JOURNAL OF BASIC SCIENCE AND ENGINEERING

Study of Fly Ash Based Geopolymer Concrete using GGBS as Binary Blend for its Strength and Microstructural properties

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Abstract: Cement and power demand of a developing country has led to the installation of cement and power plants. These plants are causing an impact on environment in the form of carbon dioxide emission and formation of ash ponds. Geopolymer concrete is a concrete with no cement. Therefore, an attempt is made to create concrete with no cement using fly ash. Strength and microstructural properties are studied on fly ash based geopolymer concrete with GGBS as binary blend along with conventional concrete. FG40 i.e., 40% fly ash and 60% GGBS is emerged as an optimum blend with higher strength properties and compact microstructure.

Keywords: Geopolymer concrete, alkaline liquid, microstructure, fly ash, GGBS, GPC

1. Introduction

Infrastructural needs of developing countries has a demand for cement and power, which initiated the installation of new cement plants and coal fired thermal power plants. Cement and thermal plants are making an impact on environment in terms of emission of green house gases and converting valuable lands into dumping yards. One ton of cement production is causing an emission of around one ton of carbon dioxide together with minor amounts of NO_x (Oxides of nitrogen) and CH_4 (Methane)[1]. 40,000 hectares of land is converted into ash ponds[2]. A typical ash pond is shown in figure 1.

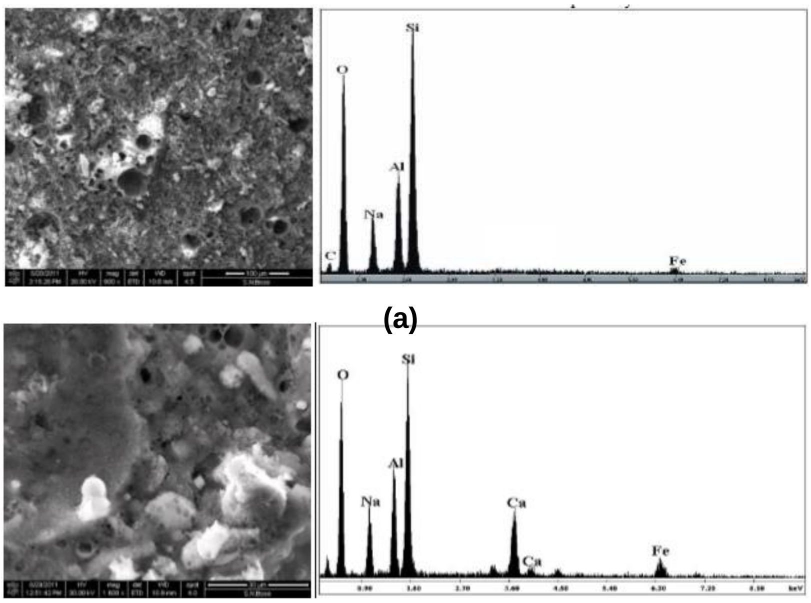
Figure 1. Typical Ash Pond

These issues are to be tackled either by partially replacing cement in concrete or by developing an alternate material. High Volume Fly Ash (HVFA) concrete is a recent advancement towards partial replacement of cement in concrete, where cement upto
60% is replaced by fly ash or a greener alternative in the form of Geopolymer concrete,

where cement is totally replaced by fly ash. Therefore, an attempt is made to study strength and microstructural properties of fly ash based geopolymer concrete with GGBS as binary blend.

2. Literature review

The term ‘geopolymer’ was coined by Joseph Davidovits in 1978. It is synthesized by source materials rich in silicon and aluminium of geological origin or by-product materials such as fly ash and alkaline solutions (Hardjito et al., 2003)[3]. The alkaline liquids are from soluble alkali metals that are usually sodium or potassium based (Wallah and Rangan 2006)[4]. Optimization of glassy phases of precursor materials can be achieved by blended GPC (Duxon, 2006)[5].
The effect of adding Ca-containing substances such as slag, cement and lime is manifested not only by increased strength, but also by lowered porosity (Skvara et al., 2006[6]; Nath and sarkar, 2014[7]). GGBS blended specimens appear to be smoother and compact than specimens without GGBS, due to the formation of C-S-H as shown in figure 2. Presence of calcium along with sodium alumino silicate hydrate in the reaction products increases with increase in GGBS content (Nath and Sarkar, 2014[7]; Dutta and Ghosh, 2014[8]).



