

Geopolymer Sand as a replacement to Natural Sand in concrete

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Abstract. Geopolymers are highly alkaline binders used as an alternative for the replacement of OPC in the manufacture of concrete. The advantages of using geopolymers are that they impart excellent mechanical strength, help in reducing carbon di-oxide emission and helps in achieving good durability properties. In addition, the increasing demand for river sand, are leading to environmental effects, thus developing an urgent need to replace river sand with an alternative construction material. Geopolymerization of fly ash in 10 M NaOH and Na₂SiO₃: NaOH= 1.8:1 solution at 100°C for one hour produced geopolymer fly ash aggregate (GFAS) to produce an alternative replacement for river sand. The specific gravity of GFAS was 1.82 indicating that these particles were light weight. The properties of concrete such as compressive strength and flexural strength was also studied by replacing river sand with GFAS in concrete. It was observed that the mechanical strength of the GFAS was nearly same as that of the river sand concrete, thus indicating GFAS can be used as an alternative material to replace river sand in concrete.

1. Introduction

Every year the concrete production is increasing, throughout the world. With the increasing demand for concrete the demand for natural aggregates is also increasing, leading to the scarcity and the rise in the cost of these natural aggregates, which necessitates to pave way for the alternative sources to replace these natural aggregates [1,2]. Various alternatives such as fly ash, bottom ash, crusher dust, have been studied by researches to replace natural sand, however these alternatives were able to replace natural sand only partially [3]–[6]. In order to meet the increasing demand of natural aggregates this research focused on utilizing fly ash to produce geopolymer fly ash sand (GFAS), by mixing fly ash with the geopolymers as the production of fly ash from thermal power plants is increasing day by day leading to the disposal problems and environmental problems. Thus, by utilizing fly ash for the manufacture of aggregates it will help in overcoming the twin problem of the country.

Geopolymers are an inorganic alumino silicate base, formed by mixing of waste materials having glassy silica and alumina content in an alkaline activator solution to produce an alumina-silica chain which has binding properties [7], [8]. The alkaline activator is a catalysing medium wherein the glassy compositions of the source materials converts into a solid compound having robust binding properties [7], [8]. Since fly ash has abundant content of silica and alumina, it is considered as one of the major by-product for the production of geopolymers [8], [9]. The other waste materials which can be used for the production of geopolymers are GGBS, metakaolin, silica fume etc [9]–[16]. Geopolymers are



advantageously used as a replacement of OPC in concrete as they aim to reduce the environmental impact of construction such as high CO₂ and greenhouse gases production, use of greater proportion of waste pozzolana's, and also to improve concrete performance such as improved compressive strength and flexural strength, low permeability, good chemical resistance and excellent fire resistance behaviour [14], [17]–[23]. Thus an attempt is made to utilize geopolymers for the production of geopolymer fly ash sand (GFAS) in the current research work as not many researchers have focused in this area and this study would provide a new area to the existing literature. [4], [8]–[13], [16], [17], [23], [27]. As per the work conducted by S Rao et al. they synthesized geopolymer fly ash sand by using NaOH and by curing it at 100°C for 7 days to replace the natural river sand in mortar [29]. U.S Agrawal et al. also prepared geopolymer fly ash sand by using NaOH and Na₂SiO₃ and curing it at 100°C for 1 hour [30]. They found that geopolymer fly ash sand can be effectively used to replace natural sand in mortar [30]. However, both the studies focused on the study on the properties of geopolymer fly ash sand and its effect on replacement with natural sand in mortar. Therefore in this study, geopolymer fly ash sand is prepared to replace the natural sand in the concrete. Various tests such as specific gravity, water absorption, compressive strength and flexural strength were tested.

2. Materials and Experimental Program

2.1. Materials

GFAS was prepared by mixing class F fly ash (FA), and alkaline activator solution. The FA having (Blaine fineness = 382.3 m² / kg, specific gravity = 2.12) was procured from NTPC Sipat, India. Table 1 shows the physical and chemical properties such as specific gravity as per IS 1727 (1967) [31], specific surface area by Blaine's air permeability apparatus as per IS 1727 (1967) [31], and chemical composition which are determined by X-ray Fluorescence (XRF). The alkaline solution was prepared by adding sodium hydroxide pellets (purity 90%) to water (10 M), before mixing with sodium silicate solution (SiO₂: Na₂O=2, SiO₂=29.8% , Na₂O=14.98%). The river sand having (density of 2.7 g/cm³) and gravel (20mm and 10mm) having (density of 2.6 g/cm³) were used for the preparation of concrete, collected locally from Nagpur, India

