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Effect of Fine Aggregate Blending with Slag on Mechanical Properties of Geopolymer Concrete

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Abstract : Geopolymer concrete (gpc) is a special type of concrete that is manufactured using industrial wastes like fly ash, ground granulated blast furnace slag(ggbs) etc.Gpc is considered as a more eco-friendly alternative to ordinary portland cement concrete. Promotion of gpc reduces the consumption of cement which in turn minimizes the emission of green house gases into the atmosphere. The present investigation is mainly focused on finding the mechanical properties of geopolymer concrete (gpc) mixes with different fine aggregate blending. Sand and slag are blended in different proportions (100:0, 50:50 and 0:100). Coarse aggregates of size 20 mm and 10 mm are blended in 60:40 proportions by percentage of weight of total coarse aggregate. Fly ash (class f) was used as geopolymer binder. Combination of sodium hydroxide (10m) and sodium silicate solution was used as an alkaline activator. Compressive strength, splitting tensile strength (sts) and flexural strength (fs) were studied after 7, 14, 28, 56 and 112 days of curing at ambient room temperature. From the results, it is revealed that the mechanical properties were increased till fine aggregate blending with slag up to 0:100.
Keywords : geopolymer concrete, fly ash, slag, fine aggregate,alkaline activator, mechanical properties.

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, rise husk ash, bagasse ash and ground granulated blast furnace slag[2-4].

Davidovits developed a binder called geopolymer to describe an alternative cementitious material which has ceramic-like properties. Geopolymer 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. 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, bagasse ash and rice husk ash. Portland cement is still the main binder in concrete construction prompting a search for more environmental friendly materials. 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]. However, recent studies revealed that GPC mixes can be developed for ambient room temperature[9].Parthiban et al. investigated the effect of Sodium Hydroxide Concentration and Alkaline Ratio on the Compressive Strength of Slag Based Geopolymer Concrete[5]. Parthiban et al. also studied the effect of Slag Content and Alkaline Concentration on the Moisture Absorption Characteristics of Geopolymer Concrete[7]. Abhilash et al. concluded that increase in flyash content in geopolymer concrete has decreased its strength[8].

2. Experimental Study

2.1. Experimental program

Our objective was to determine the effect of fine aggregate blended with slag (100:0, 50:50 and 0:100) on mechanical properties of GPC. In this respect, Fly ash (Class F) is used as geopolymer binders. Combination of sodium hydroxide (10M) and sodium silicate solution is used as an alkaline activator. Crushed granite stones of size 20 mm and 10 mm, river sand and slag were used in preparing GPC mixes having alkaline solution/binders of 0.35 (by weight). 20 mm and 10 mm size aggregates are blended in 60:40 proportions by percentage of weight of total coarse aggregate. The fine aggregate (FA) and slag are blended in 100:0, 50:50 and 0:100 proportions by percentage of weight of total fine aggregate. The mechanical properties that were determined are compressive strength, splitting tensile strength and flexural strength after 7, 14, 28, 56 and 112 days of curing at ambient room temperature.

2.2 Material properties

Fly ashis used as binders in geopolymer concrete and their physical and chemical properties was tabulated below.

Table 1:Chemical and physical properties of geopolymer binders

Particulars	Class“F” fly ash
Chemical composition	
% Silica(SiO_2)	65.6
%	28.0
% Iron Oxide(Fe_2O_3)	3.0
% Lime(CaO)	1.0
% Silica(SiO_2)	1.0
%	0.5
Loss on Ignition	0.29
Physical properties	
Specific gravity	2.24
Fineness (m^2/Kg)	360

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 used. The sodium hydroxide (NaOH) in flakes or pellets from with 97%-98% purity was alsoused. 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.Crushed granite stones of size 20 mm and 10 mm were used. 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 as per IS 2386.The gradation of the coarse aggregate was determined by sieve analysisIS 383and presented in the Tables 2 and 3.

