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STRENGTH PROPERTIES OF FLY ASH AND GGBS BASED GEO POLYMER CONCRETE

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ABSTRACT

The second most consumed product in the world is Cement. It contributes nearly 7% of the global carbon dioxide emission. Geopolymer concrete (GPC) is becoming a special type of more eco-friendly concrete alternative to Ordinary Portland Cement (OPC) concrete. This project mainly aims at the study of effect of class F fly ash (FA) and ground granulated blast furnace slag (GGBS) on the mechanical properties of geopolymer concrete (GPC) at different replacement levels (FA50-GGBS50, FA25-GGBS75, FA0-GGBS100) using Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solutions as alkaline activator. Specimens were cast and cured for different curing periods at ambient room temperature to determine the GPC mechanical properties viz. compressive, splitting tensile and flexural strength. Test results reveal that increase in GGBS replacement enhanced the mechanical properties of GPC at all ages at ambient room temperature.

Keywords: Geopolymer concrete; Fly ash, GGBS; compressive strength; splitting tensile strength; flexure strength.

1. INTRODUCTION

Concrete is the most widely used construction material in the world and Ordinary Portland Cement (OPC) is the major ingredient used in concrete. The production of cement releases large amount of carbon dioxide (CO_2) to the atmosphere that significantly contributes to greenhouse gas emissions. It is estimated that one ton of CO_2 is released into the atmosphere for every ton of OPC produced [1]. In view of this, there is a need to develop sustainable alternatives to conventional cement utilizing the cementitious properties of industrial by-products such as fly ash and ground granulated blast furnace slag [2-4]. On the other side, the abundance and availability of class F fly ash (FA) and ground granulated blast furnace slag (GGBS) worldwide create opportunity to utilize these by-products, as partial

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replacement or as performance enhancer for OPC.

Davidovits developed a binder called geo-polymer to describe an alternative cementitious material which has ceramic-like properties. Geo-polymer technology is one of the new technologies attempted to reduce the use of Portland cement in concrete. Geopolymers are environmental friendly materials that do not emit green house gases during polymerisation process. Geopolymer can be produced by combining a pozzolanic compound or aluminosilicate source material with highly alkaline solutions [5]. Geopolymers are made from source materials with silicon (Si) and Aluminium (Al) content and thus cement can be completely replaced by marginal materials such as fly ash and ground granulated blast furnace slag which is rich in silica and alumina [6 & 7]. Fly ash and GGBS reacts with alkaline solutions to form a cementitious material which does not emit carbon dioxide into the atmosphere and enhances the mechanical properties of the geo-polymer concrete.

Davidovits proposed that binders could also be produced by polymeric reaction of alkaline liquids with the silicon and the aluminium in source materials or by-product materials such as fly ash and rice husk ash. Portland cement is still the main binder in concrete construction prompting a search for more environmental friendly materials. Furthermore, it has been reported that the durability of ordinary Portland cement concrete is under examination, as many concrete structures especially those built in corrosive environments start to deteriorate after 20 to 30 years, even though they have been designed for more than 50 years of service life [1]. Palomo and Grutzeck reported that type of alkaline liquid affects the mechanical properties of GPC [7]. Palomo and Femandez-Jimenez [8] concluded that both curing temperature and curing time affects the compressive strength of GPC mixes. Gourley [9] stated that low calcium class F fly ash is more preferable thatn high calcium class C fly ash in the manufacturing of GPC. Bhikshma et al. [10] revealed that a compressive strength of 30 MPa achieved in fly ash based GPC by providing alkaline solution to fly ash ratio of 0.5 at 16 molarity of sodium hydroxide (NaOH). Sujatha et al. [11] observed that geopolymer concrete columns exhibited high load carrying capacity, stiffness and ductility until failure. Anuradha et al. [12] noted that tensile strength of GPC made with river sand is higher than that of GPC made with manufactured sand. Vijai et al. [13] developed an expression to predict 28-day compressive strength, splitting tensile strength and flexural strength of steel fibre reinforced geopolymer concrete composites.

