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Mechanical and microstructural properties of fly ash based geopolymer concrete incorporating alccofine at ambient curing

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HIGHLIGHTS

- GPC is widely used in construction industry when heat curing is adopted.
- Fly ash alone is not able to polymerize the GPC at ambient curing.
- Alccofine as an additional material has been proposed.
- The microstructure and properties of the newly material has been studied.
- Conventional concrete can be replaced by GPC even at ambient curing.

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ABSTRACT

In this study, the findings of the properties of fly ash based geopolymer concrete incorporating alccofine at ambient temperature, using 100% raw waste material as a binder have been reported. The fresh and hardened properties of alccofine activated geopolymer concrete like workability, water absorption, compressive, splitting tensile and flexural strengths have been studied as per Indian Standards. The prepared samples were investigated through X-ray diffraction (XRD) and Scanning electron microscope (SEM) for the determination of their phase, composition and microstructural properties. The results show that geopolymer concrete prepared with alccofine at ambient temperature not only improves the properties but also encourages to replace the conventional concrete. Furthermore, geopolymer concrete specimens prepared with alccofine emerge to ensure a densification process. The results of this study revealed that alccofine have a significant effect on the polymerization of the geopolymer concrete which in turn improves the strength and microstructural features. Also, increased molarity and fly ash content, improved the strength of all tested specimen.

1. Introduction

With the recent rapid increase in population the need for infrastructure development increased exponentially. This increased demand for new infrastructure is feeding the global demand for building materials like ordinary Portland cement (OPC), which is the main binding constituent for producing concrete. Currently, the global demand of the OPC is around 4 billion tons [1,2], which is second most required material after water and it is expected that this figure will increase by 8–10% in the coming years [3]. The production of cement is a highly energy intensive process which releases one-tonne of carbon dioxide (CO_2) for everytonne production of cement [4–8]. It is estimated that by the year 2020, the CO_2 emission will rise by 50% from the current levels [9–12]. These findings have put increased pressure on the concrete construction industry. Furthermore, industrial wastes require large areas of useful land for disposal which in turn has a huge impact on the environment and land usage. To overcome these challenges, researchers have recently worked on the development of substitute binder materials. One such material that has come to the forefront is by the alkali activation of silica and alumina rich compounds commonly known as Geopolymer Concrete (GPC) or Earth Friendly Concrete (EFC) [13]. The use of GPC/EFC results in low cost, CO_2 reduction, and environmentally friendly materials [14,15] by effectively utilizing industrial wastes such as fly ash,

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slag, rice husk ash etc. [16,17]. It is also found that GPC cured at elevated temperatures can out-perform conventional concrete in terms of strength and durability [18–23].

Wallah et al. reported that heat cured geopolymer concrete have better strength and resistance [24]. Okoye et al. utilized silica fume in various percentage and found that heat curing is best suited for geopolymer concrete [25]. Latif et al. partially replaced the fly ash and silica fume with Portland cement in different percentage in order to avoid the external heat curing to geopolymer concrete. The new geopolymer concrete resulted into a better strength at ambient temperature, however such a hybrid system does not utilize 100% waste as raw material [26]. Several published works are available highlighting the strength properties of geopolymer concrete produced using low calcium fly ash when cured at elevated heat for short periods [24,27–31]. However, the results are not encouraging at ambient temperature because polymerization occurs in the presence of heat which further leads to the formation of calcium aluminate silicate hydrate (CASH) and sodium aluminate silicate hydrate (NASH) compounds in the system. Literature also revealed that heat curing restricts the use of GPC to precast structural members only. So, there is a need to investigate the viability of geopolymer concrete cured at ambient temperature by examining its properties. Researchers have also tried the use of slag for obtaining ambient cured GPC with encouraging results.

In this study, low calcium fly ash based geopolymer concrete at ambient curing has been developed which is suitable for the construction industry. A blend of alccofine and fly ash was activated by alkaline solution to produced ambient cured concrete. The properties of the new binder are studied in terms of workability, compressive, splitting tensile and flexural strengths. Also, the behavior of GPC stress-strain in compression along with water absorption properties are studied. X-ray diffraction (XRD) and Scanning electron microscopy (SEM) was also performed to study the structure of the alccofine and fly ash based geopolymer concrete with different NaOH concentration, at ambient temperature. The focus of the current work is to develop and characterize the properties of ambient 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 1.95 was procured from Ultratech Ready Mix Concrete plant. The chemical composition of fly ash as determined by X-ray Fluorescence (XRF) analysis with minimum requirements as per IS 3812: 2003 [32] is given in Table 1. SEM analysis of fly ash is shown in Fig. 1. Further, the Fig. 2(a) shows the XRD analysis of fly ash and alccofine. Fly ash XRD clearly shows the presence of crystalline phase which is indicated by sharp peaks of quartz, mullite, and mellite.

