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Improving compressive strength of low calcium fly ash geopolymer concrete with alccofine

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Abstract. Geopolymer concrete is environmentally friendly and could be considered as a construction material to promote the sustainable development. In this paper fly ash based geopolymer concretes with different percentages of alccofine were made by mixing sodium hydroxide and sodium silicate as an alkaline activator and cured at ambient as well as heat environment in an electric oven at 90℃. Effects of various parameters such as the percentage of alccofine, curing temperature, a period of curing, fly ash content, was studied on compressive strength as well as workability of geopolymer concrete. The study concludes that the presence of alccofine improves the properties of geopolymer concrete during a fresh and hardened state of concrete. Geopolymer concrete in the presence of alccofine can be used for the general purpose of concrete as required compressive strength can be achieved even at ambient temperature. The 28 days compressive strength of 73 MPa, when cured at 90-degree Celsius, confirmed that it is also very suitable for precast concrete components.

Keywords: geopolymer concrete; alccofines; heat cured; ambient cured; x-ray diffraction

1. Introduction

The global concrete consumption as a construction material, is second only to water, encouraging the manufacturing of cement on a gigantic scale which was estimated at over 5.2 billion metric tons in 2019 (Green 2015). It is estimated that approximately 94.76×10^6 Joules/ton of cement production Davidovits (1994), resulting into estimated 5 to 7% of the total output of carbon dioxide Mehta (2001) which is a prominent reason promoting global warming. The world earth summits also expressed its concern about the increased emission of greenhouse gases to the atmosphere Malhotra (1999) which warn construction industry to switch over from Portland

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Provis *et al.* (2005) concluded that the permeability depends strongly on the "mix design" of the geopolymer and the reactivity of the components. Water-solids ratio, as well as aggregate-binder ratio, are influential parameters to mechanical properties of GPC (Monita 2011).

Previous investigations have shown that concrete from geopolymer binder possesses better engineering properties such as higher tensile, compressive, flexural strengths and durability in Sulphate and acidic environments than ordinary Portland cement (OPC) (Neupane *et al.* 2016). Patil *et al.* (2014) concluded in their study that heat cured geopolymer concrete achieves almost double strength in comparison to ambient cured GPC at the age of 28 days (Patil *et al.* 2014). There is an enormous potential for geopolymer concrete applications for bridges, precast structural elements, etc. with such structural properties. Internationally better carbon credits can also be obtained by using GPC.

Fresh geopolymer concrete is highly viscous and cohesive with very low workability (Hardjito *et al.* 2002). It was observed that fly ash-based concrete show very rapid rate of chemical reaction by the addition of water into the mix, resulting in flash set in a matter of minutes making it unworkable (Cross *et al.* 2005). Pradip *et al.* (2015), Nath *et al.* (2015) in their research concluded that geopolymer concrete mixtures prepared with low calcium fly ash as the primary binder resulted in very low early compressive strength at ambient curing which was further enhanced by adding some suitable activator material.

Low-calcium fly ash (Class F) based geopolymer concrete cured at ambient temperature has shown poor compressive strength (Adam 2009, Sharma and Jindal 2015). Pradip *et al.* (2015) suggested blending of OPC in fly ash based GPC improved mechanical properties at ambient temperature curing (Nath *et al.* 2015). Alccofine 1203 can also be used as an additive to enhance the mechanical properties of GPC at early ages (Jindal *et al.* 2016).

Literature study points out that the geopolymer concrete developed at ambient curing is poorly workable as well as lower compressive strength. A new methodology needs to be developed which will address these issues of low workability and poor compressive strength.

2. Objectives of study

This paper discussed the results of an investigation of compressive strength carried out on unprocessed and processed fly ash based geopolymer concrete. Therefore, in an attempt to improve workability and compressive strength, Alccofine 1203 was used in geopolymer concrete at standard laboratory temperature (ambient) as well as heat cured specimens. Heat curing was done in the electric oven at 90℃ for 24 h. Effect of fly ash content variation, along with alccofine has also been studied. Samples were cast at a 16M molarity of sodium hydroxide keeping water/geopolymer solids (W/GPS) ratio fixed with varying alkaline liquid/ fly ash (AL/FA) ratio from 0.38 to 0.46. Geopolymer solids include fly ash and alkaline solids by mass.