2. EXPERIMENTAL STUDY

2.1 Materials

Our objective was to determine the effect of fly ash and GGBS on the mechanical properties of geopolymer concrete after various curing periods at ambient room temperature. In this respect, FA and GGBS were used as binders whose chemical and physical properties are tabulated in Table 1. According to ASTM C 618 [14], class F fly ash produced from Rayalaseema Thermal Power Plant (RTPP), Muddanur, A.P and GGBS produced from the Vizag steel plant, A.P were used in the manufacturing of GPC.

Table 1: Chemical Composition and Physical Properties of Cement

Particulars	Class F fly ash	GGBS
Chemical composition		
% Silica(SiO_2)	65.6	30.61
% Alumina(Al_2O_3)	28.0	16.24
% Iron Oxide(Fe_2O_3)	3.0	0.584
% Lime(CaO)	1.0	34.48
% Magnesia(MgO)	1.0	6.79
% Titanium Oxide (TiO_2)	0.5	-
% Sulphur Trioxide (SO_3)	0.2	1.85
Loss on Ignition	0.29	2.1
Physical properties		
Specific gravity	2.24	2.86
Fineness (m^2/Kg)	360	400

The alkaline liquid used was a combination of sodium silicate solution and sodium hydroxide solution. The sodium silicate solution (Na_2O= 13.7%, SiO_2=29.4%, and water=55.9% by mass) was purchased from a local supplier. The sodium hydroxide (NaOH) in flakes or pellets from with 97%-98% purity was also purchased from a local supplier. The sodium hydroxide (NaOH) solution was prepared with a concentration of 10 M. The sodium silicate solution and the sodium hydroxide solution were mixed together one day before prior to use.

Crushed granite stones of size 20 mm and 10 mm were used as coarse aggregate and river sand was used as fine aggregate. The bulk specific gravity in oven dry condition and water absorption of the coarse aggregate 20 mm and 10mm were 2.58 and 0.3%, respectively. The bulk specific gravity in oven dry condition and water absorption of the sand were 2.62 and 1%, respectively [15].

2.2 Test methods

Compressive strength test was conducted on the cubical specimens for all the mixes after 7, 14, 28, 56 and 112 days of curing as per IS 516 [16]. Three cubical specimens of size 150 mm x 150 mm x 150 mm were cast and tested for each age and each mix. Splitting tensile strength (STS) test was conducted on the specimens for all the mixes after 28, 56and 112 days of curing as per IS 5816 [17]. Three cylindrical specimens of size 150 mm x 300 mm were cast and tested for each age and each mix. Flexural strength test was conducted on the specimens for all the mixes after 28, 56 and 112 days of curing periods as per IS 516 [16]. Three concrete beam specimens of size 100 mm x 100 mm x 500 mm were cast and tested for each age and each mix. All the test specimens were kept at ambient room temperature for all curing periods.

3. MIX DESIGN

Based on the limited past research on GPC, the following proportions were selected for the constituents of the mixtures [18]. The following scenario describes the GPC mix design of the present study:

Assume that normal-density aggregates in SSD (Saturated surface Dry) condition are to be used and the unit-weight of concrete is 2400 kg/m^3. In this study, take the mass of combined aggregates as 77% of the total mass of concrete, i.e. 0.77x2400=1848 kg/m^3. The coarse and fine (combined) aggregates may be selected to match the standard grading curves used in the design of Portland cement concrete mixtures. For instance, the coarse aggregates (70%) may comprise 776 kg/m^3 (60%) of 20 mm aggregates, 518 kg/m^3 (40%) of 10 mm aggregates, and 554 kg/m^3 (30%) of fine aggregate to meet the requirements of standard grading curves. The adjusted values of coarse and fine aggregates are 774 kg/m^3 of 20 mm aggregates, 516 kg/m^3 of 10 mm aggregates and 549 kg/m^3 (30%) of fine aggregate, after considering the water absorption values of coarse and fine aggregates.

