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Study and Analysis of Fly Ash and GGBS Based on 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. Thisproject mainly aims at the study of effect of class F fly ash (FA) and ground granulated blastfurnace 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.

I. INTRODUCTION
The geopolymer technology is proposed by Davidovits and gives considerable promise for application in concrete industry as an alternative binder to the Portland cement. In terms of reducing the global warming, the geopolymer technology could reduce the CO2 emission in to the atmosphere, caused by cement and aggregate industries about 80%. In this technology, the source material that is rich in silicon (Si) and Aluminium (Al) is reacted with a highly alkaline solution through the process of geopolymerisation to produce the binding material. The term „geopolymer" describes a family of mineral binders that have a polymeric silicon-oxygen-aluminium framework structure, similar to that found in zeolites, but without the crystal structure. The polymerisation process involves a substantially fast chemical reaction under highly alkaline condition on Si-Al minerals that result in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds. Geopolymer concrete is emerging as a new environmentally friendly construction material for sustainable development, using flyash and alkali in place of OPC as the binding agent. This attempt results in two benefits. i.e. reducing CO2 releases from production of OPC and effective utilisation of industrial waste by products such as flyash, slag etc by decreasing the use of OPC.

II. EXPERIMENTAL STUDY
Experimental program:
Our objective was to determine the effect of GGBS and Fly-ash on the mechanical properties of geo polymer concrete.

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In this respect, GGBS and Fly-ash were used as binders, Sodium hydroxide and Sodium silicate were used as alkaline activators, Crushed granite stones of size 20 mm and 10 mm of coarse aggregate are used, river sand is used as fine aggregate. Fly ash and GGBS were used as binders in geo polymer concrete and their physical and chemical properties of the Ground Granulated Blast Furnace Slag were tabulated below

Table 1. Chemical and Physical Properties of Class F Fly Ash and GGBS

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

Material properties:

Binders:

Alkaline liquids:

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 by dissolving either the flakes or the pellets in required quantity of water. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molarity, M. For instance, NaOH solution with a concentration of 10M consisted of 10x40 = 400 grams of NaOH solids (in flake or pellet form) per litre of the solution, where, 40 is the molecular weight of sodium hydroxide (NaOH) pellets or flakes.

Coarse aggregate:

Crushed granite stones of size 20 mm and 10 mm of coarse aggregate are used. The bulk specific gravity in oven dry condition and water absorption of the coarse aggregate 20 mm and 10mm as per IS code were 2.58 and 0.3% respectively. The gradation of the coarse aggregate was determined by sieve analysis as per IS code and presented in the Tables 2 and3.

Table 2. Sieve analysis of 20 mm Coarseaggregate

S.No	Sieve size (mm)	Weight retained (gm)	Percentage weight retained	Cumulative percentage weight retained	Cumulative percent passing	
					10 mm	IS 383 (1970) limits
1	10	16	0.32	0.32	99.68	85-100
2	4.75	4546	90.92	91.24	8.76	0-20
3	2.36	318	6.36	97.6	2.4	0-5

Table 3. Sieve analysis of 10 mm Coarseaggregate

S.No	Sieve size (mm)	Weight retained (gm)	Percentage weight retained	Cumulative percentage weight retained	Cumulative percent passing	
					10 mm	IS 383 (1970) limits
1	10	16	0.32	0.32	99.68	85-100
2	4.75	4546	90.92	91.24	8.76	0-20
3	2.36	318	6.36	97.6	2.4	0-5

Fine aggregate:

The sand used throughout the experimental work was obtained from the river Swarnamukhi near chandragiri in chittoor district. The bulk specific gravity in oven dry condition and water absorption of the sand as per IS code were 2.62 and 1% respectively[8]. The gradation of the sand was determined by sieve analysis as per IS code and presented in the Table 4[9].

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Table 4. Sieve analysis of Fine Aggregate (Sand)

S.No	Sieve No/ size	Weight retained (gm)	Percentage weight retained	Cumulative percentage weight retained	Cumulative percent passing	
					Fine aggregate	IS 383 (1970) – Zone II requirement
1	3/8" (10mm)	0	0	0	100	100
2	No.4 (4.75mm)	12	1.2	1.2	98.8	90-100
3	No.8 (2.36mm)	35	3.5	4.7	95.3	75-100
4	No.16 (1.18mm)	135	13.5	18.2	81.8	55-90
5	No.30 (600µm)	366	36.6	54.8	45.2	35-59
6	No.50 (300µm)	290	29.0	83.8	16.2	8-30
7	No.100 (150µm)	132	13.2	97.0	3.0	0-10

Mixture Proportions:

Based on the limited past research on GPC (Hardjito & Rangan, 2005) [10], the following proportions were selected for the constituents of the mixtures.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. Themass of geo polymer 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 solid (NaOH) is mixed with water to make a solution with a concentration of 8 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 for adequate workability.

