive strength, and compared with the strength of 28 days cured conventional cement mortar cubes.

Geopolymer Concrete Properties

Mix design for GPC equivalent to M40 grade is made designated as GM40, based on the constituent material properties[8]. Conventional river sand of specific gravity 2.64 and 12.5mm maximum size crushed granite coarse aggregates of specific gravity 2.7 are used. Super plasticizer (Supaflo special) is added for more workability by trial. The mix details of OPCC and GPC proposed are presented in Table 1.The constituents are machine mixed in a standard manner and fifteen numbers of 100mm cube specimens and 10 numbers of 100×200mm cylinder specimens are cast out of GPC. The discharged concrete is first used to conduct slump test for workability measurements based on Indian Standards[15].

The details of specimens cast for the relevant test are shown in figure 1. The prepared concrete is poured in to the oiled cube and cylindrical moulds in three layers and compacted by placing on the table vibrator. After a rest period of one day, the specimens are placed in three ovens in the laboratory for hot dry curing at 65^{o}C for 24 hours. In parallel, OPCC specimens are also cast and put for pond curing after one day. The cured specimens are tested for compressive strength[16] and splitting tensile strength[17] on 3 days of casting. Similarly, the compressive and tensile strength of OPCC specimens are also determined by testing the respective specimens after 28 days of pond curing.

Table 1 Mix proportions for OPCC and GPC

No	Constituents	OPCC (M40)		GPC (GM40)	
		Ratio	Wt (kg/m^3)	Ratio	Wt (kg/m^3)
1	Cement /Flyash	1	380	1	364
2	Sand	2.01	765	1.49	540
3	Jelly 12.5mm	3.13	1190	3.47	1260
5	w/c ratio/ Activator/FA	0.40	142	0.65	67.54

Durability Tests

Saturated water absorption (SWA) test and Sulphuric acid resistance test are conducted and the results are compared with conventional cement concrete. The SWA of concrete is determined as per ASTM standards[18] using 100mm cubes cast out of GPC and OPCC. The appropriately cured concrete cubes are immersed in water and after 90 and 180 days of immersion, they are taken out; surface water wiped off and weighed for their water saturated weight (*Ws*). The samples are then oven dried at a temperature of 105°C for 24 hours and the process is maintained until the difference in mass between two successive measurements agreed closely. After cooling to room temperature, these oven dried specimens are again weighed (*Wd*). The saturated water absorption is arrived from the following equation,

$$SWA = \frac{W_s - W_d}{W_d} \times 100\%$$

Sulfuric acid is one type of acid solution that is frequently used to simulate the acid attack in sewer pipe systems as generated bacterially from hydrogen sulfide. Acid resistance of GPC and OPCC is studied by immersing the respective cube specimens (of known weight) in 2% concentrated Sulphuric acid solution based on the literature survey[19]. The ratio of the volume of the acid solution to that of the specimens is considered as two and the solution is replaced in every 30 days of interval. After a specific period of 90 and 180 days of immersion, the specimens are taken out of the bath tub, the surface cleaned and the loose materials around removed. Then, these specimens are surface dried and the weight and compressive strength are obtained appropriately. Knowing the initial weight before immersion the weight loss is obtained. Similarly, the strength loss is obtained as the difference in the original strength and the residual strength as a percentage.

The short term properties like consistency and setting times, mortar and concrete strength and durability related results like SWA and Sulphuric acid resistance of OPCC and GPC are determined and presented in Table 2.

Table 2 Comparison of properties of OPCC and GPC

No	Properties	Geopolymer based	Cement based
1	Consistency of paste	32%	29%
2	Initial setting time (minutes)	97	49
3	Final setting time (minutes)	204	310
4	Mortar compressive strength (MPa)	43.84	42.34
5	Slump (mm)	48	53
6	Concrete compressive strength (MPa)	50.48	50.36
7	Splitting tensile strength (MPa)	4.74	4.51
8	SWA (%) in 90 days	3.116	3.218
9	in 180 days	2.553	2.791
10	Weight loss(%) in 90days	09.925	10.630
11	in 180 days	11.822	12.213
12	Strength(MPa)loss in 90days	08.370	09.645
13	in 180 days	12.070	13.032

Results and Discussion

The consistency of Geopolymer paste is 10.3% more when compared to OPC. The initial setting time is 97% more and the final setting time of Geopolymer paste is 34.2% less compared to OPC paste. This indicates that the rest period is a must and the cast specimens are to be safely protected for any water loss.

Themortar compressive strength is 3.5% more for Geopolymer mortar.The slump of GPC is observed to be 9.4% less than OPCC. This indicates that extra water may be required for more workability.

