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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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cement to a greener alternative binder with desirable structural properties.

French scientist Joseph Davidovits in 1978 introduced the concept of geopolymer concrete, proposing alkaline liquid as an activator, to be used to react with some source material rich in silicon and aluminum, such as, fly ash (Adam and Horianto 2014, Singh *et al.* 2015, Xie 2015, Junaid *et al.* 2015), metakaolin (Aredes *et al.* 2015, Duan *et al.* 2015, Ozer and Soyer-Uzun 2015, Slaty *et al.* 2015), silica fume (Adak *et al.* 2014), rice husk ash (Prabu *et al.* 2014), slag (Kumar *et al.* 2010, Phoo-ngernkham *et al.* 2015) etc. to produce geopolymer mortar as a binder. In geopolymer concrete, polycondensation of silica and alumina precursors results in the development of binding properties which provide the required strength properties. Globally researchers are taking a keen interest in geopolymer binders due to its advantages over ordinary Portland cement, environmental benefits and better engineering and durability properties (Provis 2014). Industrial by-products, such as fly ash, rice husk ash, blast furnace slag can be utilized as a source material for geopolymer binder, providing efficient management of waste material and significantly reducing greenhouse gas emission in the production process.

1.1 Chemistry of geopolymer concrete

In Geopolymer Concrete, alumina (Al_2O_3) and silica (SiO_2) from any rich source of the aluminosilicates such fly ash, rice husk ash, silica fume, and/or slag (Davidovits 1988, Lloyd and Rangan 2010) react with metal alkalis to form binders. These industrial by-products do not require calcination as in the case of OPC and replace each cubic meter of OPC with GPC reducing carbon emissions by 45% to 80% (Davidovits 1994, McLellan *et al.* 2011). Researchers agree on the geopolymer reaction mechanism in three separate but inter-related stages; namely: the dissolution of Si and Al from the source material, condensation and polycondensation forming a 3D network of polymeric chain and ring structure consisting of Si-O-Al-O bonds forming silico-aluminates termed as ‘geopolymer backbone’(Hardjito 2005, Junaid *et al.* 2015). Class C fly ash owing to rich in CaO causes durability related issues (Wallah and Rangan 2006), so class F fly ash has been used as a source of aluminosilicates.

1.2 Properties of geopolymer concrete

The properties of geopolymer concrete which signify its application as an alternative construction material to cement concrete are as follows:

The resistance of alkali activated metakaolin or fly ash to chemical attack by acids such as nitric, sulphuric, or hydrochloric has been claimed to be far better than that of Portland cement mortar of concrete (Provis and Deventer 2009). Studies performed by Fernández-Jiménez *et al.* (2007), García-Lodeiro *et al.* (2007), Fernández-Jiménez (2009) have shown that GPC produced from activated fly ash are less susceptible to alkali-silica reaction than OPC. This has been attributed to the absence of calcium in the geopolymer system which results in less expensive alkali-aggregate reaction products. The geopolymer concrete show lower sorptivity and chloride penetration depth than ordinary concrete (Shaikh 2014). Ganesan *et al.* (2013) concluded in their study that mechanical properties of geopolymer concrete can be suitably enhanced with the addition of steel fibers. Geopolymer showed improved resistance against elevated temperatures in comparison to binders made with Portland cement (Buchwald 2006). This was endorsed to the fact that the water present in the aluminosilicate gel is not structurally bound, contrary to the water present in calcium silicate hydrates formed during Portland cement hydration.

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 1 Chemical composition and physical properties of processed and unprocessed fly ash

Composition (%)	Processed Fly ash	Unprocessed Fly ash	IS 3812-2003 requirement (BIS 2003)
Silica+alumina+iron oxide (SiO_2+Al_2O_3+Fe_2O_3): wt%	95.91	91.25	70.0 (Min)
Silica (SiO_2): wt%	62.55	56.90	35.0 (Min)
Calcium Oxide (CaO): wt%	0.87	0.85	Not specified
Magnesia (MgO): wt%	0.39	1.21	5.0 (Max)
Sulphur trioxide (SO_3): wt%	1.32	1.38	3.0 (Max)
Sodium oxide (Na_2O): wt%	0.46	0.52	1.5 (Max)
Total chlorides: wt%	0.05	0.025	0.05 (Max)
Loss on ignition: wt%	0.52	1.85	5.0 (Max)
Fineness-specific surface, m^2/kg	321.7	255.2	320 (Min)