(b)

Figure 2. Microstructure of Samples (a) Without GGBS (b) With 15% GGBS

Source: (Dutta and Ghosh, 2014[99])

3. Materials and methodology

3.1 Materials

Fly ash used as base material, is procured from Bellary thermal power plant, Kudithini, Karnataka and GGBS used as blending material, is obtained from JSW, Bellary, Karnataka. Liquid sodium silicate with 47.50% concentration and sodium hydroxide in flakes form with 97% purity, are procured from Shree Chem, Bangalore. Locally available coarse, fine aggregates and cement are used. Table 1 and 2 shows the physical and chemical properties of materials used. Conplast SP 430 is used as Naphthalene based superplasticizer. Different materials used are shown in figure 3.

Table 1. Physical Properties of Materials Used

Material	Fly ash	GGBS	Fine aggregate	Coarse aggregate	Alkaline liquid
Specific gravity	2.20	2.79	2.42	2.5	1.54

Table 2. Chemical Properties of Materials Used

Sl. no.	Constituents	Percentage by weight		
		Fly ash	GGBS	Cement
1	Silicon dioxide (SiO_2)	55.31	35.49	19.93
2	Aluminium oxide (Al_2O_3)	29.04	17.88	4.23
3	Iron oxide (Fe_2O_3)	4.50	0.22	4.76
4	Calcium oxide (CaO)	-	35.58	60.40

Fly ash **GGBS** **Liquid Na_2SiO_3** **NaOH flakes**

Figure 3. Different Materials Used

3.2 Methodology

Geopolymer concrete is produced with fly ash as base material. Blended geopolymer concrete is produced by blending fly ash with GGBS at 20% replacement level. Strength and microstructural properties are studied for these blends. Also a comparison is made with conventional concrete.

3.2.1. Mix proportions: Mix design is carried out for M30 grade of concrete. Conventional concrete is proportioned as per IS:10262-2009[9] and GPC is proportioned as per the procedure given by Patankar et al., (2015)[10], due to lack of standard mix design procedure for geopolymer concrete. Alkaline liquid to fly ash ratio is kept as 0.35 and hydroxide to silicate ratio is taken as 1.00. Concentration of sodium hydroxide solution is maintained as 13M. Mix proportion for GPC and conventional concrete is shown in Table 3.

Table 3. Mix proportion of GPC and CC

Concrete type	Geopolymer concrete	Conventional concrete
Mix proportion	1:1.51:3.28:0.35	1:1.48:2.6:0.45

3.2.2 Casting and curing: Mixing and casting of specimens is carried out in conventional manner. Fine aggregate, coarse aggregate and binding materials are mixed in dry condition for 3-4 minutes and then the alkaline solution, with superplasticizer at 3% by weight of binding material, is added to the dry mix. Figure 4 shows the casting of specimens. Specimens are demoulded after 24 hrs of casting and subjected to curing. Conventional concrete is subjected to water curing and GPC is subjected to ambient curing.

Figure 4. Casting and Curing of Specimens

4. Results and discussions

The specimens are designated as FA100 for 100% fly ash and FGn for fly ash and GGBS blends at n% of fly ash. Fly ash is replaced at an increment of 20% by weight with GGBS. Strength and microstructural properties are studied on geopolymer concrete and compared with conventional concrete.

4.1 Strength characteristics

Strength of hardened concrete is measured by compressive strength test and flexural strength test according to IS: 516-1959 (Reaffirmed in 2004)[11], split tensile stength test according to IS: 5816-1999[12], shear strength test according the procedure proposed by C.D. Modhera and N. K. Bairagi [13] and impact strength test according the procedure proposed by ACI committee 544 (ACI 544.2R-89)[14]. Results of strength characteristics are shown in table 4. Variation of strength characteristics is shown in figure 6 and 7.