Table 2:Sieve analysis of 20 mm coarse aggregate

S.No	Sieve size (mm)	Weight retained (gm)	% weight retained	Cumulative percentage weight retained	Cumulative percent passing	
					20 mm	IS 383 (1970) Limits
1	20	358	7.16	7.16	92.8	85-100
2	16	2428	48.56	55.72	44.28	N/A
3	12.5	1249	24.98	80.7	19.3	N/A
4	10	582	11.64	92.34	7.66	0-20
5	4.75	376	7.52	99.86	0.14	0-5

Table 3: Sieve analysis of 10 mm coarse aggregate

S.No	Sieve size (mm)	Weight retained (gm)	% 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

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 perIS 2386 were 2.62 and 1% respectively. The gradation of the sand was determined by sieve analysisas per IS 383 and presented in the Table 4. Fineness modulus of sand was 2.59.

Table 4:Sieve analysis of fine aggregate (sand)

S.No	Sieve No/ size	Weight retained (gm)	% 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

The slag used in the experimental work is obtained from LancoInfratech Limited, Sri Kalahasti, Chittoor District. The Bulk Specific gravity in oven dry condition and Water absorption were 2.8 and 1.9 respectively as per IS 2386. The gradation of the slag was determined by sieve analysis as per IS 383 and presented in the Table 5. Fineness modulus of slag was 3.75.

Table 5:Sieve analysis of slag

S.No	Sieve No/ size	Weight retained (gm)	% 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	3.2	3.2	96.8	90-100
3	No.8 (2.36mm)	35	22.1	25.3	74.7	75-100
4	No.16 (1.18mm)	135	36.8	62.1	37.9	55-90
5	No.30 (600μm)	366	25.1	87.2	12.8	35-59
6	No.50 (300μm)	290	10.6	97.8	2.2	8-30
7	No.100 (150μm)	132	1.6	99.4	0.6	0-10

2.3. 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. 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.Three cylindrical specimens of size 150mm x 300mm were cast and tested foreach 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. 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.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 binder (fly ash) and the alkaline liquid = 2400 – 1848 = 552 kg/m^3. Take the alkaline liquid-to-fly ash ratio by mass as 0.35; the mass of fly ash = 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) + 45 + 16 = 470 kg. Hence, the water-to-geopolymer solids ratio by mass = 82/470 = 0.17. Extra water is calculated on trial basis to get adequate workability.The geopolymer concrete mixture proportions are shown in Table 6.

Table 6:GPC mix proportions

Materials		Mass (kg/m^3)		
		FA100-SLAG0	**FA50-SLAG50**	**FA0-SLAG100**
Coarse aggregate	20 mm	774	774	774
	10 mm	516	516	516
Fineaggregate(FA)	Sand	549	274.5	-
Slag		-	274.5	549
Flyash		409	409	409
Sodium silicate solution		102	102	102
Sodium hydroxide solution		41 (10M)	41 (10M)	41 (10M)
Extra water		55	55	55
Alkaline solution/ binders (by weight)		0.35	0.35	0.35
Water/ geopolymer solids (by weight)		0.29	0.31	0.33

4.Results and Discussion

4.1 Compressive strength

Table 7 Shows the compressive strength of GPC mixes with fine aggregate and slag blending(FA100-SLAG0; FA50-SLAG50; FA0-SLAG100) at different curing periods.

Table 7:Compressive strength of GPC

Mechanical property	ge (days)	Mix type		
		'A100-SLAG0	**'A50-SLAG50**	**'A0-SLAG100**
Compressive strength, f'_c (MPa)	7	10.26	27	39
	14	18.46	31.5	45.3
	28	24.12	37.4	50.5
	56	28.5	42.3	54.2
	112	31.3	46.4	58.6

It was observed that there was a significant increase in compressive strength with the increase in percentage of slag from 0% to 100% in all curing periods as shown in Fig. 1. It can be concluded that the increase in slag replacement level enhances strength improvement in geopolymers. The GPC with 100% slag sample exhibited compressive strength values of 39 MPa, 45.3 MPa, 50.5 MPa, 54.2 MPa and 58.6MPa after 7, 14, 28, 56 and 112 days of curing respectively at ambient room temperature as shown in Table 7.