The mass of geopolymer binders (fly ash and GGBS) and the alkaline liquid = 2400 – 1848 = 552 kg/m^3. Take the alkaline liquid-to-fly ash+GGBS ratio by mass as 0.35; the mass of fly ash + GGBS = 552/ (1+0.35) = 409 kg/m^3 and the mass of alkaline liquid = 552 – 409 = 143 kg/m^3. Take the ratio of sodium silicate(Na_2SiO_3) solution-to-sodium hydroxide(NaOH) solution by mass as 2.5; the mass of sodium hydroxide (NaOH)solution = 144/ (1+2.5) = 41 kg/m^3; the mass of sodium silicate solution = 143 – 41 =102 kg/m^3. The sodium hydroxide solids (NaOH) is mixed with water to make a solution with a concentration of 10 Molar. This solution comprises 40% of NaOH solids and 60% water, by mass.

For the trial mixture, water-to-geopolymer solids ratio by mass is calculated as follows: In sodium silicate solution, water = 0.559x102 = 57 kg, and solids = 102 – 57 = 45 kg. In sodium hydroxide solution, solids = 0.40x41 = 16 kg, and water = 41 – 16 = 25 kg. Therefore, total mass of water = 57+25 = 82 kg, and the mass of geopolymer solids = 409 (i.e. mass of fly ash and GGBS) + 45 + 16 = 470 kg. Hence, the water-to-geopolymer solids ratio by mass = 82/470 = 0.17. Extra water of 55 litres is calculated on trial basis to get adequate workability. The geopolymer concrete mixture proportions are shown in Table 2.

Table 2: GPC mix proportions

Materials		Mass (kg/m^3)		
		FA50-GGBS50	FA25-GGBS75	FA0-GGBS100
Coarse aggregate	20 mm	776	776	776
	10 mm	517	517	517
Fine aggregate		554	554	554
Fly ash (Class F)		204.5	102	0
GGBS		204.5	307	409
Sodium silicate solution		102	102	102
Sodium hydroxide solution		41 (10M)	41 (10M)	41 (10M)
Extra water		55	55	55
Alkaline solution/ (FA+GGBS) (by weight)		0.35	0.35	0.35
Water/ geopolymer solids (by weight)		0.29	0.29	0.29

4. RESULTS AND DISCUSSION

4.1 Compressive strength

Table 3 shows the compressive strength of GPC mixes with different proportions of fly ash and GGBS (FA50-GGBS50; FA25-GGBS75; FA0-GGBS100) at different curing periods.

Table 3: Compressive strength of GPC

Mechanical property	**Age (days)**	**Mix type**		
		FA50-GGBS50	**FA25-GGBS75**	**FA0-GGBS100**
Compressive strength, f'_c (MPa)	7	40	44.4	52.4
	14	46.5	48.2	56.2
	28	53.5	55.5	58.6
	56	63	74	83
	112	65	77	87

It was observed that there was a significant increase in compressive strength with the increase in percentage of GGBS from 50% to 100% in all curing periods as shown in Fig. 1. It can be concluded that the increase in GGBS replacement level enhances strength improvement in geopolymers. The GPC with 100% GGBS sample exhibited compressive strength values of 52.4 MPa, 56.2 MPa, 58.2 MPa, 83 MPa and 87 MPa after 7, 14, 28, 56 and 112 days of curing respectively at ambient room temperature as shown in Table 3.

