Comparative insight on the use of fly ash based geopolymer concrete incorporating alccofine at varied concentration of sodium hydroxide

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ABSTRACT- Development of sustainable construction materials has been the viewpoint of research efforts worldwide in recent years. Although the use of Portland cement is unavoidable, many efforts are being made to minimize the use of Portland cement in concrete. It is time to deploy new technology materials like geopolymers that offer waste utilisation and emissions reduction. An alternate to the OPC has been found out known as geopolymer concrete (GPC). In this study, GPC will be made of fly ash incorporating alccofine in various percentages of 5%, 10% and 15% as partial replacement to fly ash. Alkaline activator for geopolymerisation was prepared by mixing various concentration of Sodium hydroxide solution at 10M, 13M and 16M with Sodium silicate solutions are used. Control mix is casted for M30 grade concrete. The samples are proposed to be cured by hot-curing for 24 hours and mechanical properties were examined. The result was examined that, at 16M concentration of sodium hydroxide with 5 to 10% replacement of alccofine the strength properties was being increased due to the higher leaching out of silica and alumina with higher molar concentration which increases the geopolymerisation process inturn increases the strength properties.

Keywords: Geopolymer concrete, alumino-silicate, molarity, micro filler, geopolymerisation.

1. Introduction

Concrete is the second most consumed materials after water and it shape our built environment. Popularity of concrete as construction material is on the three counts 1) excellent mouldability 2) adequate strength and 3) amenable to the utilization of local materials as ingredients. Cement industry accounts considerable share for CO_2 emission due to high environmental carbon footprint of cement. The carbon footprint is a measure of the amount of CO_2 released through combustion. In order to reduce carbon footprints of cement applications, manufacturers have started looking towards low carbon cements around the world. It is time to deploy new technology materials like geopolymers that offer waste utilisation and emissions reduction. GPC have high strength, with good resistance to durability characteristics. The approaches of GPC are commonly formed by alkali activation of industrial aluminosilicate waste materials such as Fly ash, GGBS and rice husk and have a very small Greenhouse footprint when compared to conventional concretes. Two main constituents of geopolymer ingredients are source materials and alkaline liquids. Source materials involves the production of binders from alumina and silica which can be obtained from Low-cost materials or industrial by-products such as fly ash, GGBS, rice husk ash, etc and therefore, this can also be termed as sustainable geopolymer concrete. These source materials react with alkali-activating solutions and form cross-linked three-dimensional alumino-silicate network network consisting of Si-O-Al-O bonds [1]. The mechanism for the geopolymerisation process activation involves three major reactions (a) Dissolution of Si and Al atoms from the source material through the action of hydroxide ions (b) Orientation or condensation of precursor ions into monomers (c) Setting or polycondensation or polymerization of monomers into polymeric structures. Alccofine has higher fineness, so acts as an micro filler and is rich in alumina content which have enhanced the hydration and geopolymerisation process. In this study, low calcium fly ash based geopolymer concrete at oven curing for 24 hours has been developed which is suitable for the construction industry. A blend of alccofine and fly ash was activated by alkaline solution to produced heat cured concrete. The properties of the binders are studied in terms of workability, compressive and flexural strengths. The focus of the current work is to develop and characterize the properties of heat cured alccofine and fly ash based geopolymer concrete.

2. Experimental approach

2.1. Materials for geopolymer concrete mixture

2.1.1. Fly ash

In this study, local available low calcium class-F fly ash with specific gravity 2.84 is procured from Tuticorin thermal power plant in Tamilnadu. The chemical composition of fly ash with minimum requirements as per IS 3812: 2003 [17] is given in Table 1. Physical properties are shown in table 2.