Table 4. Strength Characteristic Results for GPC and CC

Specimen ID	Compressive strength (MPa)	Split tensile strength (MPa)	Flexural strength (MPa)	Shear strength (MPa)	Impact strength at final failure (kN-m)
FA 100	48.89	4.01	7.53	4.44	17.92
FG 80	50.37	4.95	7.73	6.11	19.31
FG 60	51.26	5.00	8.00	6.48	20.69
FG 40	60.44	5.19	8.67	7.78	28.17
FG 20	55.70	4.95	7.47	7.41	14.83
FG 0	44.15	3.96	7.20	6.67	2.19
CC	38.96	3.25	5.93	3.89	0.71

Vol. 21, No. 1, (2024)
ISSN: 1005-0930

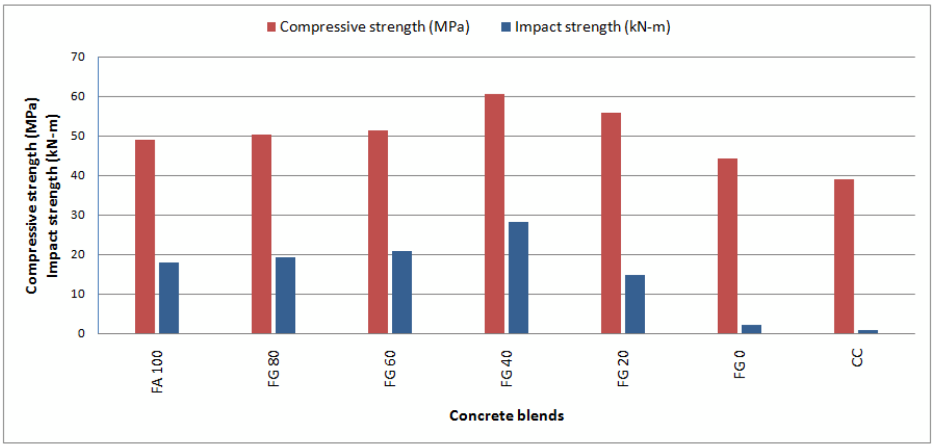


Figure 6. Variation of Compressive and Impact Strength

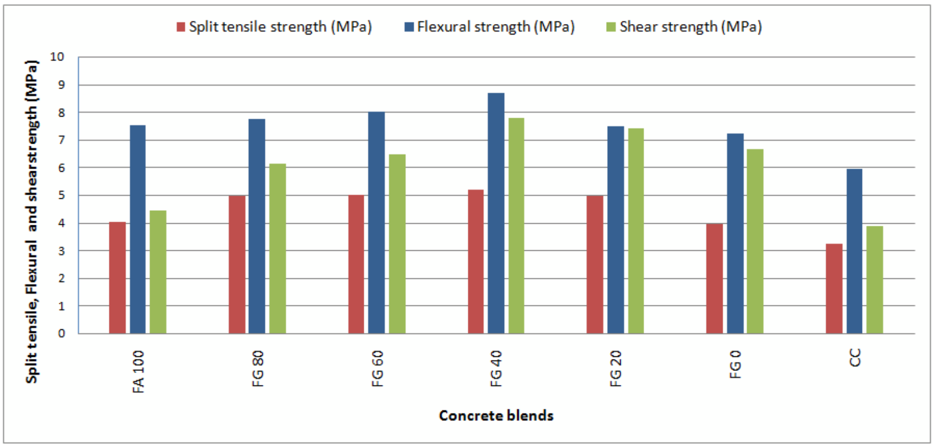


Figure 7. Variation of Split Tensile, Flexural and Shear strength

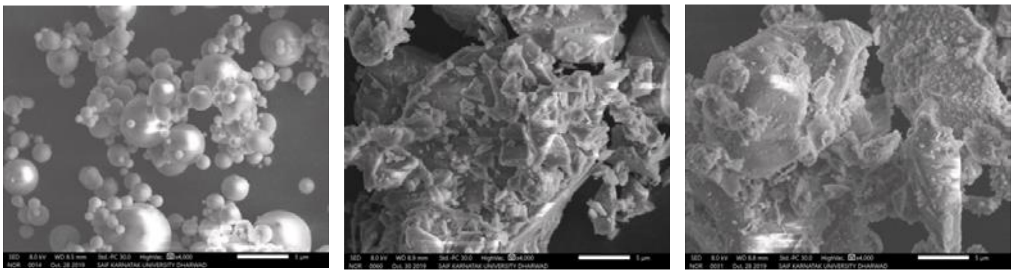
Strength of 100% fly ash geopolymer concrete is more than conventional concrete. It shows 14-27% increase in strength as compared to conventional concrete. Replacement of fly ash with GGBS shows better strength for all replacement levels in comparison with conventional concrete. GGBS when used as binary blending material shows improvement in strength upto 60% replacement level. FG40 has shown 45-100% increase in strength w.r.t conventional concrete and 15-75% increase w.r.t FA100. Percentage increase in impact strength of 100% fly ash geopolymer concrete and blended GPC is much higher than other strengths w.r.t conventional concrete.

The improvement in strength characteristics for blending of GGBS is due to the presence of calcium oxide, which provides an additional alkalinity for polymerization. The presence of substantial quantities of Ca ions in slag combines with Si to undergo dissolution leading to the formation of calcium silicates. At the same time, NaOH solution causes leaching of Si and Al from the source materials and result in increased polymerization, forming alumino silicates. The coexistence of calcium and alumino silicates is responsible for the increase in strength.

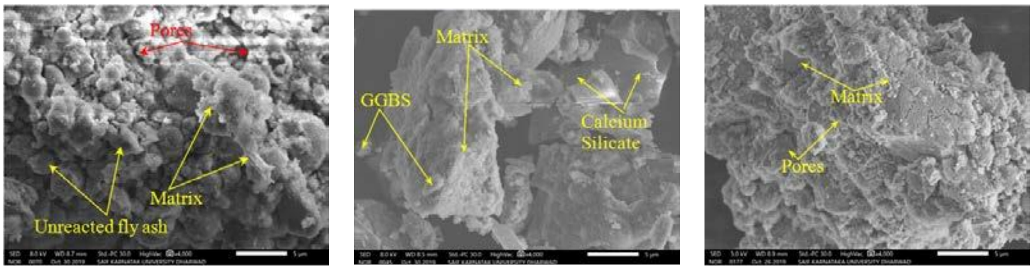
4.2 Microstructural properties

