ISSN 2229-5518

AN EXPERIMENTAL STUDY ON EFFECT OF GGBS ONSTRENGTH CHARACTERISTICSOF GEOPOLYMER CONCRETE

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Abstract: The objective of this project is to study the effect of class fly ash (FA) and ground granulated blast furnace slag (GGBS) on the mechanical properties of geopolymer concrete (GPC) at different replacement levels. Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solution have been used as alkaline activators. In the present investigation, it is proposed to study the mechanical properties viz. compressive strength, split tensile strength of low calcium fly ash and GGBS based geo polymer concrete. These properties have been determined at different curing periods like 7, 14, and 28, 56, 112 days and at ambient room temperature.

KEYWORDS: Geopolymer concrete, sodium silicate, sodium hydroxide, fly ash, granulated blast furnace slag, compressive strength, split tensile strength

I. INTRODUCTION.

The production of Portland cement consumes considerable energy and at the same time contributes a large volume of CO_2 to the atmosphere. The climate change due to global warming has become a major concern. The global warming is caused by the emission of greenhouse gases, such as carbon dioxide (CO_2), to the atmosphere by human activities. The cement industry is held responsible for some of the CO_2 emissions, because the production of one ton of Portland cement emits approximately one ton of CO_2 into the atmosphere [1]. However, Portland cement is still the main binder in concrete construction prompting a search for more environmentally friendly materials. Several efforts are in progress to supplement the use of Portland cement in concrete in order to address the global warming issues. These include the utilization of supplementary cementing materials such as fly ash, silica fume, granulated blast furnace slag, rice-husk ash and metakaolin, and the development of alternative binders to Portland cement. One possible alternative is the use of alkali-activated binder using industrial by-products containing silicate materials. In 1978, Davidovits proposed that binders could be produced by a polymeric reaction of alkaline liquids with the silicon and the aluminium in source materials of geological origin or by-product materials such as fly ash, GGBS and rice husk ash. He termed these binders as geopolymer [1]. The most common industrial by-products used as binder materials are fly ash (FA) and ground granulated blast furnace slag (GGBS) [2-4].

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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 Kothagudem Thermal Power station (KTPS), Kothagudem, T.S and GGBS produced from the Vizag steel plant, A.P were used in the manufacturing of GPC

Table: 1 Chemical Composition& Physical properties

S.NO	Particulars	Class F fly ash	GGBS
	Chemical composition	**Class F fly ash**	**GGBS**
1	% Silica(SiO_2)	65.6	30.61
2	% Alumina(Al_2O_3)	28.0	16.24
3	% Iron Oxide(Fe_2O_3)	3.0	0.584
4	% Lime(CaO)	1.0	34.48
5	% Magnesia(MgO)	1.0	6.79
6	% Titanium Oxide (TiO_2)	0.5	-
7	% Sulphur Trioxide (SO_3)	0.2	1.85
8	Loss on Ignition	0.29	2.1
	Physical properties		
9	Specific gravity	2.24	2.86
10	Fineness (m^2/Kg)	360	400

The alkaline liquid used was a combination of sodium silicate solution and sodium hydroxide solution. The sodium silicate and sodium hydroxide (NaOH) in flakes or pellets from with 97%-98% purity solution was purchased from a local supplier.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, 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 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 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.

3.0 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/m3. In this study, take the mass of combined aggregates as 77% of the total mass of concrete, i.e. 0.77x2400=1848 kg/m3. 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/m3 (60%) of 20 mm aggregates, 518 kg/m3 (40%) of 10 mm aggregates, and 554 kg/m3 (30%) of fine aggregate to meet the requirements of standard grading curves. The adjusted values of coarse and fine aggregates are 774 kg/m3 of 20 mm aggregates, 516 kg/m3 of 10 mm aggregates and 549 kg/m3 (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/m3. 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/m3 and the mass of alkaline liquid = 552 – 409 = 143 kg/m3. Take the ratio of sodium silicate(Na2SiO3) solution-to-sodium hydroxide(NaOH) solution by mass as 2.5; the mass of sodium hydroxide (NaOH)solution = 144/ (1+2.5) = 41 kg/m3; the mass of sodium silicate solution = 143 – 41 =102 kg/m3. 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:

S.NO	Particulars	Mass Kg/m^3		
		FA50-GGBS50	FA25-GGBS75	FA0-GGBS100
1	Coarse aggregate 20mm	776	776	776
2	Coarse aggregate 10mm	517	517	517
3	Fine aggregate	554	554	554
4	Fly ash (Class F)	204.5	102	0
5	GGBS	204.5	307	409
6	Sodium silicate solution	102	102	102
7	Sodium hydroxide solution	41 (10M)	41 (10M)	41 (10M)
8	Extra water	55	55	55
9	Alkaline solution/ (FA+GGBS) (by weight)	0.35	0.35	0.35
10	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.

S.NO	Mechanical property	Age(days)	Mix type		
			FA50-GGBS50	FA25-GGBS75	FA0-GGBS100
1	Compressive strength, *f'c* (MPa)	7	40	44.4	52.4
2		14	46.5	48.2	56.2
3		28	53.5	55.5	58.6
4		56	63	74	56
5		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.

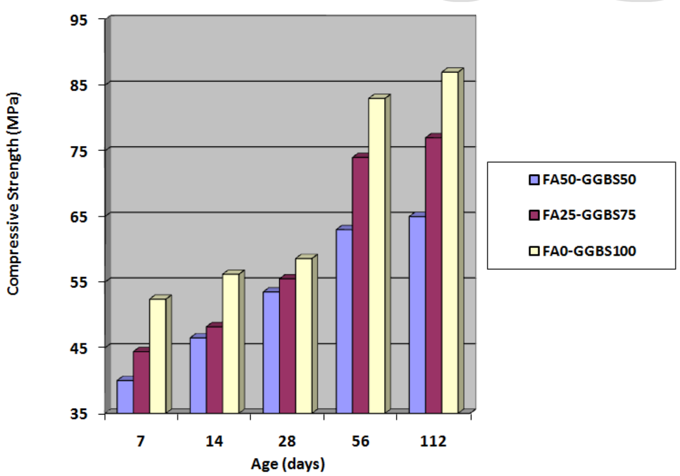

Figure 1. Compressive strength versus age

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.

S.NO	Mechanical property	Age(days)	Mix type		
			FA50-GGBS50	FA25-GGBS75	FA0-GGBS100
1	Splitting tensile strength, *fct* (MPa)	28	3.25	3.39	3.54
2		56	3.38	3.52	3.83
3		112	3.52	3.89	4.12

Table 4: Splitting tensile strength of GPC.

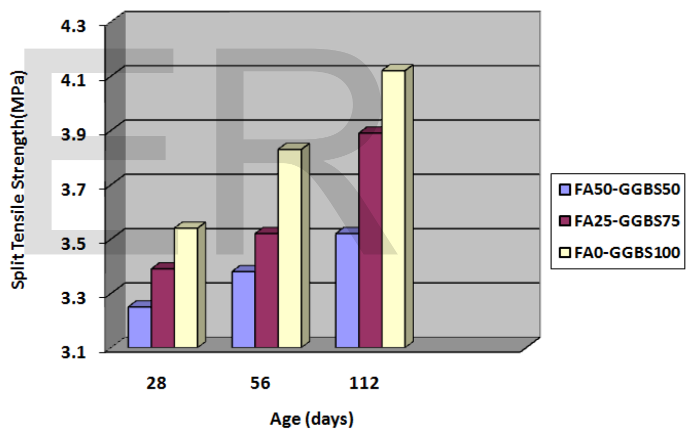

Figure 2. Splitting tensile strength versus age

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

S.NO	Mechanical property	Age(days)	Mix type		
			FA50-GGBS50	FA25-GGBS75	FA0-GGBS100
1	Flexural strength, *fcr* (MPa)	28	5.35	5.51	5.76
2		56	5.92	6.16	6.34
3		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.