Table 1 Chemical composition of class F fly ash

S.NO	Specification	Values (%)
1	Silica	57.79
2	Iron –Oxide	7.04
3	Aluminum oxide	20.18
4	Calcium oxide	2.97
5	Magnesium oxide	1.98
6	Titanium oxide	1.03
7	Phosphorous	0.26
8	Sulphate	0.84
9	Alkali oxide	3.69
10	LOI	4.22

Table 2 Physical properties of class F fly ash

S.NO	Specification	Values
1	Color	Grey
2	Specific gravity	2.84
3	Bulk density	0.994 g/cm^3

2.1.2. Alccofine

Alccofine 1203 (AF) is a microfine material which is based on low calcium silicate slag. Alccofine improves workability by reducing the water demand. Due to its unique chemistry and ultrafine particle size, GPC strength improved [17]. Alccofine 1203 produces enhanced performance either as a cement replacement or as an additive. Chemical and physical properties of alccofine 1203 used are given in Table 3 and Table 4.

Table 3 Chemical composition of alccofine

S.NO	Specification	Values (%)
1	CaO	0.13
2	Al_2O_3	21.40
3	SiO_2	35.50
4	MgO	6.20
5	Fe_2O_3	1.20
6	SO_3	0.13

Table 4 Physical properties of alccofine

S.NO	Specification	Values
1	Specific gravity	2.9
2	Bulk density	680 Kg/m^3
3	Specific surface area	1200 m^2/kg

2.1.3. Aggregate

For the preparation of all the test specimens, good quality and well-graded aggregates in dry condition was utilized. An M-sand and coarse aggregates with maximum size of 20mm is used. Physical properties of the aggregates are given in Table 5. Both coarse and fine aggregates conform to IS 383-1970 [17].

Table 5 Properties of aggregate

Property	Fine aggregate	Coarse aggregate
Specific gravity	2.6	2.71
Fineness modulus	3.6	4.08
Water absorption	2.24%	0.38%

Table 6 Mix percentages used in this study

Mix	Molarity [M]	Fly ash %	Alccofine %	Fine aggregate %	Coarse aggregate %
M1	10	100	0	100	100
M2	13	100	0	100	100
M3	16	100	0	100	100
M4	10	95	5	100	100
M5	13	95	5	100	100
M6	16	95	5	100	100
M7	10	90	10	100	100
M8	13	90	10	100	100
M9	16	90	10	100	100
M10	10	85	15	100	100
M11	13	85	15	100	100
M12	16	85	15	100	100

2.1.4. Alkaline activators

Sodium hydroxide and sodium silicate were used in this study as an alkaline activator which plays a vital role in the geopolymerization process. Sodium hydroxide solutions of required molarity were prepared from pellets with 98% purity and sodium silicate solution (Na_2SiO_3) (15.60% Na_2O, 30.40% SiO_2 and 54% water) were procured commercially.

2.1.5. Superplasticizer

Sodium silicate and sodium hydroxide solutions are more viscous than water; hence their use makes the GPC more cohesive and sticky than nominal mix. So, in order to improve the workability of the fresh geopolymer mix, a Naphthalene Sulphonate based water reducing superplasticizer confirming to IS 9103:1999 [17] is used.

2.2. Manufacture of geopolymer concrete

The mixture proportions of nine GPC with and without alccofine at 10M, 13M and 16M concentration of sodium hydroxide are studied. Mix percentage is prepared for all the ten mixes tabulated in Table 6, while superplasticizer amount was kept at 2% of the fly ash content. Quantity of Materials required per cubic meter for geopolymer Concrete according to mix design was given in Table 7.

Table 7 Quantities of geopolymer concrete mixes

Materials	Quantity (kg/m^3)
Binder	400
Sodium hydroxide	57.14
Sodium silicate	142.86
Fine aggregate	540
Coarse aggregate	1260
Binder to alkaline solution ratio	0.35

2.3. Preparation, casting and curing of GPC specimens

Before the mixing of concrete, aggregates were prepared to the saturated surface dry condition. Sodium hydroxide solution was prepared 24 h prior to casting and mixed with sodium silicate solution at a required quantity about 1 h before actual mixing of the GPC. Fly ash, aggregates and alccofine were first dry mixed, followed by addition of the activator solutions to the dry mix and the mixing continued to produce required homogeneity of GPC. Superplasticizer and any additional water were added during the mixing process. All the specimens were compacted on a vibrating table for 2–3 min. 150 mm cubes were prepared for compressive strength testing and 500 mm long beam were casted for flexural strength testing. The samples were then cured in the oven at 80° C for 24 hours and then at room temperature till the age of testing.