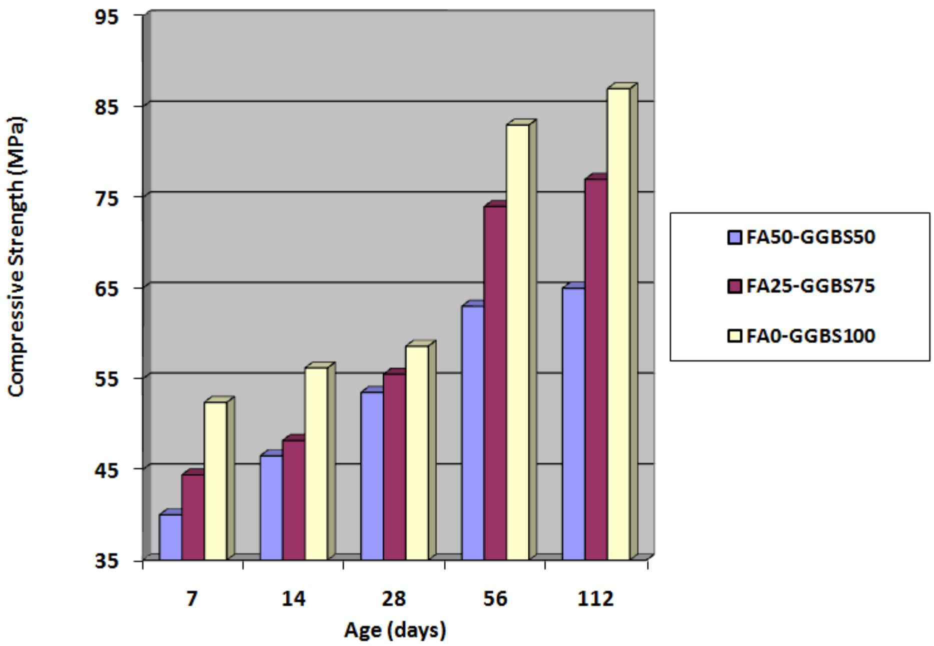

Figure 1. Compressive strength versus age

4.2 Splitting tensile strength

Table 4 shows the splitting tensile strength (STS) of GPC mixes with different proportions of fly ash and GGBS (FA50-GGBS50; FA25-GGBS75; FA0-GGBS100) at different curing periods. It was observed that there was a significant increase in splitting tensile strength with the increase in percentage of GGBS from 50% to 100% in all curing periods as shown in Fig. 2. It can be concluded that the increase in GGBS replacement level improves the microstructure of GPC thus leads to enhancement of splitting tensile strength of GPC. The GPC with 100% GGBS sample exhibited splitting tensile strength values of 3.54 MPa, 3.83 MPa and 4.12 MPa after 28, 56 and 112 days of curing respectively at ambient room temperature as shown in Table 4.

Table 4: Splitting tensile strength of GPC

Mechanical property	**Age (days)**	**Mix type**		
		FA50-GGBS50	**FA25-GGBS75**	**FA0-GGBS100**
Splitting tensile strength, f_{ct} (MPa)	28	3.25	3.39	3.54
	56	3.38	3.52	3.83
	112	3.52	3.89	4.12

