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Characteristic study of geopolymer fly ash sand as a replacement to natural river sand

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HIGHLIGHTS

- A new approach to replace the natural sand by artificial sand in the field of civil engineering.
- Fly ash and geopolymer was utilized to prepare artificial sand known as geopolymer fly ash sand (GFS).
- Different properties of geopolymer fly sand (GFS) were studied and compared with the natural river sand (NRS).

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ABSTRACT

The increase in construction activities is leading to the depletion and the exploitation of the natural river sand, causing adverse effects on the environment. Therefore there is an urgent need to find an alternative substitute or replacement of natural river sand. Presently crushed sand or high volume fly ash are used as natural sand replacement, however geoploymer fly ash sand could be better environment friendly replacement. In this research geopolymer fly ash sand (GFS) particles are prepared by geopolymerising fly ash and its properties are compared with natural sand which yield satisfactory results in terms of physical, chemical, mechanical and durability properties. GFS has comparable specific gravity (2.46), good particle size distribution (zone-I) and frictional angle (42°) as compared to natural river sand (NRS). Though GFS has pH (12.2) value and water absorption (5.61%) value slightly higher than the NRS, the soundness and the alkali silica reaction are within limits as per Indian Standard code. The mortar specimens with GFS achieved 93.6% at 28 day compressive strength as compared to NRS, indicating GFS has the potential to replace natural river sand in construction activities.

1. Introduction

With the increase in the construction activities, the demand for river sand has increased exponentially causing the depletion and exploitation of the natural sand thus resulting adverse effects on the environment such as sliding of the river shores, lowering water table, etc. Hence, there is an urgent need for the identification of an alternative binding material for the replacement of river sand in the preparation of concrete [1]. In addition to this, in India, nearly 110 million tons of fly ash is produced annually from the thermal power plants, out of which only 30% fly ash is used, while the rest is dumped into the landfills [2]. Various researches were done by replacing natural sand with fly ash, however it was found that fly ash can only replace natural sand partially [3–6]. The study conducted by Siddique et al. suggested replacement of natural sand by fly ash up to 40% [4]. If the natural sand is completely replaced by fly ash a large reduction in compressive strength (73.1%) and workability (13.4%) was reported bya Turhan Bilin et al. [7]. Thus, to utilize the large volumes of fly ash and to reduce the use of depleting natural sand, this research focused on the preparation of the geopolymer fly ash sand and its incorporation into the mortar and concrete as a complete replacement of natural sand.

In the recent past, geopolymer concrete are widely researched as a replacement to traditional OPC as they help in reducing CO_2 emission by 26–45% [8–12]. Another major advantage of utilizing geoploymer concrete is its ability to utilize waste materials such as fly ash, ground granulated blast furnace slag, etc as, geopolymers are mainly composed of inorganic alumino-silicate network, formed by the dissolution of materials having silica and alumina in an alkaline solution containing sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) or potassium hydroxide (KOH) and potassium silicate (K_2SiO_3) yielding polymeric Si–O–Al–O bonds

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in polymeric form [8,13,14]. The physio-chemical, microstructural and mechanical properties of the geopolymer product depends on the chemical compositions of the source materials and the alkaline liquid [11,14,15]. Geopolymer concrete has been reported to achieve good mechanical strength and durability properties [16–18]. However most of the studies reported that heat curing is required to activate geopolymer concrete. Generally with the increase in the temperature range from 60° to 120 °C, an increase in the mechanical strength properties of the geopolymer concrete was observed by many researchers [18–24]. Whereas some researchers reported a gradual increase in strength of geopolymer concrete at ambient curing temperature [20,25,26]. Geopolymer binders have contributed significantly, towards resistances to sulphate, acid and fire exposures [4,8–13,16,17,23,27,28]. Many researches were done by replacing OPC cement with geopolymer however only few researches have focused on replacing geopolymer with natural river sand [9,12,24,28]. As per the work conducted by E J Guades, they have replaced fly ash with natural sand in the preparation of geopolymer fly ash mortar and observed that with the increase in the amount of sand the compressive and tensile strength of the mortar reduces [29].

In the study conducted by S Rao et al. [30] laboratory trial were conducted to produce fly ash geopolymer sand as a replacement the natural river sand in concrete. Various properties such as specific gravity, particle size distribution, pH, TDS, frictional angle, XRD, SEM and mortar properties of fly ash geopolymer sand. In this study, they have used laboratory grade amorphous silica and sodium hydroxide and the duration of curing time required for fly ash geopolymer sand was very high (100 °C for 7 days) but it has the potential to be reduced and applied in concrete. Hence the current research firstly, focused on examining the usefulness of geopolymer fly ash sand (GFS) as a replacement to natural river sand (NRS) secondly, on the reduction of curing period to one hour and thirdly, on the use of industrial grade of sodium silicate and sodium hydroxide instead of laboratory grade chemicals to meet an alternative environment friendly as well as techno-economical material to replace the depleting NRS and also to utilize the abundant fly ash in the country.