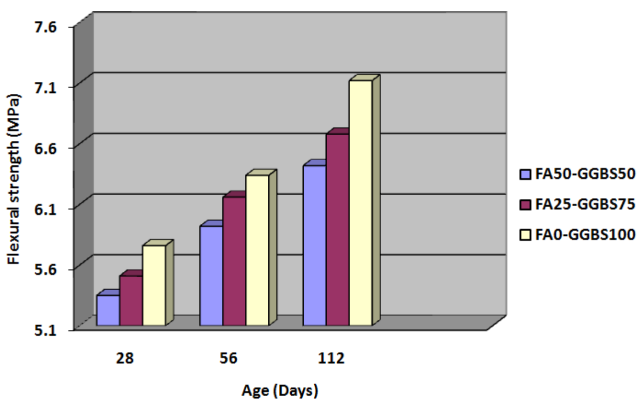

Figure 3. Flexural strength versus age

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.

REFERENCES.

[1]. Davidovits J. Geopolymers: man-made geosynthesis andthe resulting development of very early high strength cement, *Journal of Materials Education*, **16**(1994) 91-139.

[2]. Nath P, Sarker PK. Effect of GGBS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition, *Construction Building Materials*, **66**(2014) 163-71.

[3]. Sarker PK, Kelly S, Yao Z. Effect of exposure on cracking, spalling and residual strength of fly ash geopolymer concrete, *Materials and Design*, **63**(2014) 584-92.

[4]. Deb P, Nath P, Sarker PK. The effects of ground granulated blast-furnace slag blending with fly ash and activator content on the workability and strength properties of geopolymer concrete cured at ambient temperature, *Materials and Design*, **62**(2014) 32-9.

[5]. Davidovits J. Geopolymers: inorganic polymeric new materials, *Journal of Thermal Analysis*, **37**(1991) 1633-56.

[6]. Davidovits J. Global warming impact on the cement andaggregate industries, *World Resource Review*, **6**(1994) 263-78.

[7]. Palomo SA, Grutzeck MW, Blanco MT. Alkali-activated fly ashes – A cement for the future, *Cement and Concrete Research*, **29**(1999) 1323-9.

[8]. Palomo SA, Femandez-Jimenez A. Alkaline activation of fly ashes: NMR study of the reaction products, *Journal of the American Ceramic Society*, **87**(2004) 1141-5.

[9]. Gourley JT. Geopolymers, opportunities for environmentally friendly construction materials, conference, adaptive materials for a modern society, Sydney, Institute of Materials Engineering Australia, Nos. 15-26, **49**(2003) 1455-61.

[10]. Bhikshma V, Koti reddy M, Srinivas Rao T. An experimental investigation on properties of geopolymer concrete (no cement concrete), *Asian Journal of Civil Engineering*, **13**(2012) 841-53.

[11]. Sujatha T, Kannapiran K, Nagan S. Strength assessment of heat cured geopolymer concrete slender column, *Asian Journal of Civil Engineering*, **13**(2012) 635-46.

[12]. Anuradha R, Sreevidya V, Venkatasubramani R, Rangan BV. Modified guidelines for geopolymer concrete mix design using indian standard, *Asian Journal of Civil Engineering*, **13**(2012) 353-64.

[13]. Vijai K, Kumutha R, Vishnuram BG. Effect of inclusion of steel fibres on the properties of geopolymer concrete composites, *Asian Journal of Civil engineering*, **13**(2012) 377-85.

[14]. ASTM C 618: Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete, 2003.

[15]. IS 2386. Methods of test for aggregates for concrete. Part III - Specific gravity, Density, Voids, Absorption and Bulking, Bureau of Indian Standards, New Delhi, India, 1963.

[16]. IS 516. Methods of tests for strength of concrete, Bureau of Indian Standards, New Delhi, India, 1991.

[17]. IS 5816. Splitting tensile strength of concrete method of test, Bureau of Indian Standards, New Delhi, India, 1999.

[18]. Hardjito D, Rangan BV. Development and Properties of Low-Calcium Fly Ash-Based Geopolymer Concrete. Research Report GC1, Perth, Australia: Faculty of Engineering, Curtin University of Technology, 2005.

[19]. Siddiqui KS. Strength and Durability of Low-Calcium Fly Ash-based Geopolymer Concrete, Final Year Honours Dissertation, The University of Western Australia, Perth, 2007.

[20]. Sreenivasulu C, Ramakrishnaiah A, Guru Jawahar J. Mechanical Properties of Geopolymer Concrete Using Granite Slurry as Sand Replacement, *International Journal of Advances in Engineering and Technology*, **8**(2015) 83-91.