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Strength and permeation properties of alccofine activated low calcium fly ash geopolymer concrete

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Abstract. This paper presents the experimental investigations on the compressive strength and permeation properties of geopolymer concrete prepared with low calcium fly ash as the primary binder activated with different percentage of Alccofine. The durability aspect was investigated by performing permeable voids and water absorption tests since permeability directly influences the durability properties. The test results show that Alccofine significantly improves the compressive strength and reduces the water permeability thus enhances the durability of geopolymer concrete at ambient curing regime which encourages the use of geopolymer concrete at ambient curing condition thus promising its use in general construction also.

Keywords: alccofine; ambient curing; compressive strength; geopolymer concrete; permeable voids; water absorption

1. Introduction

The degree of civilization and the economic development of any nation is reflected by the growth of its infrastructure and highlighted by the production of concrete. Concrete is considered indispensable for growing infrastructural demand of the modern world. Concrete is the globally used material due to its versatile mechanical properties which make it second most consumed construction material in the world (WBCSD 2002). From the invention of Portland cement in 1824 to nowadays, it became an important part of the concrete (Aspdin 1824). Ordinary Portland cement is the most famous and easily available cement for making concrete. However, its accessibility and availability do not make it suitable and perfect for use. Environmental hazards related to cement manufacturing is overcoming its benefits (Jos *et al. 2016)*. According to the recent data available, global production of cement crossed 4.1 billion metric tons (USWCP 2015). Production of ordinary Portland cement contributes to almost 4% of total greenhouse gas emission.

With the growing concern of the researchers on global warming due to greenhouse gasses, now the time demands some serious and bold decision regarding cement and to discourage the production of OPC globally. Before making any bold decision to curtail the production of OPC, finding its alternate is a big challenge, and in view of the encouraging results obtained from previous research, Geopolymer concrete can act as a major supplement for Ordinary Portland cement concrete.

Davidovits introduced the concept of Geopolymer Concrete (GPC) in 1978. Davidovits proposed that agricultural or industrial waste material such as fly ash, rice husk ash, ground granulated blast furnace slag (ggbfs) which are rich in silica and alumina can react with an alkaline liquid to form Geopolymer mortar which can act as a binder (Davidovits 1999). Fly ash used in Geopolymer concrete is the waste product obtained from burning of coal in thermal power plants. Thus, with the manufacturing of fly ash based Geopolymer concrete, carbon emission can be reduced as well as waste fly ash can also be utilized effectively. Further fly ash based Geopolymer concrete can be used as an alternative to OPC based concrete due to its several advantages. The studies by Camoes *et al.* (2003), Nath and Sarkar (2011) and Patil *et al.* (2015) reveal that fly ash based Geopolymer concrete has higher durability than that of OPC based concrete. Water absorption characteristic also plays a significant role in determining the durability of concrete. Adam (2009) and Sharma and Jindal (2015) pointed out that the low-calcium fly ash (Class F) based geopolymer concrete at ambient curing shows poor compressive strength. Ganesan *et al.* (2013) found that addition of steel fiber can suitably enhance the mechanical properties of Geopolymer concrete. Shaikh (2014) concluded that Geopolymer concrete shows lower chloride penetration depth and sorptivity than ordinary concrete. Patil *et al.* (2014) concluded that heat cured GPC achieved almost double the compressive strength of ambient cured Geopolymer concrete at the age of 28 days. Pradip *et al.* (2015) suggested that the blending of OPC can also improve the mechanical properties of fly ash based GPC at ambient curing. Jindal *et al.* (2015) showed that Alccofine can also be used as an additive to enhance the mechanical

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properties of GPC at early ages. Jindal *et al.* (2015) indicated that addition of Alccofine in geopolymer concrete results into the development of high strength geopolymer concrete on oven curing. Jindal *et al*. (2017) pointed out that Alccofine, when added to geopolymer mixture significantly enhances the compressive strength as well as improves the workability at ambient as well as heat curing regime.

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. The utilization and disposal of such a vast quantity of fly ash is a phenomenal task. The efficient use of this resource material would not only minimize the disposal problem but also help in the conservation of limited minerals, reduce the emission of greenhouse gases and enhance performance and durability of structure (Jain 2016). The current study was targeted to investigate the effect of Alccofine on water absorption, permeable voids in geopolymer concrete which directly affect the durability aspects.