2. Materials and experimental program

2.1. Materials

The geopolymer fly ash sand (GFS) used in this study, was prepared by mixing fly ash in the sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3), geopolymer solution. The fly ash used in the study was procured from Sipat Thermal Power Plant, India and its 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], particle size distribution by Microtac Particle Size analyzer and chemical composition as per XRF (X-ray fluorescence) were determined and tabulated in Table 1. The specific gravity and the specific surface area of the fly ash particles was found as of 2.12 and 382.3 m^2/kg respectively. The diameter of the fly ash particle varied from 37 μm to 420 μm and the median particle size of 159.7 μm as observed in Fig. 1. On the basis of SiO_2 = 52.32%, Al_2O_3 = 26.29%, Fe_2O_3 = 5.96% and CaO = 5.83% content the fly ash was identified as class-F fly ash as per ASTM (C618 08) [47].

The NaOH and Na_2SiO_3 used for the study was procured from Kerala, India having 90% purity in the pellet form and SiO_2: Na_2O = 2 (where, SiO_2 = 29.8%, Na_2O = 14.9%) respectively. The other materials such as cement confirming to IS 8112: 2013 [32] and natural river sand (NRS) were obtained locally.

2.2. Optimization of the geopolymer liquid solution

Preliminary trials were conducted in order to optimize the amount of NaOH and Na_2SiO_3 for the preparation of geopolymer fly ash sand (GFS). For this purpose the cubes of 70.7 mm × 70.7 mm × 70.7 mm were cast by mixing fly ash, NaOH and Na_2SiO_3 in the proportion of 3:1 by varying the molarity of NaOH from 6 M-12 M and the ratio of Na_2SiO_3/NaOH from 0.5 to 2.5 respectively as shown in Fig. 2. The compressive strength of the cubes was tested after heating the specimens for 1 h at 100 °C. From the Fig. 2, it was observed that the 10 M NaOH and Na_2SiO_3/NaOH ratio of 2 yield maximum compressive strength and was selected as the optimum geopolymer liquid solution.

2.3. Preparation of geopolymer fly ash sand particles (GFS)

For the preparation of GFS, fly ash was heated up to 60 °C to remove extra moisture content and the optimum geopolymer liquid solution as obtained (10 M NaOH, Na_2SiO_3/NaOH = 2) were mixed together for 10 min in the proportion of 3:1 to produce a dry mix having a workability of 26 s as per Vee Bee Consistometer Test [48]. This mix was then sieved through 4.75 mm and 2.36 mm sieve to yield particles of varying size similar to the shape and size of the natural river sand (NRS) (Fig. 3) after heating the sieved particles for 1 h at 100 °C. After heating the particles, it was kept in ambient temperature for one day. Tests such as specific gravity, water absorption, particle size distribution direct shear test, pH, soundness, alkali

Table 1
Physical and chemical properties of fly ash.

Properties	Fly ash %wt
Specific Gravity	2.12
Specific Surface Area	382.3 m^2/kg
Particle Size Distribution	37–420 μm
Median Particle Size	159.7 μm
SiO_2	52.32
Al_2O_3	26.29
Fe_2O_3	5.96
CaO	5.83
K_2O	0.81
MgO	1.57
Na_2O	0.04
TiO_2	1.66
SO_3	0.15
P_2O_5	0.47
Loss on Ignition	4.48
Total	99.553

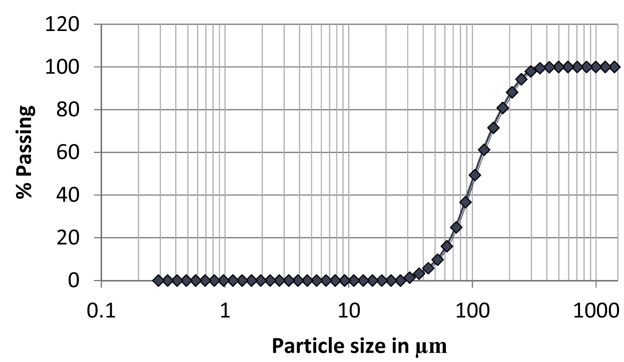

Fig. 1. Particle size analysis of fly ash.

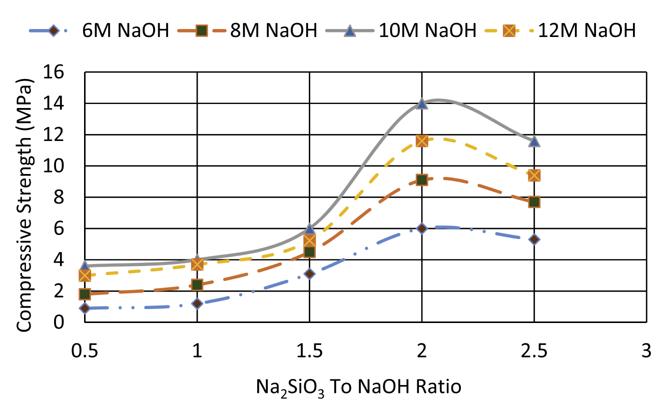

Fig. 2. Optimization of geopolymer liquid solution as a function of NaOH and Na_2SiO_3/NaOH.