The microstructure analysis is studied by using the scanning electron microscopy (SEM) with energy dispersive X-ray spectroscopy (EDS) and X-ray diffraction (XRD) analysis. SEM with EDS and XRD analysis is carried out on conventional concrete, FA100 and optimum blend of blended GPC.

4.2.1 SEM with EDS analysis: Figure 8 shows the microstructural images of binding materials, geopolymer concrete and conventional concrete at 4000X magnification level. Table 5 shows elemental composition of GPC and CC.



Fly ash **GGBS** **Cement**



FA 100 **FG 40** **CC**

Figure 8. Microstructure of binding materials, GPC and CC

Table 5: Elemental composition of GPC and CC

Element	Weight (%)		
	FA100	FG40	CC
Al	11.41	3.90	1.98
Si	17.95	8.85	4.69
Ca	1.00	3.48	17.55
Si/Al	1.57	2.26	2.36
Ca/Si	0.055	0.393	3.84

Microstructure of fly ash appears to be glassy, hollow, spherical particles of different sizes, which are cenospheres (thin walled hollow spheres). Microstructure of GGBS is flaky and angular in shape and microstructure of cement appears to have polygonal irregular shape.

Fly ash particles are surrounded by polymerization matrix. FA100 shows higher degree of unreacted or partially reacted fly ash particles indicating lesser degree of dissolution of fly ash particles and hence reduced polymerization. The microstructure of FG40 appears to be more bulky and dense with merely any unreacted/partially reacted fly ash particles. This shows complete dissolution of fly ash particles and increased polymerization. Si/Al and Ca/Si ratios increased w.r.t. FA100 indicating presence of both alumino silicates and calcium silicates due to the presence of CaO in GGBS. Conventional concrete appears to be heterogeneous with some pores. Si/Al and Ca/Si ratios are higher than FA100. Inspite of increased ratios strength of CC is less w.r.t. FA100. This may be due to alumino silicates will not impart any strength in CC, whereas both alumino silicates and calcium silicates take part in strength gain in case of GPC.