Present paper puts forward an attempt to gain better compressive strength and durability properties of geopolymer concrete with the addition of Alccofine at ambient temperature curing regime due to limited use of heat cured geopolymer concrete. In the study, the effect of different percentage of Alccofine on compressive strength, permeable voids and water absorption characteristics of low calcium fly ash Geopolymer concrete under ambient curing is studied.

2. Material requirements

2.1 Fly ash

Activating alumino-silicate based source material on reacting with an alkaline solution can produce Geopolymer concrete. Davidovits (1988) proposed that silica and alumina rich fly ash can be used as one of the source material for geopolymer binder. Class-F fly ash was used as source material, which was procured from Ultratech RMC plant Panchkula, Haryana confirming to IS 3812-2003. The composition of fly ash is given in Table 1.

2.2 Alccofine

According to M/s. Counto Micro Fine Products Pvt. Ltd, alccofine 1203 is a mineral admixture which is highly reactive, consists of high glass content as slag and is obtained through the process of controlled granulation (ACL 2014) having a specific surface area of more than 12000 cm^2/gm. It is one type of super-pozzolanic material, which helps in reducing the permeability of concrete and creates dense packing in concrete; and thus, reduces the water content and ultimately increases the compressive strength of concrete. The physical and chemical properties of Alccofine as obtained from the supplier are shown in Table 2.

2.3 Coarse aggregate

The coarse aggregate was taken from a locally available crusher; it comprised of downgraded aggregate of sizes, 14 mm, 10 mm and 7 mm, respectively. The mixture of these three sizes of aggregates produces denser concrete with better mechanical properties (Jindal *et al.* 2015). The aggregates were washed in order to render it free from dust etc. and after dried for obtaining the saturated surface dry condition. It was lightly sprinkled with water. The aggregates used to confirm to IS 383-1970. The physical properties of aggregates are shown in Table 3.

2.4 Fine aggregate

Fine aggregates confirming to IS 383 -1970 of the specific gravity of 2.32 were also procured from the locally available market of Ambala Cantt. The physical properties of aggregates are shown in Table 3.

Table 1 Composition of fly ash used

Composition (%)	Quantity	Value as per IS: 3812-2003
Silica+alumina+iron oxide (SiO_2+Al_2O_3+Fe_2O_3): wt%	95.91	70.0 (*Min*)
Silica (SiO_2): wt%	62.55	35.0(*Min*)
Calcium Oxide (CaO): wt%	0.87	Not specified
Magnesia (MgO): wt%	0.39	5.0 (*Max*)
Sulphur trioxide (SO_3): wt%	1.32	3.0 (*Max*)
Sodium oxide (Na_2O): wt%	0.46	1.5 (*Max*)
Total chlorides: wt%	0.05	0.05 (*Max*)
Loss on ignition: wt%	0.52	5.0 (*Max*)
Fineness-specific surface, m_2/kg	321.7	320 (Min)

Table 2 Physical and chemical properties of Alccofine

Chemical Properties		Physical Properties	
Constituents	Composition (%)	Physical Property	Results
SiO_2	35.30	Particle Size Distribution (in micro metre)	
MgO	6.20	d10	1.8
Al_2O_3	21.40	d50	4.4
		d90	8.9
Fe_2O_3	1.20	Bulk Density (kg/m^3)	680
SO_3	0.13	Specific Gravity	2.70

Table 3 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%

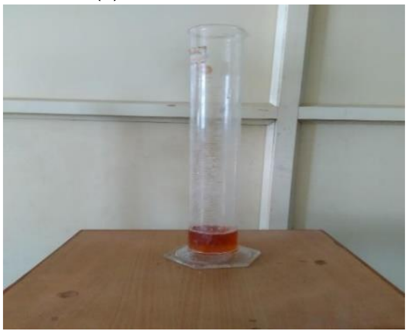
2.5 Alkaline liquid

In the polymerization process, alkaline solution plays a significant role. Hardijito and Rangan (2005) concluded that most commonly used alkaline solution in polymerization process is the combination of potassium hydroxide or