Table 2 Physical properties of aggregates

Physical property	Fine aggregates	Coarse aggregates
Specific Gravity	2.32	2.60
Fineness Modulus	2.92	7.10
Water Absorption	1.5 %	0.8 %

ash. The utilization and disposal of such a large quantity of fly ash is an extraordinary task which needs to be performed within various environment protection laws. The efficient use of this resource material would not only minimize the disposal problem but help in conservation of limited minerals, reduce the emission of greenhouse gases and enhance performance and durability of structure (Jain 2016).

In this study, an effort has been made to improve the mechanical properties of low calcium fly ash based geopolymer with the addition of alccofines. Alccofine was used as an additive up to 10% percent by weight of fly ash into class F fly ash-based geopolymer. The mechanism of alccofine as an additive on compressive strength was investigated using X-ray diffraction (XRD).

4. Experimental programme

4.1 Material preparations

The details of the materials used and the methodology attempted to study geopolymer concrete with Alccofine 1203 are described in the following paragraphs:

4.1.1 Fly ash

Low calcium fly-ash (Class F) was used in this investigation. The processed and unprocessed fly ash used was procured from Ultratech Ready Mix Concrete plant and locally available market respectively from Panchkula, Haryana. Un-processed flyash is generally used by local flyash based cemented tile factories for manufacturing nonstructural members. The chemical compositions and physical properties of unprocessed and processed fly ash are given in Table 1.

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

Table 5 Mix proportion of geopolymer concrete mixes

Mix No./ Designation	Quantity of ingredients (kg/m^3)								
	Coarse aggregates			Fine Aggregates	Fly Ash	Alccofine (% age of fly ash)	NaOH	Na_2SiO_3	Water
	14 mm	10 mm	7 mm						
M1A0/M1A0P	614	460	269	575	350	0.0	38	95	36.02
M1A0UP	614	460	269	575	350	0.0	38	95	36.02
M1A5	614	460	269	575	350	5	38	95	36.02
M1A10	614	460	269	575	350	10	38	95	36.02
M2A0/M2A0P	600	450	260	565	370	0.0	44.4	111	31.58
M2A0UP	600	450	260	565	370	0.0	44.4	111	31.58
M2A5	600	450	260	565	370	5	44.4	111	31.58
M2A10	600	450	260	565	370	10	44.4	111	31.58
M3A0/M3A0P	565	445	255	540	400	0.0	52.58	131.45	27.07
M3A0UP	565	445	255	540	400	0.0	52.58	131.45	27.07
M3A5	565	445	255	540	400	5	52.58	131.45	27.07
M3A10	565	445	255	540	400	10	52.58	131.45	27.07

M1A0, A5, A10 (Mix 1 with fly ash content of 350 kg/m^3 and Alccofine 0%, 5%, 10% respectively), M1A0P, M1A0UP (Mix 1 , Alccofine 0%, Processed fly ash , unprocessed fly ash resp)

given in Table 4.

4.1.5 Super plasticiser

A Naphthalene Sulphonate based water reducing superplasticizer confirming to BIS 9103 (1999) is used to improve the workability of fresh geopolymer mix.

4.2 Mix proportion of geopolymer concrete

The mix design of geopolymer concretes with fly ash was done in reference to the proposed design mix by (Junaid *et al.* 2015) for the different proportion of fly ash. Similar to that of conventional concrete, coarse and fine aggregates were taken approximately 75-77% by mass of the entire mixture. The concentration of NaOH solution was 16 M so as to achieve better compressive strength (Lloyd and Rangan 2010). 2% Naphthalene Sulphonate based superplasticizer was used to improve the workability of fresh geopolymer mix. Higher W/GPS ratio improves the workability but reduces the compressive strength. Therefore, a fixed W/GPS ratio of 0.27 was used to achieve higher compressive strength. Alkaline liquid to fly ash (AL/FA) ratio was kept 0.38, 0.42 and 0.46 respectively for mix designated M1A0, M2A0, and M3A0 respectively. Mix M1A0, M2A0, and M3A0contain fly ash content 350 kg, 370 kg and 400 kg per meter cubic of geopolymer mix. The exact mix proportion of geopolymer concrete mixes is given in Table 5. GPC mixes with different amount of Alccofine 1203 (0%, 5%, and 10%) were also made to analyze its effect on workability and compressive strength of geopolymer concrete.

