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# Formulation of Fly Ash Geopolymer Sand (FGPS) as a Sustainable Alternative to Natural River Sand

D. D. Mohan Kumar[1], K. Asha[2]

[1]*P.G. Student, Department of Civil Engineering, Dayananda Sagar College of Engineering, Bangalore, India*
[2]*Associate Professor, Department of Civil Engineering, Dayananda Sagar College of Engineering, Bangalore, India*

***Abstract*— In India, country is facing two major problems, one is the scarcity of natural river sand with increase in the demand of it by the construction industry for the infrastructural development. And the other is the 100% utilization of fly ash, by-product produced annually by coal based thermal power plant in the country. By adopting fly ash geopolymerization processes we can produce a sustainable alternative to natural river sand. With this formulation we can overcome twin problems faced by the country and also save our surrounding environment. In this research fly ash geopolymer sand (FGPS) particles are prepared by Class F fly ash geopolymerization process and its properties are compared with natural river sand which yield satisfactory results in terms of physical, chemical properties. FGPS has comparable specific gravity (2.41), good particle size distribution (zone-I) as compared to natural river sand (NRS). Though FGPS has pH (11.37) value, TDS (799mg/L) and water absorption (6.45%) value slightly higher than the NRS as per Indian Standard code.**

**Index Terms—Fly Ash, Fly Ash Geopolymer, Sand Geopolymer, Natural River Sand**

## I. Introduction

In the last 15 years it has been clear that availability of natural river sand (fine aggregate) is decreasing. As a part of infrastructural development of the country there is an increase construction activity which in turn increase the demand of the Natural River Sand causing depletion and exploitation of the natural river sand thus resulting adverse effects on the environment such as sliding of the river shores, lowering water table, etc. hence there is a urgent need for identification of an alternative filling material for the replacement natural river sand in concrete. In addition to this, In India, nearly 180 million tons of fly ash is produced in the annual year 2016-2017 as a by-product from coal based thermal power plant, out of which only 40% (Class C) fly ash is used, utilization of the remaining (Class F) fly ash is a big task which need to be taken a call for by the researcher [1].

The fly ash geopolymer process is one of such alternative methodology which can overcome the twin problem of the country that is an alternative for Natural River sand (fine aggregate) can be produced and the 100% fly ash utilization can be done to save the river and environment.

The production of fly ash-based geopolymer is composition of fly ash activated using an alkaline activator which undergoes a process called geopolymerization which can occur under mild conditions and is considered to be a cleaner process than that of the production of cement because it produce a lower $CO_2$ foot print to the environment. The main factor affecting the geopolymarization process is the concentration and amount of alkali solution that sodium hydroxide, sodium silicate to sodium hydroxide ratio, the solid to solution ratio, temperature and period at which curing is carried. Fly ash based geopolymer produced have good mechanical properties like compressive strength and durability properties like high resistance to chloride, sulphuric and acid efflorescence [2].The fly ash based geopolymer exhibits both amorphous and crystalline phase at different temperature The microstructure of geopolymer consist of dense fly ash and alkaline activator gel which form an heterogeneous matrix which also exhibits both thermal and chemical stability of particle suspension with less water absorption property then that with the ordinary Portland [3]. Fly ash based Geopolymer cement exhibits a much higher spallation resistance then that of the ordinary Portland cement when it is suddenly cooled down by water after the high temperature heating to archive the desired results which also make it as an excellent construction for the structure prone to fire [4]. As the concentration of sodium silicate in the form of alkaline activator increases in the fly ash based geopolymer it compressive strength also increases [5]. The compressive strength of fly ash based geopolymer increases as the sodium silicate/sodium hydroxide ratio increases [6]. The compressive strength of the fly ash based geopolymer paste is greatly affected sodium silicate percentage added and aluminate content precent in the fly ash that is the Si/Al ratio. The fly ash based geopolymer paste also shows high polymerization reactivity at an early age [7]. Fly ash based geopolymer composite specimens have the existence of cordierite, mullite, quartz composition by the Xrd result [8].The above study made by the well know researcher give us an affair idea about the vast application of fly ash based geopolymer.