(a) Coarse and fine aggregates with fly ash

(b) Alccofine-1203

(c) Alkaline Solution



(d) Superplasticizer

Fig. 1 Materials for geopolymer concrete

sodium hydroxide and potassium silicate or sodium silicate. Palomo *et al.* (1999), Xu *et al.* (2000), Hardijito *et al.* (2004) and Fernandez *et al.* (2005) revealed that the alkaline solution containing sodium hydroxide and sodium silicate acts as an effective activator for Geopolymer concrete. In the present study, a combination of sodium hydroxide and sodium silicate was used as the alkaline solution. Sodium hydroxide was taken in pellet form with 98% purity. A solution of sodium hydroxide with water was

Table 4 Mix proportions (in Kg) of GPC 35 per cubic meter of GPC

Mix	Fly Ash	CA (14 mm)	CA (10 mm)	CA (7 mm)	FA	Alccofine	NaOH	Na_2SiO_3	Superplas-ticizer	Water (kg)
M1	420	565	445	255	543	0%	52.34	130.37	2%	13
M2	420	565	445	255	543	5%	52.34	130.37	2%	13
M3	420	565	445	255	543	10%	52.34	130.37	2%	13

CA: coarse aggregates; FA: fine aggregates

Fig. 2 Mixing of materials in pan mixer

Fig. 3 Geopolymer concrete cube moulds

prepared one day prior the casting to release heat due to the exothermic reaction of sodium hydroxide with water on the basis of previous research by Jindal *et al.* (2016), the molarity of sodium hydroxide solution was taken as 16M. Sodium silicate solution with SiO_2/Na_2O=1.875 and density of 1.46 g/cm^3 was used.

2.6 Superplasticizer

A Naphthalene based superplasticizer was used in order to increase the workability of Geopolymer concrete. The quantity of superplasticizer was taken as 2% of the total mass of fly ash. It was mixed with the solution of sodium hydroxide and sodium silicate prior to use in the mixture. Fig. 1(a)-(d) shows the different materials used in the present investigation.

3. Experimental procedure

The present study makes use of the mix design proposed by Junaid *et al.* (2015) for G35 mix proportion of Geopolymer Concrete. GPC samples were prepared with,

Fig. 4 Compressive strength testing

Fig. 5 Water absorption test

and without adding Alccofine at room temperature as per mix proportions given in Table 4. The sodium hydroxide solution of 16M (Molarity) was prepared by dissolving 444g pellets of NaOH per kg of solution. Sodium hydroxide solution was prepared one-day prior casting; because it involves exothermic reaction. A solution of sodium hydroxide was mixed with sodium silicate solution along with the dose of superplasticizer thoroughly at least one hour before casting of geopolymer concrete. The aggregates and the fly ash were mixed for 5 minutes before wet mixing. The materials were mixed uniformly for 10 minutes in pan mixer, which is shown in Fig. 2. After mixing, cubes are subjected to vibration for proper compaction of geopolymer concrete. Specimens were kept at room temperature of 27°C, which is shown in Fig. 3. After the rest period of 48 hours (in the air at room temperature regime), samples were taken out from the moulds and air-dried at room temperature.

3.1 Compressive strength testing

GPC specimens were tested for 28 days compressive strength on the 28^{th} day of casting as per IS 516-1959. All samples were tested at room temperature (25±10°C). Specimens were tested for compressive strength as shown in Fig. 4.

3.2 Permeable voids and water absorption testing

Specimens of different percentage of Alccofine were also tested for water absorption and permeable voids in accordance to ASTM C 642-82(ASTM 1982). Permeable voids and water absorption tests were conducted on four cubes per sample with mix design M1, M2, and M3, as shown in Table 4.

Specimens were kept in an oven at 105°C and weight of samples after 24 hours were observed. Again samples were put in oven until they attained constant weight. The difference between the oven dried specimens (A) and saturated surface dry samples (B) was calculated. The value of permeable voids in percentage was calculated as below:

Permeable Voids = [(A-B)/B] × 100

The oven dry specimens were weighed after cooling them at room temperature. Specimens were then immersed in water as shown in Fig. 4 and weight gain after 30 minutes of immersion was observed. This weight was used to calculate initial absorption. Again, the specimen was weighed after some time to check the change in weight if any. This process continues until the difference between two consecutive weights become almost negligible. The weight of the specimen now gives the final absorption value. Final absorptions for specimens were observed to be at 90 hours.

