

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 and increases the strength properties.

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

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I. 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 CO₂ emission due to high environmental carbon footprint of cement. The carbon footprint is a measure of the amount of CO₂ 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 alkaliactivating solutions and form cross-linked threedimensional 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/cm³ 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 Al₂O₃ 21.40 3 SiO₂ 35.50 4 MgO 6.20 5 Fe₂O₃ 1.20 6 SO₃ 0.13 Table 4 Physical properties of alccofine S.NO Specification Values 1 Specific gravity 2.9 2 Bulk density 680 Kg/m³ 3 Specific surface area 1200 m²/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 Coarse aggregate aggregate Specific gravity 2.6 2.71 Fineness 3.6 4.08 modulus Water absorption 2.24% 0.38% Table 6 Mix percentages used in this study

Mix Molarity [M] Fly ash % Alccofine % Fine Coarse aggregate % 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 (Na₂SiO₃) (15.60% Na₂O, 30.40% SiO₂ 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 conforming 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/m³) Binder 400 Sodium hydroxide 57.14 Sodium silicate 142.86 Fine aggregate 540 Coarse aggregate 1260 Binder to alkaline solution 0.35 ratio 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/mm²) 7 days 28 days

MIX	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

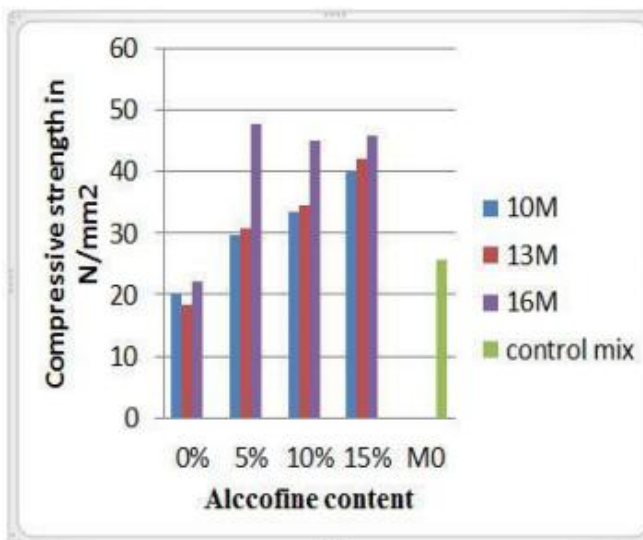
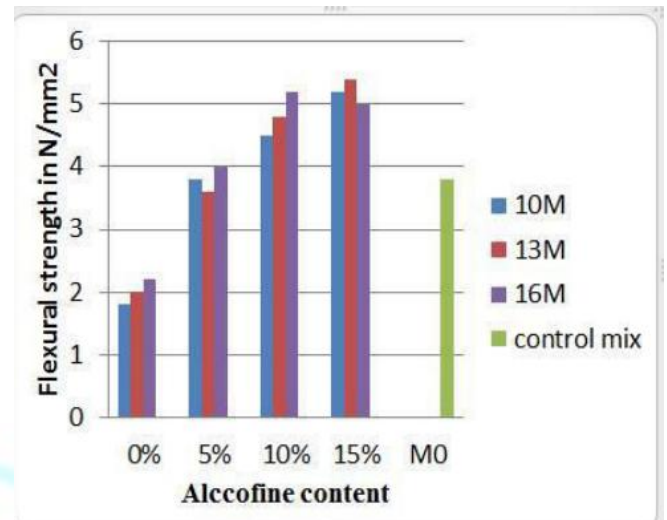


Fig.1. Chart for 7 days compressive strength

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 SiO₂/Na₂O 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/mm²) 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



II. 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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