In some recent research conduct by the other researcher they have synthesis and characterized the concept of fly ash geopolymer sand but coming to the overall study of the materials used in it and its factor effecting the strength of the fly ash geopolymer sand was a gap which is taken up by us in the present study [9] and [10].

In the present research a lab trail conducted to produce fly ash geopolymer sand which can be used as sustainable alternative for (fine aggregate) Natural River sand in concrete. In this study we have used fly ash (Class F), sodium hydroxide pellets and sodium silicate solution with varying factors which affect the compressive strength of fly ash based geopolymer specimen such as molarity of sodium hydroxide solution, solid to solution ratio, sodium silicate to sodium hydroxide, curing period and temperature, to produce fly ash geopolymer sand

(FGPS). Further the study focus on comparing the various physical, chemical and mineralogical properties of fly ash Geopolymer Sand with natural river sand and also aim in developing the technique to utilize the fly ash produced in India by the thermal power plant.

## II. Materials and Methodology

### *A) Materials:*

Fly ash was procured from Raichur thermal power plant (RTPS) located in Shakthinagar, Raichur district, Karnataka state, India which is of class F grade with low calcium content. An industrial grade sodium hydroxide pellets and sodium silicate solution was poured from chemical industry in Bangalore. And locally available natural river sand in Bangalore was used for comparative study of all the properties with that of fly ash geopolymer sand. All the physical and chemical properties of fly ash are stated in Table-I.

TABLE I
PHYSICAL-CHEMICAL PROPERTIES OF FLY ASH (CLASS F)

| Parameter | Value |
|---|---|
| **Physical properties:** | |
| Specific gravity | 2.18 |
| **Particle size distribution (%) by Hydrometer Analysis** | |
| Sand fraction (4.75 mm to 75micron) | 29% |
| Silt fraction (75 micron to 2 micron) | 69% |
| Clay fraction (< 2 micron) | 4% |
| **Chemical properties:** | |
| pH | 11.58 |
| EC (µS/cm) | 811 |
| TDS (mg/L) | 527 |
| Loss on ignition (%) | 0.2 |

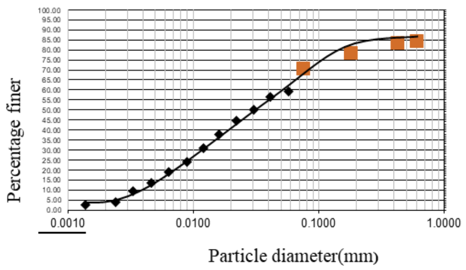


Fig. 1. Particle Size Distribution of Fly Ash (Class F)

### *B) Preliminary test to optimize the fly ash based geopolymer specimen:*

Preliminary test were conducted to obtain the optimum amount of material to be added to obtain the high compressive strength fly ash based geopolymer specimen by varying the molarity of sodium hydroxide solution (NaOH), sodium silicate (Na2SiO3) to sodium hydroxide (NaOH) ratio and solid to solution ratio with varying curing temperature and period. For obtaining the compressive strength of the specimen 70.6 x 70.6 x 70.6 mm cube moulds where used. Varying the NaOH from 8M to 12M, Na2SiO3/NaOH ratio from 0.5:1 to 2:1, solid to solution ratio from 2:1 to 4:1 with variation of curing temperature from 70°C to 150°C and curing period from 1hr to 3hrs.

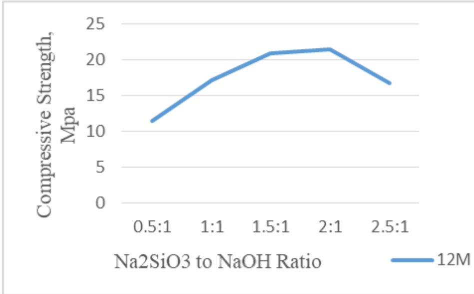


Fig. 2. Effect of Sodium silicate to sodium hydroxide ratio on the Compressive strength of fly ash based geopolymer

From the above Preliminary test conducted the higher compressive strength was achieved for 12M NaOH, Na2SiO3/NaOH ratio 1.5:1, Solid to solution ratio 3.5:1 with curing temperature of 120°C and curing period from 2.3hrs.