As presented in figure 3, the 3day cube compressive strength of hot cured GPC is almost same as the 28day strength of pond cured OPCC. The cube compressive strength of GPC is only 0.25% greater than that of OPCC but, the splitting tensile strength of GPC is 5.1% greater than OPCC.

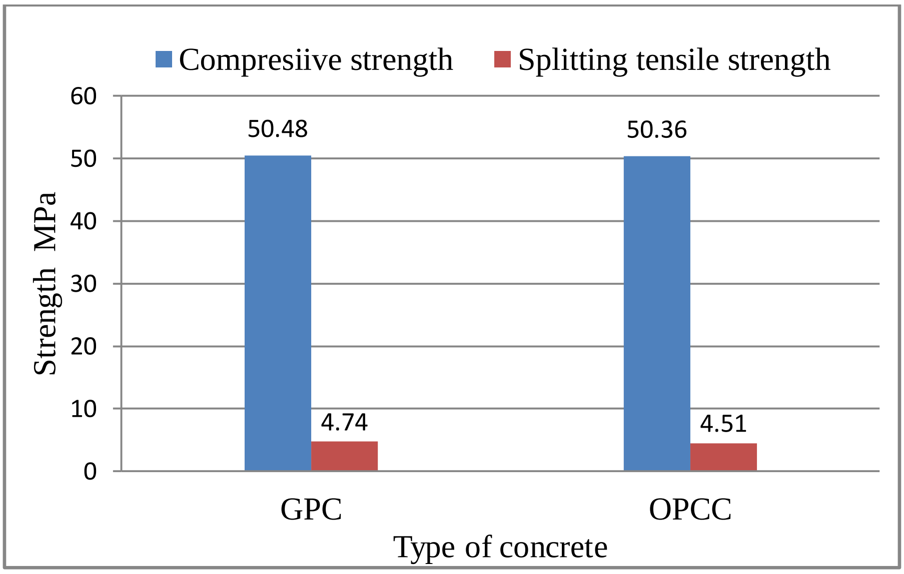

Fig.3 Comparison of strength of concrete

The Comparison of durability related properties of both GPC and OPCC is made in figure 4. For both OPCC and GPC, the SWA is always less for 180 days of immersion than the 90 days immersed case. Compared to OPCC, the SWA is 3.2% less for 90 days immersion and 8.5% less for 180 days of immersion in water for GPC.

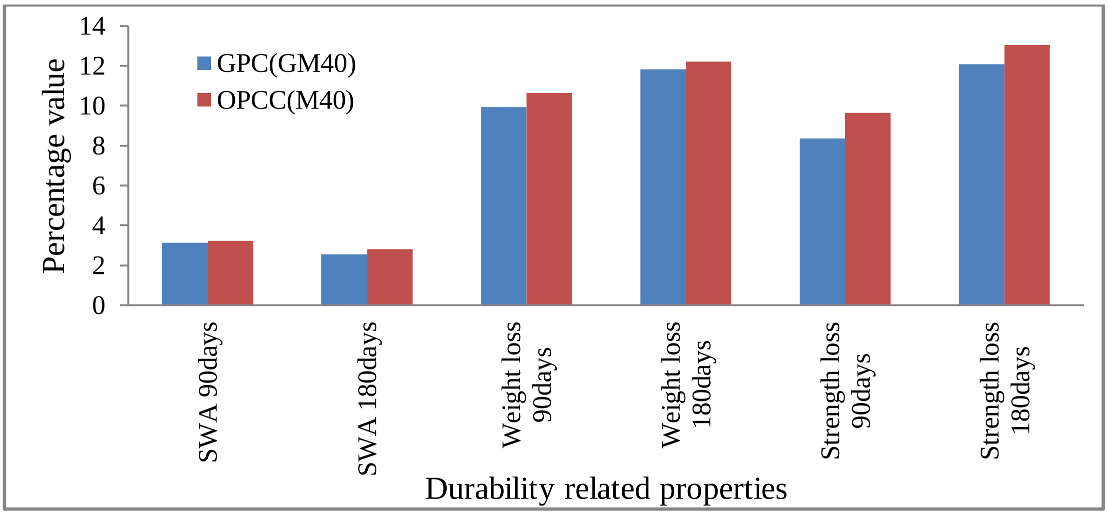

Fig.4 Comparison of durability related properties of GPC and OPCC

In case of Sulphuric acid resistance test by 2% Sulphuric acid immersion, the weight loss is observed to be 6.6% less for GPC in 90 days of immersion and 3.2% less for 180 days of immersion compared to OPCC. Similarly, the strength loss is respectively 13.2% and 7.4% less for GPC for 90 days and 180 days of immersion in comparison with that of OPCC.

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