2.1.2. Alccofine

Alccofine 1203 (AF) is a microfine material which is based on low calcium silicate slag. Alccofine controls high reactivity because of controlled granulation and it also improves workability by reducing the water demand. Due to its unique chemistry and ultrafine particle size, GPC strength improved [33–36]. Alccofine 1203 produces high-performance concrete either as a cement replacement or as an additive, to improve concrete properties in both fresh and hardened states. Chemical compositions and physical properties of alccofine 1203 used are given in Table 2. XRD was performed on alccofine, which normally consists of calcite and shown in Fig. 2(b).

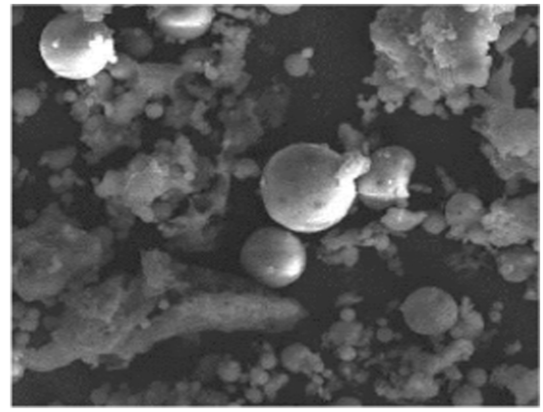

Fig. 1. SEM image of fly ash particles.

2.1.3. Aggregates

For the preparation of all the test specimens, good quality and well-graded aggregates in surface dry condition were used. Natural available fine sand and coarse aggregates with maximum size 14, 10 and 7 mm are used. Properties of the aggregates are given in Table 3 and grading curves are shown in Fig. 3. Both coarse and fine aggregates conform to IS 383-1970 [37] while fine aggregate used is crushed sand which is graded conforming to IS: 2386 (Part I)-1963 [38].

2.1.4. Alkaline activators

Sodium hydroxide and sodium silicate were used in this study as an alkaline activator which play 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) with SiO_2/Na_2O between 1.90 and 2.01 were procured commercially. The specification of the sodium silicate is as shown in Table 4.

2.1.5. Superplasticizer

Sodium silicate (SS) and sodium hydroxide (SH) solutions are more viscous than water, hence their use makes the GPC more cohesive and sticky than conventional concrete [39]. So, in order to improve the workability of the fresh geopolymer mix, a Naphthalene Sulphonate based water reducing superplasticizer confirming to IS 9103:1999 [40] is used.

2.2. Manufacture of geopolymer concrete

The mixture proportions of nine GPC with and without alccofine are studied. The mixes were prepared, based on the previous studies on the GPC [41–45]. Trial mixes prepared with more than 10% alccofine showed improved compressive strength but will result into uneconomical mix. Based on the trial results with different percentage of alccofine, it was decided to prepare all the nine mixes tabulated in Table 5, with 10% alccofine, while superplasticizer amount was kept at 2% of the fly ash content. The GPC mixtures are designed by their variable constituents in the mixture and are given in Table 5.

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 mixing and mixed with sodium silicate solution at a required ratio about 1 h before actual mixing of the GPC. Fly ash, aggregates and alccofine were first dry mixed in the pan mixture, followed by addition of the activator solutions to the dry materials and the mixing continued for about 5 min to produced alccofine activated fresh 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 and split tensile strength testing. The samples were then cured at the ambient condition at 27 °C. Indian Standard methods were used for sampling and testing of fresh and hardened GPC [46–48]. The procedure for preparing the GPC samples is outlined in the form of the flow chart as stated in Fig. 4.

Table 1
Chemical composition and physical properties of processed fly ash.

Sample	SiO_2 [%]	Al_2O_3 [%]	Fe_2O_3 [%]	SO_3 [%]	CaO [%]	Na_2O [%]	LOI [%]	Specific surface area [m^2/kg]
Fly ash	62.55	29.02	4.22	0.22	1.1	0.20	0.52	321.7
Requirement as per IS:3812-2003	70% min. by mass			3% max by mass	–	1.5% max by mass	5	320