3. Results and discussion

3.1. Workability

The workability of fresh GPC was determined immediately after mixing of concrete using the slump cone test. The fresh GPC mixes were found to be highly viscous. The workability of GPC mixes without alccofine (M1, M5, M9) is observed to be very low. In view of the results, it was observed that slump values improved by 12% when molarity is changed from 16 M to 10M. In other words, workability decreases with the increase in the concentration of the sodium hydroxide. The reason for lower values could be high viscous due to increased molarity. Further, the decrease in the slump values with the increase in NaOH molarity may be due to hardening process due to calcium content present in the alccofine. The increase in calcium content was not only due to the presence of alccofine but also due to its binder sources like fly ash which formed additional monomers which increased the rate of solidification and hence increased its strength [3,17]. The slump values obtained for all the GPC mixes prepared with 15% alccofine and 2% plasticizer indicates less viscous and good workability.

3.2. Compressive strength

The GPC samples of size 150X150X150 mm are tested for compressive strength. The testing is done on a set of three identical samples for each case at the age of 7 and 28 days. The mean values obtained for the compressive strength at different molar concentration are represented in Fig. 1. It can be seen from Fig. 1 that with increase in molarity there was increase in compressive strength of all the mixes. It is clear that concentration of NaOH effects the strength of the GPC. This indicates that 16 M may be an optimal molarity, in order to make the GPC effective in terms of economy. The effect of alccofine at 400 kg fly ash and 16 M sodium hydroxide has increased the strength as the total specific surface area increased, resulting in strength of 50.4 MPa with 5% replacement of alccofine. This increase in compressive strength at oven curing may be due to the presence of calcium in alccofine and fly ash which results into formation of CSH bond in the system apart from the NASH and CASH. Fly ash is the main source of the silica and alumina, which increases when the amount of fly ash is increased in the system and it influences the polymerization reaction and hence increases the NASH and CASH which results in higher strength.

Table 8 Compressive strength results

MIX	Compressive strength (N/mm^2)	
	7 days	**28 days**
M0	25.6	36.8
M1	20.2	26.5
M2	29.8	35.6
M3	33.5	38.9
M4	40.2	45.6
M5	18.5	23.7
M6	30.8	32.4
M7	34.6	38.5
M8	42.0	45.9
M9	22.2	28.7
M10	47.8	50.4
M11	45.0	47.8
M12	40.1	45.9