Initial Water Absorption = [(C-B)/B] ×100

Final Water Absorption = [(D-B)/B] × 100

B = Weight of the oven dried sample in air

C = Weight of the sample after 30 minutes of immersion in water

D = Final Absorption of the sample after 90 hours.

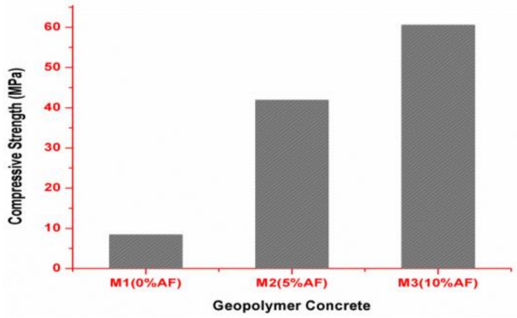


Fig. 6 Effect of Alccofine contents on compressive strength

4. Results and discussion

The test results of compressive strength, permeable voids and water absorption of GPC with varying percentage of Alccofine are explained in the subsequent sub-sections.

4.1 Compressive strength

It can be seen from Fig. 6 that the compressive strength of GPC specimens at ambient curing is very low i.e., 8.45 MPa in respect of the GPC mix without Alccofine. The compressive strength of geopolymer concrete, with the addition of Alccofine by 5%, increases nearly by 500%. However, with 10% addition of Alccofine, the rate of increase in compressive strength decreases because voids in specimens are already occupied by Alccofine fine particles. Thus, increase in compressive strength is observed to be only about 145% when compared with a considerable increase (around 500%) corresponding to 5% addition of Alccofines.

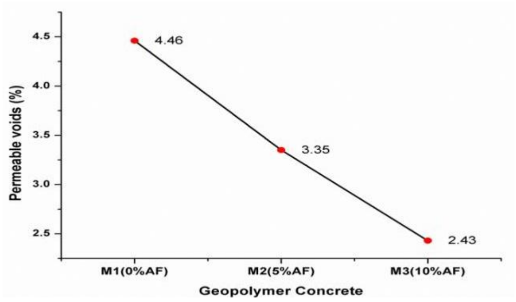


Fig. 7 Effect of Alccofine contents on permeable voids

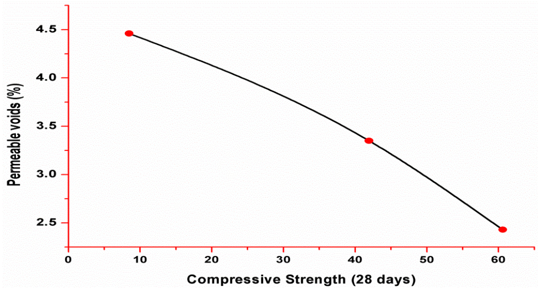


Fig. 8 Variation of permeable voids with compressive strength

4.2 Permeable voids

As seen from Fig. 7, the permeable voids are observed to be 4.46% by mass in respect of GPC mixes without Alccofines. As Alccofine content increases to 5% in the mix, permeable voids are found to decrease by 25% by mass. Alccofine, due to its ultra-fine structure, fills the voids between the particles and thus, decreases the permeable voids in the cubes. With further increase in Alccofine contents up to 10% the permeable voids are found to decrease by 27%. Thus, it can be clearly noted that with 5% increase in the alccofines content the permeable voids decrease by 25%. The relationship between the compressive strength and permeable voids is shown in Fig. 8 which clearly shows that with an increase in compressive strength a significantly decrease in permeable voids is observed.