Table 1. Physical and Chemical Properties of Fly ash

Properties	Fly ash (%wt)
Specific Gravity	2.12
Specific Surface Area	382.3m ² /kg
SiO ₂	52.32
Al ₂ O ₃	26.29
Fe ₂ O ₃	5.96
CaO	5.83
K ₂ O	0.81
MgO	1.57
Na ₂ O	0.04
TiO ₂	1.66
SO ₃	0.15
P ₂ O ₅	0.47
Loss on Ignition	4.48
Total	99.553

2.2. Preparation of GFAS

The preparation of GFAS was carried out in Pilot Plant at VNIT, Nagpur as shown in Figure 1. The geopolymer liquid solution (10M NaOH, $\text{Na}_2\text{SiO}_3/\text{NaOH}=2$) was prepared in the geopolymer liquid hopper (No.1, as marked in the Figure) and weighed in the measuring unit for geopolymer liquid solution (No. 2) and added in the centrifugal mixer (No. 5). Simultaneously, the known amount of FA from the fly ash hopper (No. 3) was transferred in to the centrifugal mixer (No. 5) with the help of screw conveyor (No. 4). In the fly ash hopper (No. 3) a heating unit is provided where the FA is heated up to 60°C. In the centrifugal mixer (No.5), the optimum geopolymer liquid solution was mixed with fly ash for 10 minutes in the proportion of 3:1 to produce a dry mix having workability of 26 seconds as per Vee-Bee Consistometer test. This mix was then passed through granulator (No. 6), and then in to the vibro sieve (7) where it was sieved through 4.75mm and 2.36mm sieve yielding GFAS particles of varying sizes. These sieved particles were immediately transferred in to the heating unit with a belt conveyor where heating is carried out for 1 hour at 100°C to produce GFAS particles as shown in Figure 2. This GFAS was then tested for specific gravity, water absorption and particle size distribution. As well the cubes and beams using GFAS by completely replacing river sand were cast and tested for compressive strength and flexural strength.



Figure 1. Pilot Plant for the preparation of GFAS.



Figure 2. Different Sizes of GFAS.

3. Results and Discussion

3.1. Specific Gravity and Water Absorption

The average specific gravity and the water absorption of the GFAS as determined by IS 2386 (Part-III): 1963 [33] was observed as 1.86 and 9.21% respectively making GFAS, a light-weight though porous sand as compared natural sand with specific gravity and water absorption as 2.67 and 0.82% respectively.

3.2. Particle Size Distribution

The particle size distribution curve for the GFAS and the natural sand was determined as per IS 2386 (Part-I):1963 [34] and was found to follow the Zone-I distribution as per IS 383: 2016 [35] and shown in Figure 3. From the Figure it can be observed that the particle size distribution curve of GFAS and NRS are within the upper and lower limits of natural sand thus confirming as zone-I as per IS 383: 2016 [35].

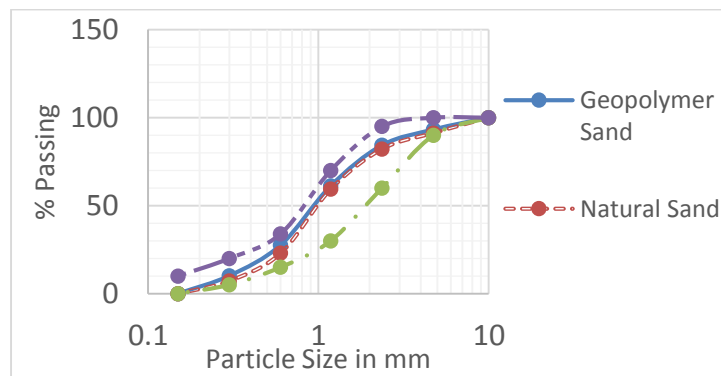


Figure 3. Particle Size Distribution of GFAS and NRS.

3.3. Compressive Strength

The compressive strength of the GFAS and NRS concrete was determined by preparing 16 cubes each of size 150mm X 150mm X 150mm and curing it for 7, 28 and 56 days as per IS 516: 1959 [35]. The cubes were prepared for 25MPa design strength as per the mix design shown in table-2. The compressive strength test results of GFAS Concrete (GFASConc) and NRS Concrete (NRSConc) are shown in Figure 4. From the Figure, it was observed that the GFASConc achieved a compressive strength of 95.1% at 28 days as compared to the NRSConc. However, at 56 days GFASConc achieved 99.6% compressive strength as compared to river sand indicating increase in the compressive strength with the increase in the curing time for concrete cubes.