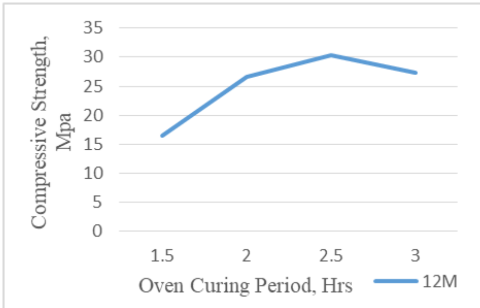


Fig. 3. Effect of curing period on the Compressive strength of fly ash based geopolymer

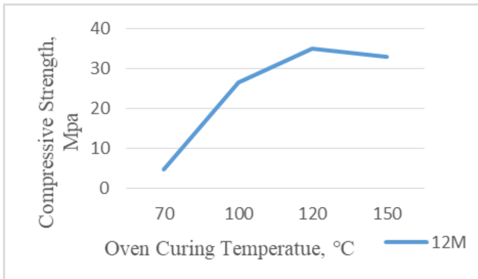


Fig. 4. Effect of curing temperature on the Compressive strength of fly ash based geopolymer

### *C) Methodology for preparation of fly ash geopolymer sand (FGPS):*

For the preparation of FGPS, fly ash was heated in oven at 60 °C to remove moisture content and the optimum amount of material obtained (12 M NaOH, Na2SiO3/NaOH = 1.5:1) were mixed together for 5 min in the proportion of 3.5:1 to produce a dry mix of 1.4Kg/m3 further kept in Oven curing for 15min at 120°C and This dry mix was then sieved through 4.75 mm sieve to yield particles of varying size similar to the shape and size of the natural river sand (NRS) and again the sieved particles were heated for 2h 30min at 120°C, it was kept in ambient temperature for 24hrs and used for further analysis of physical and chemical properties.


Fig. 5. Fly ash geopolymer sand

## III. RESULTS AND DISCUSSION

*A) Physical properties:*

1. *Specific gravity and Water Absorption of FAPS and natural river sand:*

   The specific gravity and water absorption of FGPS and natural river sand particles were determined in accordance with IS 2386-Part III (1963). The average specific gravity of FGPS and natural river sand particles correspond to 2.41 and 2.62 respectively (Table *I*). The specific gravity of fly ash corresponds 2.18 (TABLE ). The dense fly ash and alkaline activator gel which form a heterogeneous matrix along with dissolution of cenospheres during geopolymer reactions is considered responsible for imparting higher Specific gravity to the FGPS particles in comparison to fly ash particles. The average water absorption of FGPS and natural river sand particles corresponds to 6.45% and 0.96% respectively.

2. *Grain size distribution of FGPS and natural river sand:*

   The sieve analysis was determined in accordance with IS 2386- Part I (1963) Fig. 6 presents the grain size distribution of FGPS and river sand specimens. The FGPS particles are characterized by coarse (4.75 to 2 mm), medium (2mm to 425 micron) and fine (425 to 75micron) sand fractions of 35, 46 and 19% respectively. The natural river sand specimen also as course (22%) medium (59 %) and fine (19 %) sand fractions (Table 2, Fig. 6). The FGPS particles are characterized by uniformity coefficient (Cu) and coefficient of curvature (Cc) values of 7.2 and 1.03 respectively classifying them as well graded sand (SW) according to IS 1498 (1970). The Natural river sand specimen classifies as poorly graded sand (SP) based on its Cu (4.09) value.