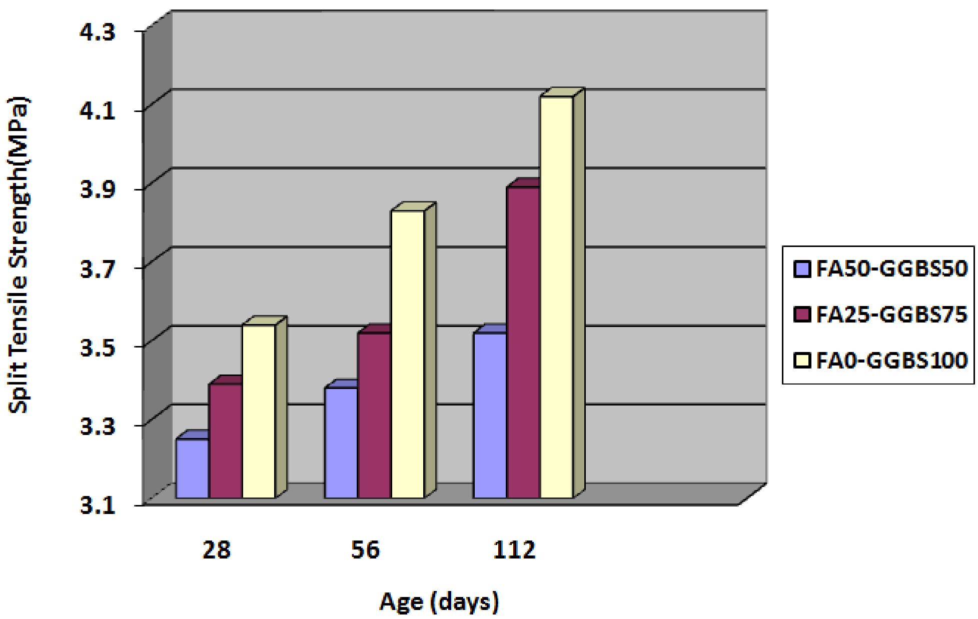

Figure 2. Splitting tensile strength versus age

4.3 Flexural strength

Table 5 shows the flexural strength of GPC mixes with different proportions of fly ash and GGBS (FA50-GGBS50; FA25-GGBS75; FA0-GGBS100) at different curing periods.

Table 5: Flexural strength of GPC

Mechanical property	Age (days)	Mix type FA50-GGBS50	FA25-GGBS75	FA0-GGBS100
Flexural strength, f_{cr} (MPa)	28	5.35	5.51	5.76
	56	5.92	6.16	6.34
	112	6.42	6.68	7.12

It was observed that there was a significant increase in flexural strength with the increase in percentage of GGBS from 50% to 100% in all curing periods as shown in Fig. 3. It can be concluded that the increase in GGBS replacement level refines the pore structure of GPC thus improves the flexural strength of GPC. The GPC with 100% GGBS sample exhibited splitting tensile strength values of 5.76 MPa, 6.34 MPa and 7.12 MPa after 28, 56 and 112 days of curing respectively at ambient room temperature as shown in Table 5.

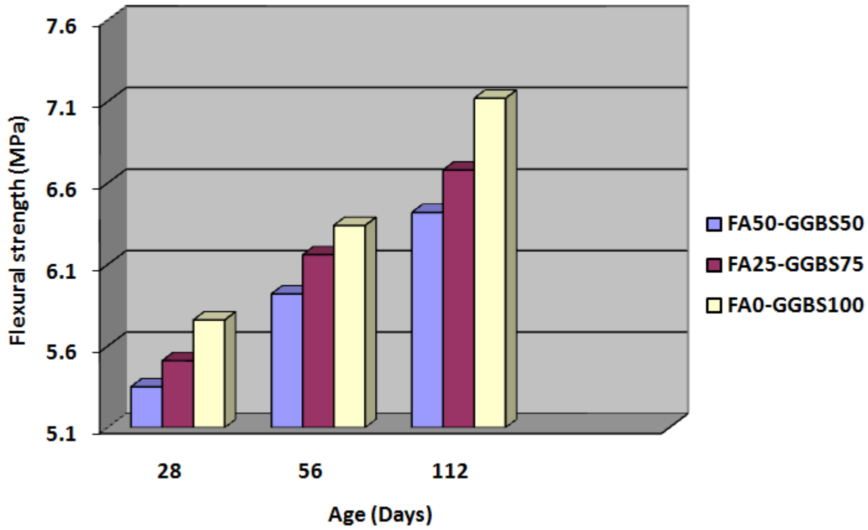

Figure 3. Flexural strength versus age

From the results it is revealed that GGBS and FA blended GPC mixes attained enhanced mechanical properties at ambient room temperature curing itself without the need of heat curing as in the case of only FA based GPC mixes Siddique [19 & 20]. Because, the bonding of geopolymer paste and aggregates is so strong that tends to increase the mechanical properties of GPC.

5. CONCLUSIONS

Based on the results of this experimental investigation, the following conclusions can be drawn:

GGBS blended FA based GPC mixes attained enhanced mechanical properties at ambient room temperature curing itself without the need of heat curing as in the case of only FA based GPC mixes.

The increase in GGBS replacement in GPC mixes enhanced the mechanical properties at ambient room temperature curing at all ages.

Keeping in view of savings in natural resources, sustainability, environment, production cost, maintenance cost and all other GPC properties, it can be recommended as an innovative construction material for the use of constructions.

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