Upto 40% replacement of fly ash with GGBS, the increase in compressive strength w.r.t. FA100 is marginal and 25-31% w.r.t. CC, whereas with 60% replacement by GGBS, compressive strength increases by 23% w.r.t. FA100 and 55% w.r.t. CC. Therefore, addition of GGBS plays a vital role in strength attainment.

4.2.2 XRD analysis

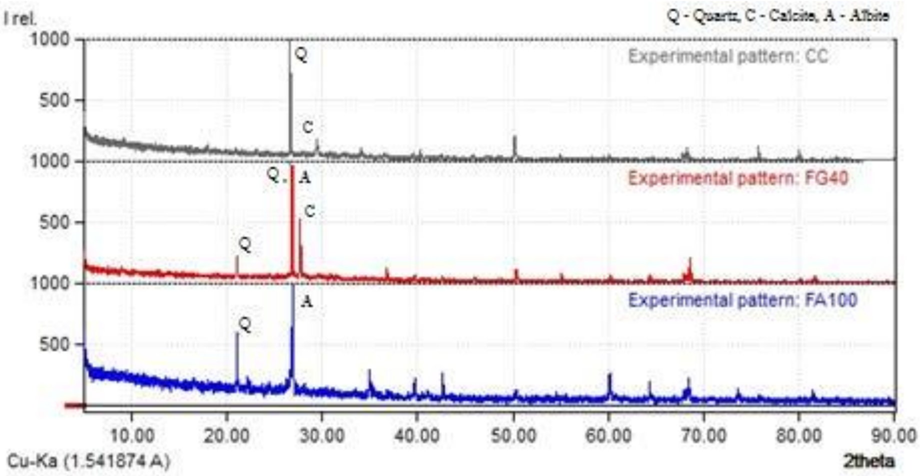


Figure 9. XRD Pattern for GPC and CC

XRD patterns for geopolymer concrete and conventional concrete is shown in figure 9. In conventional concrete strength is attained by the formation of calcium silicates, which is represented by the presence of quartz and calcite. Geopolymer concrete attains its strength by the formation of sodium alumino silicates, which is represented by the presence of albite and quartz. When GGBS is added as blending material, a new diffraction peak is observed at 27°, which is the formation of calcium silicates. Thus, GGBS blended geopolymer concrete attains strength from alumino silicates and calcium silicates.

5. Conclusions

Based on the experimental work carried out on strength and microstructure, following conclusions are drawn.

- Strength properties of 100% fly ash geopolymer concrete are more than conventional concrete. It shows an increase of 14-27% in comparison with conventional concrete.
- Blended GPC shows improvement in strength upto 60% replacement level with FG40 (40%FA+60%GGBS) as optimum blend exhibiting a maximum of 45-100% increase in strength w.r.t conventional concrete and 15-75% increase w.r.t FA100.
- SEM with EDS analysis shows FA100 with higher degree of unreacted or partially reacted fly ash particles and FG40 appears to be more bulky and dense with merely any unreacted/partially reacted fly ash particles. Formation of alumino silicates increases in blended geopolymer concrete as compared to FA100.
- Geopolymer concrete attains its strength by the formation of sodium alumino silicates, which is represented by the presence of albite and quartz in XRD analysis.

Vol. 21, No. 1, (2024)
ISSN: 1005-0930

- When GGBS is added as blending material, a new diffraction peak is observed at 27°, indicating the formation of calcium silicates. Thus, GGBS blended geopolymer concrete attains strength from alumino silicates and calcium silicates.
- Upto 40% replacement of fly ash by GGBS, the increase in compressive strength w.r.t. FA100 is marginal and 25-31% w.r.t. CC, whereas with 60% replacement by GGBS compressive strength increases by 23% w.r.t. FA100 and 55% w.r.t. CC. Therefore, addition of GGBS plays a vital role is strength attainment.

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