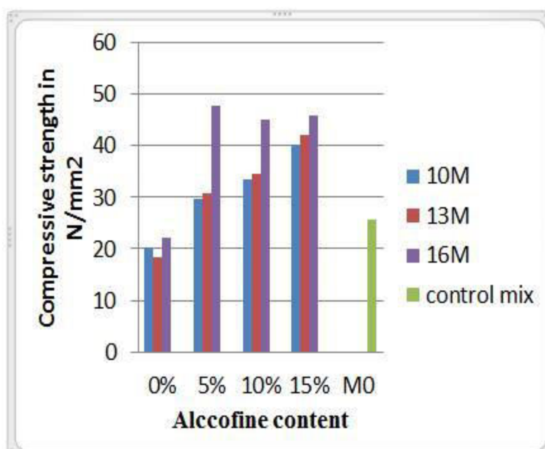

Fig.1. Chart for 7 days compressive strength

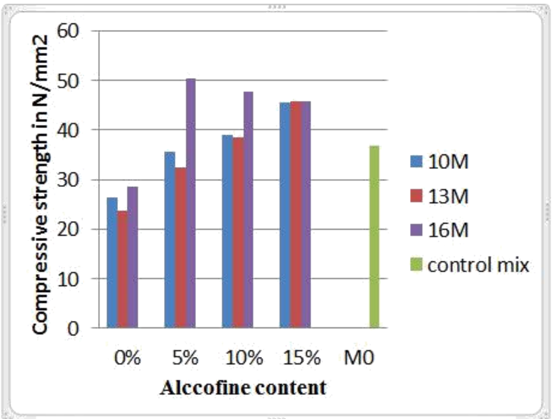

Fig.2. Chart for 28 days compressive strength

Fig.3 Geopolymer concrete cube after failure

3.3. Flexural strength

The flexural tensile strength of the geopolymer specimens was studied and the influence of NaOH molarity, age and quantity of binder material with the inclusion of alccofine on the flexural strength was carried out at 7 and 28 days at beams of size 500 x 100 X 100 mm. Although the strength increment was on the higher side, still the best results were obtained by the specimens with 16 M after 28 days. Strength development after the completion of initial temperature curing period was not significant due to polymerization products NASH which did not react further at normal temperature. Strength properties were related to the amount of NaOH in the alkaline solution. As SiO_2/Na_2O increases then the degree of dissolution and hydrolysis accelerated. Particle size is important since it determines the surface area that available for dissolution by alkaline solution.

Table 9 Flexural strength results

MIX	Flexural strength (N/mm^2)	
	7 days	28 days
M0	3.8	4.2
M1	1.8	2.5
M2	3.8	5.0
M3	4.5	5.6
M4	5.2	5.8
M5	2.0	2.4
M6	3.6	4.2
M7	4.8	5.2
M8	5.4	5.6
M9	2.2	2.8
M10	4.0	5.4
M11	5.2	6.6
M12	5.0	5.8

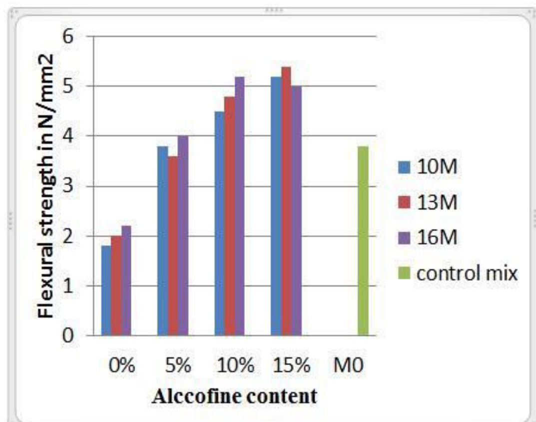

Fig.4 Chart for 7 days flexural strength

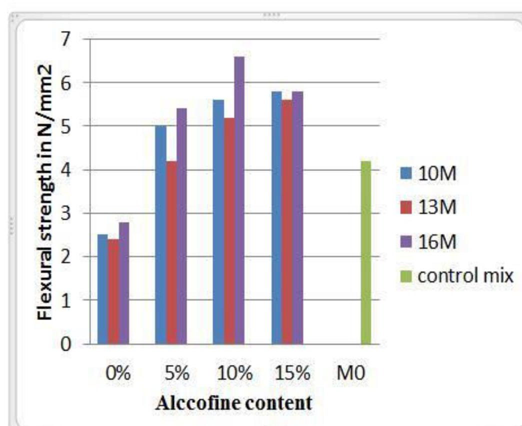

Fig.5 Chart for 28 days flexural strength

Fig.6 Testing of beam

4. Conclusion

In this project mechanical properties of geopolymer concrete and conventional concrete is compared. From the observations of test results following conclusions are made:

1) The 28 days strength of the GPC mix was obtained at hot curing and it was observed that the improvement in the strength was due to hydration in addition to polymerization.
2) The 28-days compressive strength of GPC is increased by 40% at 5% addition of alccofine with 16M and decreased upto 36% without the addition of alccofine at all molar concentrations compared to conventional concrete.
3) The 28-days flexural strength of GPC is increased by 57% at 10% addition of alccofine with 16M and decreased upto 43% without addition of alccofine at all molar concentrations compared to conventional concrete.
4) The mechanical properties of fly ash based GPC incorporating alccofine found to be improved.
5) Maximum compressive and flexural strength at hot curing was obtained, with 16 M NaOH concentration.
6) Increased molarity of sodium hydroxide enhances the mechanical strength but reduce the workability of GPC.

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