3. Research significance

Previous investigations on inorganic geopolymer, cured at higher temperatures (heat curing) have shown higher strength development. The fly ash generation in India has already crossed 200 million tons per year and likely to increase to more than 300 million tons by the year 2017 (Jain 2016). Nearly 75-80% of the total fly ash production in India is of low calcium (Class F) type fly

Table 3 Chemical composition of sodium silicate solution

Composition (%)	
Silica (SiO_2)	34.78
Sodium Oxide (Na_2O)	16.22
$Na_2O : SiO_2$	1:2.144
Total solids	51.00
Water content	49.00

Table 4 Chemical composition & physical properties of alccofine 1203

Chemical Composition		Physical Properties	
Constituents	Composition (%)	Physical Property	Results
Fe_2O_3	1.20	Bulk Density (kg/m^3)	680
SO_3	0.13	Specific Gravity	2.70
SiO_2	35.30	Particle Size Distribution d10 (in micro metre) d50 d90	1.8
MgO	8.20		4.4
Al_2O_3	21.40		8.9
CaO	32.20	Specific Surface Area	12000 cm^2/gm

4.1.2 Aggregates

The coarse aggregates were procured from a locally available crusher, it comprised of 14 mm, 10 mm and 7 mm downgraded. The aggregate is washed, dried and lightly sprinkled with water to obtain the aggregate in saturated surface-dry (SSD) condition before use. Sieve analysis is performed to determine the particle size distribution as prescribed in BIS 383 (1970) while fine aggregate used are crushed sand and graded as prescribed in BIS 2386-I (1963). The physical properties of coarse and fine aggregates are given in Table 2.

4.1.3 Alkaline solution

Sodium hydroxide in the form of pellets with 98% purity and sodium silicate solution are procured commercially from the market. The concentration of NaOH plays a significant role in the compressive strength of geopolymer concrete. GPC prepared at a concentration of 16 M sodium hydroxide provides higher compressive strength as compare to 8 M and 12 M (Suresh 2013). In this study, 16 M NaOH solution was prepared and left for a rest period of 24 h before mixing with sodium silicate solution. The mixture of sodium hydroxide and sodium silicate was left for 24 h before using it for a polymerisation process.

4.1.4 Alccofine 1203

Alccofine 1203 (AF) is a specially processed product based on slag of high glass content with high reactivity obtained through the process of controlled granulation. Due to its unique chemistry and ultra-fine particle size, Alccofine increases workability by reducing water demand and improving compressive strength. Alccofine1203 is known to produce a high-strength concrete in two different ways: as a cement replacement by reducing the cement content (usually for economic reasons), and as an additive to improve concrete properties (in both fresh and hardened states) by (Pawar and Saoji 2013). The chemical compositions and physical properties of Alccofine 1203 are

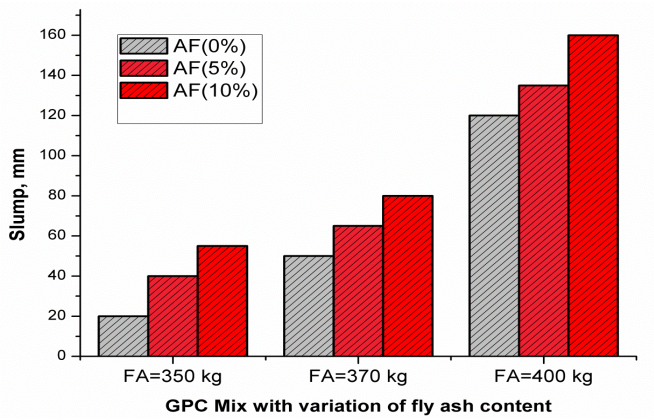

Fig. 1 Workability (slump) of fly ash based geopolymer concrete with different content of alccofines from 0% to 10% (FA-Fly ash, AF-Alccofine)

proportion in Table 5 at room temperature, then a rest period of 24 hours was given after casting followed by heat curing at 90℃ for 24 hours in an electric oven along with moulds. Sharma and Jindal (2015) suggested that ambient curing of geopolymer concrete results into the development of poor early compressive strength, therefore heat curing and ambient curing methods are adopted to do the comparative study with and without the addition of alccofine. Curing temperature plays a major role in polymerization process which has very significant role in the setting and hardening of geopolymer concrete resulting in high compressive strength (Hardjito *et al.* 2005). It has already been established that at higher temperatures the aluminosilicate phase in fly ash is highly activated as such curing at an elevated temperature between 60℃ to 90℃ provides higher early compressive strength (Martínez-Ramírez *et al.* 2000, Chareerat *et al.* 2007).

Sodium hydroxide was prepared as mentioned in 0. Sodium hydroxide and sodium silicate solution along with the dose of superplasticizer shaken at least one hour thoroughly in advance to the mixing of ingredients of concrete. Aggregates were dry mixed for 5 minutes then wet mixing for 10 minutes carefully to achieve uniform mixture which significantly affects the structural properties of concrete. After mixing, the concrete mixture was cast in a 150 mm size steel cubes moulds as per BIS 516 (1959). Six number of concrete cubes were cast for each mix to determine the average compressive strength.

4.4 Workability test

Slump test method as per BIS 1199 (1959) is followed to determine the workability of fresh GPC as per the slump test apparatus in compliance to BIS 7320 (1974). Different samples of GPC were tested for workability to check the effect of varying flyash and alccofine content.