4.3 Initial and final water absorption

The effect of the contents of Alccofine on the initial and final water absorption is also studied. The relationship between the initial and final water absorption for different proportion of Alccofine is shown in Fig. 9. For Geopolymer concrete specimens, the initial and final absorption are observed to be 3.16% and 5.87% by mass for the Geopolymer concrete without Alccofine. Even a small addition of Alccofine of 5% decreases the initial and final water absorption of the specimens up to 35% and 15% by mass, respectively. However, with further 5% addition of the Alccofines, a decrease in initial and final water absorption is observed to be 15% and 4.8%, respectively by mass. The reduction in the rate of initial and final absorption attributed to the fact that initially when the Alccofine is added, it occupies the voids of specimens due to its microfine structure. However, with the further

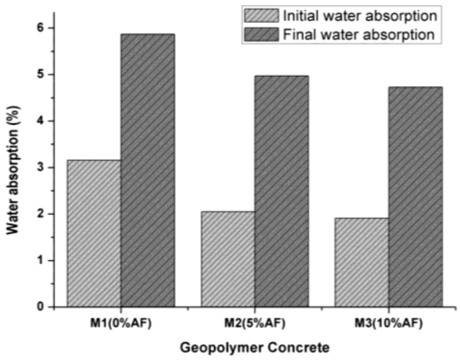


Fig. 9 Effect of Alccofine contents on initial and final water absorption

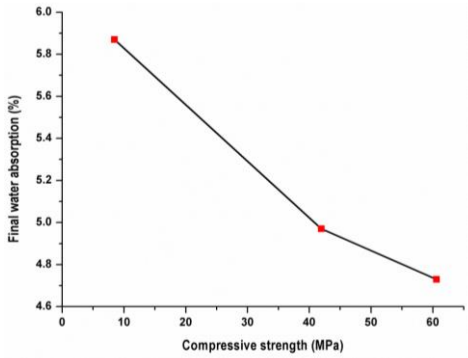


Fig. 10 Variation of final water absorption with compressive strength

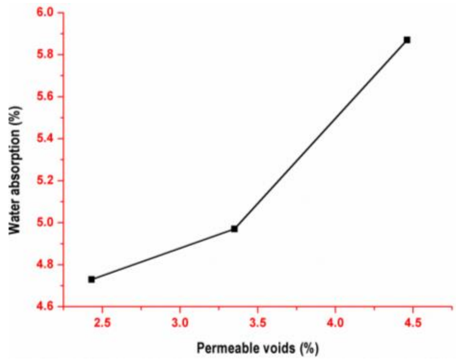


Fig. 11 The relationship between permeable voids and water absorption

addition of the Alccofine, there seem to be fewer voids available and as a result of which initial and final water absorption reduces. According to CEB (1989), if initial surface absorption of concrete is less than 3% by mass, then it can be termed as “good concrete”. In the present study, a specimen without Alccofine shows initial water absorption greater than 3% by mass; but on the addition of Alccofines, it decreases much below 3% by mass. So, The Geopolymer concrete made with Alccofine in the present study, therefore, can be regarded as the ‘good concrete’ in accordance with CEB (1989) recommendations.

The variation in the final water absorption with compressive strength is shown in Fig. 10. From Fig. 10, it is seen that with a decrease in the water absorption, compressive strength increases. The relationship between water absorption and permeable voids is shown in Fig. 11. From Fig. 11 it is seen that increase in permeable voids further increases the water absorption of GPC specimen.

5. Conclusions

From the above-discussed investigation results, following conclusions are drawn:

• A low compressive strength is achieved by GPC at ambient curing condition due to a lesser rate of polymerization. The addition of Alccofine enhanced the compressive strength of GPC significantly due to its unique structural properties like higher specific area which have filled the micropores in GPC, which is one of the prominent reason for achieving denser concrete. Higher calcium oxide content in Alccofine is also responsible for accelerating the polymerization process.

• The high compressive strength of geopolymer concrete is achieved by adding 10% Alccofine even at ambient temperature which addresses the difficulties faced during in case of higher temperature curing process.

• Permeable voids and compressive strength are inversely proportional to each other. Thus, a reduction in permeable voids results in an increase in compressive strength. A significant decrease in permeable voids in the order of nearly 25% with the addition of Alccofine by 5% is seen which is one of the prominent reason of getting better compressive strength in Alccofine added geopolymer concrete.

• So, Alccofine significantly improves the compressive strength as well as water permeation properties. Thus, a better durable geopolymer concrete is achieved with a small quantity of alccofines.

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