Table 5. GPC Mix Proportions

Materials		Mass (kg/m^3)		
		FA50-GGBS50	FA75-GGBS25	FA100-GGBS0
Coarse aggregate	20 mm	774	774	774
	10 mm	516	516	516
Fine aggregate	Sand	549	549	549
Fly ash (Class F)		204.5	306.75	409
GGBS		204.5	102.25	0
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

III. RESULTS AND DISCUSSIONS

Compressive Strength:

Table 6. 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 6. Compressive strength of GPC

Mechanical property	Age (days)	Mix type		
		FA50-GGBS50	FA75-GGBS25	FA100-GGBS0
Compressive strength, f_c (MPa)	7	40	21.3	10.1
	14	46.5	30.5	18.2
	28	53.5	35.4	24.5
	56	63	49	38
	112	65	52	41

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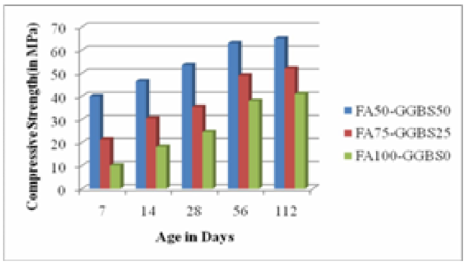

Fig. 1. Compressive strength versus Age Split Tensile

It was observed that there was a significant decrease in compressive strength with the increase in percentage of Fly ash from 50% to 100% in all curing periods as shown in Fig. 1. It can be concluded that the increase in Fly ash replacement level has significant decrease strength in geopolymers but still exhibits good normal strength. The GPC with 100% Fly ash sample exhibited compressive strength values of 10.1 MPa, 18.2 MPa, 24.5 MPa, 38 MPa and 41 MPa after 7, 14, 28, 56 and 112 days of curing respectively at ambient room temperature.

Strength:

Table 7. Shows the split tensile strength of GPC mixes with different proportions of fly ash and GGBS (FA50-GGBS50; FA25-GGBS75; FA0-GGBS100) at different curing periods.

Table 7. Split tensile strength of GPC

Mechanical property	Age (days)	Mix type		
		FA50-GGBS50	FA75-GGBS25	FA100-GGBS0
Split tensile strength, f_{ct} (MPa)	28	3.25	3.04	2.82
	56	3.38	3.16	2.98
	112	3.52	3.33	3.12

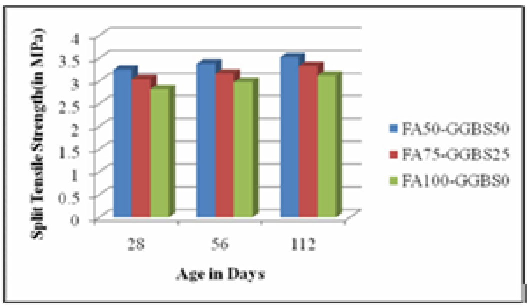

Fig. 2. Split tensile strength of mixes

It was observed that there was a significant decrease in splitting tensile strength with the increase in percentage of Fly ash from 50% to 100% in all curing periods as shown in Fig. 2. It can be concluded that the increase in Fly ash replacement level weakens the microstructure of GPC thus leads to detriment of splitting tensile strength of GPCbut the decrement is less. The GPC with 100% Fly ash sample exhibited splitting tensile strength values of 2.82 MPa, 2.98 MPa and 3.12 MPa after 28, 56 and 112 days of curing respectively at ambient roomtemperature.

Flexural strength:

Table 8. 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 8. Flexural strength of GPC

Mechanical property	Age (days)	Mix type		
		FA50-GGBS50	FA25-GGBS75	FA0-GGBS100
Flexural strength, f_{cr} (MPa)	28	5.35	5.06	4.98
	56	5.92	5.36	5.14
	112	6.42	5.96	5.44

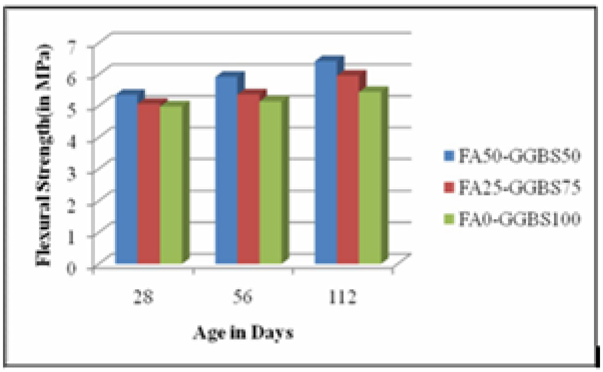

Fig. 3. Flexural strength of mixes

It was observed that there was a significant decrease in flexural strength with the increase in percentage of Fly ash from 50% to 100% in all curing periods as shown in Fig. 3. It can be concluded that the decrease in GGBS replacement level reduce the Silica content of GPC thus lessens the flexural strength of GPC but

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maintains its strength. The GPC with 100% Fly ash sample exhibited Flexural strength values of 4.98 MPa, 5.14 MPa and 5.44 MPa after 28, 56 and 112 days of curing respectively at ambient room temperature. 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 (2007).

IV. CONCLUSIONS

Based on the test results, the following conclusions are drawn:

1. 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 GPCmixes.
2. Fly ash based GPC mixes have attained comparable values of mechanical properties at ambient room temperature curing at all ages to normalStrength.
3. 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 at low cost for the use of constructions.
4. Though 100% Fly ash exhibited decrease in strength, it maintains the strength. The cost is also low compared to the 50% GGBS& 50% Flyash

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