4.3 Casting of geopolymer concrete

Geopolymer concrete (GPC) samples were prepared with and without Alccofine as per mix

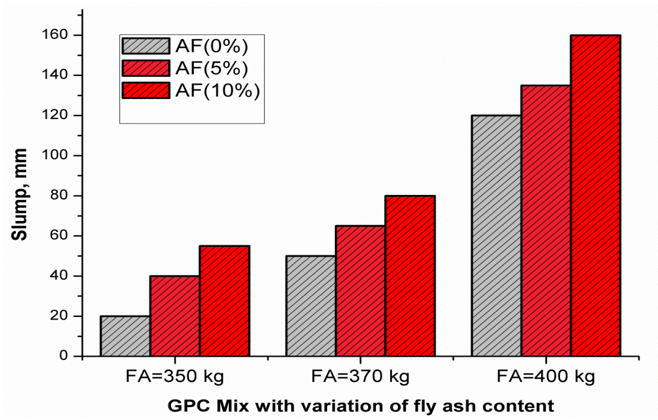

Fig. 1 Workability (slump) of fly ash based geopolymer concrete with different content of alccofines from 0% to 10% (FA-Fly ash, AF-Alccofine)

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 3^{rd}, 7^{th} and 28^{th} 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℃).

4.6 X-ray diffraction studies

Powder X-ray diffractometer was performed for fly ash, alccofines powder, and geopolymer concrete at different percentage of alccofines to evaluate the modification induced by the geopolymerisation phenomenon, in particular on the formation of crystalline products which results in the enhancement of mechanical properties.

5. Results and discussions

The results obtained for workability and compressive strength with the mix proportions as shown in Table 5 have been shown and discussed in details under in the following paragraphs.

5.1 Workability

Workability of GPC mixes was studied using slump cone test and is presented in Fig. 1. The fresh geopolymer concrete mixes were observed highly harsh and particularly in the case of GPC with unprocessed fly ash which produced slump less concrete. Workability of fresh geopolymer mix was significantly improved by using 2% Naphthalene Sulphonate based superplasticizer. It was observed that the workability of geopolymer concrete was very low in case of mixture without alccofine. Poor workability of geopolymer concretes without alccofine may be due to high water requirements with increased specific surface area of fly ash.

5.1.1 Effect of type and content of fly ash

Geopolymer mixture prepared with unprocessed fly ash results into slump less concrete i.e., the slump obtained was zero. Fig. 1 shows that GPC mix made with processed type of fly ash provides a measurable slump value which gets improved significantly on increasing the fly ash content. The small increment in slump value was observed from 20 mm to 55 mm on increasing fly ash content from 350 kg/m^3 to 400 kg/m^3.

The zero slump obtained in case of unprocessed fly ash is due to lesser fineness. The noticed increase in slump might be caused by increase in fine spherical particles with the increase in fly ash content.

5.1.2 Effect of alccofine content

Geopolymer concrete mix containing alccofine results into good workable concrete showing a significant increase in workability on increasing the alccofine content as shown in Fig. 1. A collapse slump was observed with 10% alccofine content due to its microfine structure with fineness more than 12000 cm^2/gm (Patel *et al.* 2014). Further, the slump was comparable for the mix with 10% alccofine with minimum fly ash content to that of maximum fly ash content without alccofine.

Alccofine due to its controlled higher fineness may have resulted into increased ball bearing effect which has enhanced the workability of GPC.

5.2 Compressive strength

The compressive strength of GPC cast with different type of fly ash and alccofine content along with method of curing has been discussed in the following paragraphs.