Table 2. Mix Proportion for concrete.

Cube ID	Cement in kg/m ³	River Sand in kg/m ³	Geopolymer fly ash sand in kg/m ³	Coarse Aggregate in kg/m ³	Plasticizer in kg/m ³
				10mm 20mm	
GFASConc	350	-	700	770 1370	3.5
NRSConc	350	700	-	770 1370	1.75

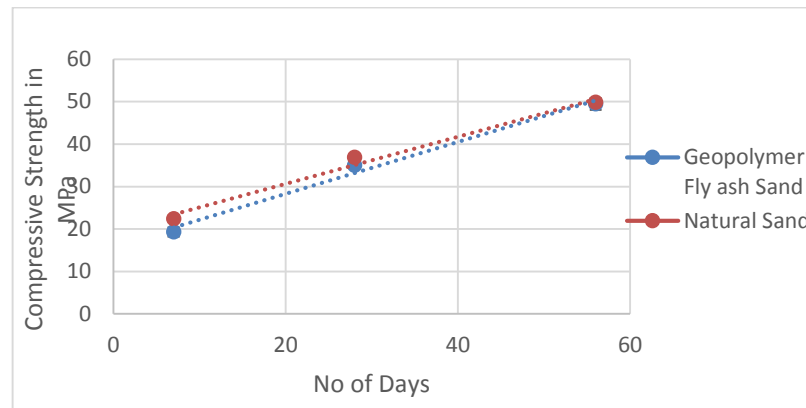


Figure 4. Compressive Strength of GFASConc and NRSConc.

3.4. Flexural Strength

The flexural strength of the concrete using GFAS was determined by the preparation of 6 beams each of size 150mm X 150mm X 700mm and testing it after 28 days and 56 days curing as per IS 516: 1959 [35]. The results were compared with natural sand beams as shown in Figure 5. From the Figure, it can be observed that GFASConc cubes achieved 97.74% strength at 28 days and 98.81% strength at 56 days as compared to NRSConc indicating GFAS can be used to replace river sand in concrete as well as in road construction activities.

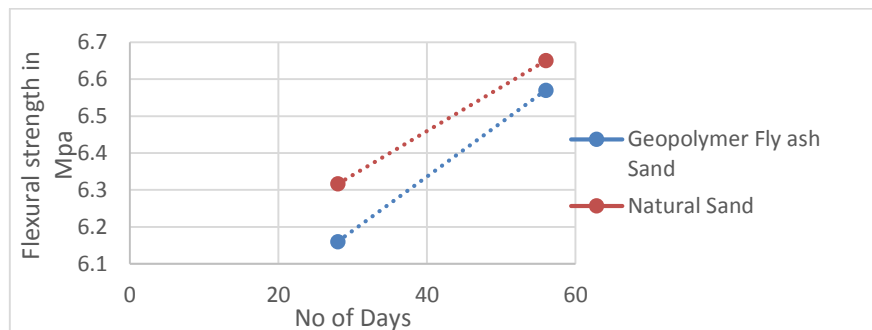


Figure 5. Flexural Strength of GFASConc and NRSConc.

4. Conclusion

GFAS was prepared by mixing alkaline activator containing 10M NaOH and Na₂SiO₃/NaOH ratio= 2:1 as with fly ash in the proportion of 1:3 respectively yielding similar properties as that of natural sand.

- GFAS had a specific gravity of 1.86 which was less as compared to natural sand (2.67), indicating GFAS are light weight particles.
- The particle size distribution curve of GFAS confirmed to zone-I, which was similar to that of river sand.
- The water absorption of 9.21% was observed in case of GFAS while NRS had 0.82% water absorption indicating GFAS are porous in nature.

- d) The compressive strength properties of the GFASConc was 95.1% at 28 days as and nearly 100% at 56 days as compared to the NRSSConc indicating increase in the compressive strength with the increase in the curing time for concrete cubes.
- e) The flexural strength result of GFASConc was 97.74% strength at 28 days and 98.81% strength at 56 days as compared to NRSSConc indicating GFAS can be used to replace river sand in concrete
- f) With this study, it may be concluded that the GFAS could be used suitably as an alternative to natural sand in construction activities.

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