4.5 Testing of geopolymer specimens

The GPC specimens of size 150 mm after a rest period 24 hours are cured in an electric oven at 90℃ for 24 hours. GPC samples after curing are tested for compressive strength on 3rd, 7th and 28th days of casting as per BIS 516 (1959). Ambient cured samples are also tested for compressive strength. All cubes were tested at room temperature (25±10℃).

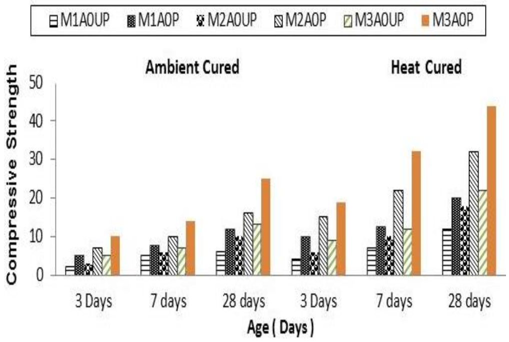

Fig. 2 Comparison of compressive strength of processed and unprocessed fly ash based GPC

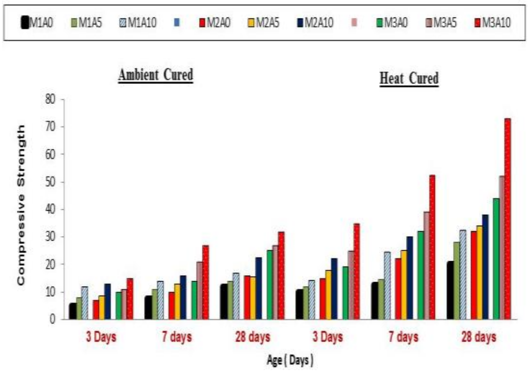

Fig. 3 Effect of variation of fly ash content, alccofine, curing type and age of casting on the compressive strength of fly ash based geopolymer concrete

5.2.1 Effect of type of fly ash and method of curing

Influence of type of fly ash on compressive strength of geopolymer concrete (GPC) is illustrated in Figs. 2-3. It shows that the compressive strength achieved by GPC is significantly improved in the case of processed type of fly ash in ambient as well as heat cured conditions. The compressive strength of the GPC (Mix M1A0UP) using unprocessed fly ash increased from 2 MPa to 6 MPa and 4 MPa to 12 MPa at the ages of 3 days and 28 days for ambient and heat cured specimens respectively. However, the compressive strength increased from 5 MPa to 12 MPa and 10 MPa to 20 MPa when GPC (Mix M1A0P) based on processed fly ash without alccofine were tested at the ages of 3 days and 28 days at ambient and heat curing respectively.

It is evident from the above graph that GPC prepared with 400 kg of processed fly ash at ambient curing can be used up to 20 MPa compressive strength. The compressive strength of the sample M3A0P (FA=400 kg) further increased when the temperature was raised to 90℃. The results obtained show nearly 100% to 130% increment in early compressive strength (3 and 7 days). However, it shows more than 75% increase at 28 days of compressive strength. Heat cured processed fly ash based GPC showed an increase of 66% to 120% in comparison to ambient curing at all ages.

This increase in compressive strength at higher temperature had been due to the properties of fly ash concrete which have better fire resistance as different hydrant products are different when compared with Portland cement concrete.

of rich silica material as fly ash and rich alumina material alccofine. Moreover, ultra-high fineness of alccofine subsequently may have plugged the microspores enhancing the compressive strength of geopolymer concrete.

5.2.4 X-ray diffraction (XRD) studies

Fig. 1 shows X-ray diffraction curves for geopolymer concrete with and without alccofine. The same figure also shows the curves for alccofine and fly ash. A comparison which immediately clarifies that polymerization has transformed amorphous material into crystal material and more significantly in the presence of alccofine. The intensity of quartz at 2θ=26.60 has increased with increase in alccofine content. Further, the peak of C-S-H at 2θ=40.30 have decreased with the increase in alccofine content. This can also be concluded (Buchwald 2006) that water is not structurally bound in geopolymer concrete and at higher alccofine content water molecules in the form of hydrates and hydroxides decreased. However, many peaks at 2θ=54.0, 38.50 and 67.70 of calcium magnesium silicates were observed in geopolymer concrete. All these reasons might have resulted in better compressive strength in the presence of alccofines.

6. Conclusions

Based on the above results and discussions presented, following conclusions can be derived upon:

• Unprocessed fly ash doesn't gain any desirable mechanical properties.

• The presence of alccofine produces better workable concrete with processed and unprocessed fly ash geopolymer concrete.

• Minimum required compressive strength for general construction purpose can be achieved with alccofine even at room temperature.

• The increase in compressive strength is significant at 90℃ in the presence of alccofine and perhaps provides an opportunity for the most economical and sustainable way to achieve higher compressive strength.

• XRD study points out that on the addition of alccofine, amorphous material changes into the crystalline material which is responsible for the improved compressive strength of GPC.

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