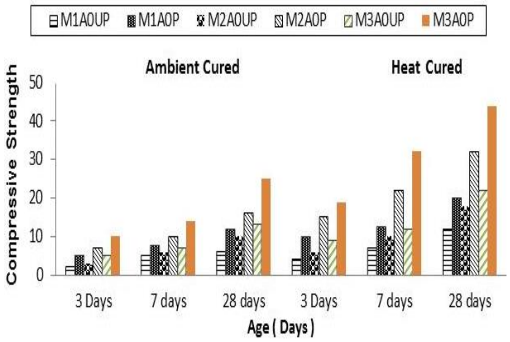

Fig. 2 Comparison of compressive strength of processed and unprocessed fly ash based GPC

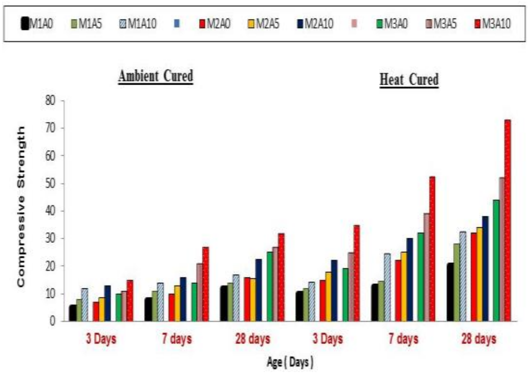

Fig. 3 Effect of variation of fly ash content, alccofine, curing type and age of casting on the compressive strength of fly ash based geopolymer concrete

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.

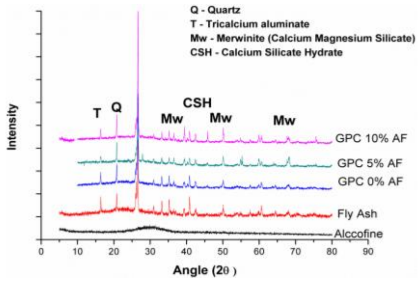

Fig. 1 XRD curves for geopolymer concrete with and without alccofines

5.2.2 Effect of fly ash content

Effect of variation of fly ash content on compressive strength of GPC with processed fly ash is shown in Fig. 3. It is observed that early ages (3 and 7 days) compressive strength of GPC prepared using processed fly ash increased from 5 MPa to 7 MPa and 10 MPa, 7.5 MPa to 10 MPa and 16 MPa as well as 28 days compressive strength increased from 12 MPa to 16 MPa and 25 MPa in case of ambient curing on varying the fly ash content from 350 kg to 370 kg and 400 kg respectively. It is as such obvious that the processed fly ash geopolymer concrete could achieve minimum required compressive strength used for general construction purpose. Whereas the highest compressive strength obtained at 400 kg/m^3 unprocessed fly ash content at ambient temperature was 13 MPa which is less than 20 MPa the required characteristic strength of M20 (BIS 456 2000).

Increased fly ash content attributes to the increased quantity of binder material as well as the development of denser concrete improving the compressive strength parameter. Geopolymer concrete based at processed fly ash results into better concrete in comparison to unprocessed fly ash due to better fineness and controlled chemical composition.

5.2.3 Effect of alccofine content

Effect of alccofine content on compressive strength of various mixes is shown in Fig. 3. It is observed that early ages (3 and 7 days) compressive strength of processed fly ash based GPC (M1A5 and M1A10) increased in the range of 20% to 45% whereas up to 62% at the age of 28 days when heat curing adopted. A similar pattern is observed in the case of higher fly ash content. Therefore, it shows that the addition of alccofine improves the early age as well as ultimate compressive strength. A compressive strength of GPC of 35 MPa and 15 MPa can be developed at the age of 3 days using 10% alccofine at heat curing and ambient cured, which resulted into 73 MPa and 32 MPa at the age of 28 days respectively. However, it is also observed that at higher fly ash content, the percentage increase in compressive strength is relatively less in comparison to GPC mix with lower fly ash content.

It can, therefore, be seen that geopolymer concrete with alccofine can achieve target strength for M25 even when the specimens are ambient cured. Literature, however, has insisted that heat curing is essential for geopolymer concrete to meet minimum required compressive strength. There remains no doubt that heat curing makes alccofine more efficient at higher fly ash content and the same specimens could reach 73 MPa. This indicates that geopolymer concrete with alccofine can be very useful for general purpose construction and for precast industries.

If the properties of fly ash and alccofine are compared, it is noticeable that alccofine has higher fineness and is rich in alumina content. Therefore, the hydration is more effective in the presence 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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