The uniformity coefficient (Cu) and coefficient of curvature (Cc) are defined as (IS 1498 1970):

$$C_u = \frac{D60}{D10} \qquad (1)$$

$$C_c = \frac{D^2 30}{D60 \times D10} \qquad (2)$$

D60, D30 and D10 refer to particle diameters in the particle size distribution curves at 60, 30 and 10 % finer respectively.

TABLE I
PHYSICAL-CHEMICAL PROPERTIES OF FAPS AND NRS PARTICLES

| PARAMETERS | FGPS | NRS |
|---|---|---|
| **Physical properties** | | |
| Specific gravity | 2.41 | 2.62 |
| Water Absorption (%) | 6.45 | 0.96 |
| **Particle size distribution (%)** | | |
| Coarse Sand fraction (4.75 to 2 mm) | 34 | 22 |
| Medium sand fraction (2mm to 425micron) | 46 | 59 |
| Fine sand fraction (425 to 75micron) | 19 | 19 |
| Uniformity coefficient (Cu) | 7.2 | 4.09 |
| Coefficient of curvature (Cc) | 1.03 | 1.35 |
| **Chemical properties** | | |
| pH | 11.37 | 9.58 |
| TDS (mg/L) | 799 | 111 |

Well graded sands (SW) possess uniformity coefficient > 6 and coefficient of curvature between 1 and 3 (IS 1498 1970).

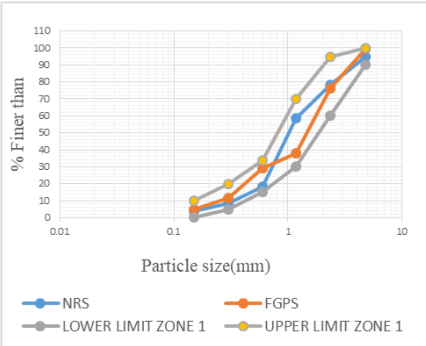


Fig. 6. Grain Size Distribution of FGPS and Natural River Sand

*B) Chemical properties:*

1. pH and Electrical conductivity of FGPS and Natural river sand specimens: The pH of FGPS particles correspond to 11.3 (Table-I). Blending the strongly alkaline FGPS particles with cement to prepare concrete should not impede their mechanical properties, as strong alkaline pH (12.8-13.7) is induced on cement hydration.
2. The electrical conductivity (EC) of the FAPS specimens correspond to 1.23 mS/cm that corresponds to total dissolved solids (TDS) concentration of 799 mg/L

$$1\text{mg/L} = 1.54\ \mu\text{S/cm} \qquad (3)$$

Based on TDS value, the FGPS particles classify as fairly good soil material IS 2720-Part 21. The river sand particles are characterized by pH of 9.58 and TDS of 111 mg/L respectively (Table-II).

## IV. Conclusion

The optimum formulation obtained to produce the fly ash geopolymer sand (FGPS) was 12 M Sodium Silicate solution with sodium silicate /sodium hydroxide ratio equal to 1.5:1 and solid to solution ratio of 3.5:1 with curing period of 2.3hrs and curing temperature at 120°C respectively produced a similar physical and chemical properties as that of natural river sand. While comparing the physical properties of the fly ash geopolymer sand with that of the natural river sand, an average specific gravity of 2.41 which was slightly lesser when compared to natural river sand 2.62, however they exhibited a higher specific gravity than fly ash 2.18 due to dense fly ash and alkaline activatior gel which form a heterogeneous matrix. The average water absorption of fly ash geopolymer sand 6.45% was a higher value compared to that of natural river sand 0.96%. The particle size distribution curve of FGPS and natural sand both confirmed to zone-I and the coefficient of curvature and coefficient of uniformity of fly ash geopolymer sand particles classified it as well graded soil (SW) as uniformity coefficient (Cu) = 7.2 and coefficient of curvature (Cc) = 1.03 . The chemical properties of fly ash geopolymer sand the pH of 11.37 and total dissolved solid of 799mg/L was higher when compared with natural river sand the pH of 9.58 and total dissolved solid of 111mg/L.

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