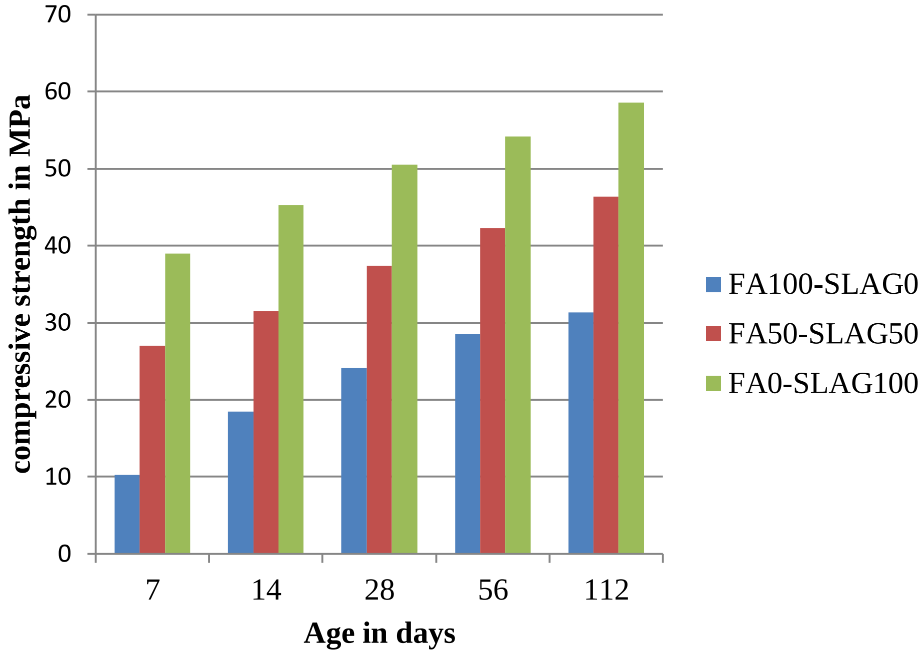

Figure 1. Compressive strength versus Age

4.2 Split tensile strength

Table 8 Shows the split tensile strength GPC mixes with fine aggregate and slag blending(FA100-SLAG0; FA50-SLAG50; FA0-SLAG100) at different curing periods.

Table 8:Split tensile strength of GPC

Mechanical property	**Age (days)**	**Mix type**		
		FA100-SLAG0	**FA50-SLAG50**	**FA0-SLAG100**
Split tensile strength, f_{ct} (MPa)	28	1.84	2.42	3.21
	56	2.04	2.53	3.51
	112	2.18	2.84	3.76

It was observed that there was a significant increase in splitting tensile strength with the increase in percentage of slag from 0% to 100% in all curing periods as shown in Fig. 2. It can be concluded that the increase in slag replacement level improves the microstructure of GPC thus leads to enhancement of splitting tensile strength of GPC. The GPC with 100% slag sample exhibited splitting tensile strength values of 3.21 MPa, 3.51 MPa and 3.76MPa after 28, 56 and 112 days of curing respectively at ambient room temperature as shown in Table 8.

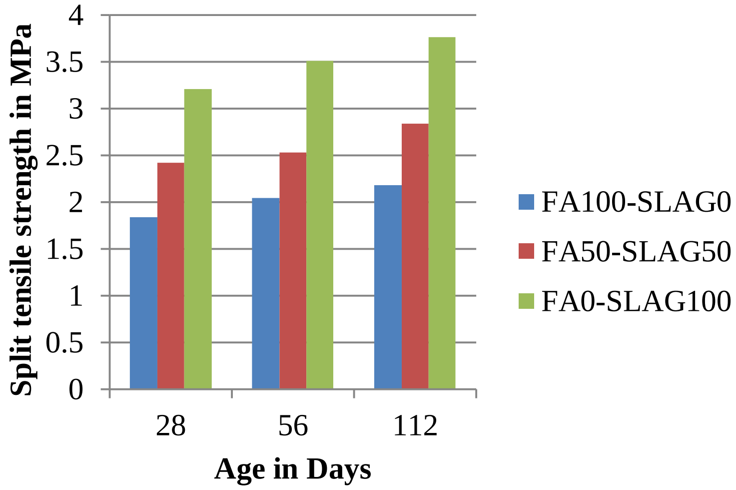

Figure 2.Split tensile strength of mixes

4.3 Flexural strength

Table 9 Shows the flexural strength of GPC mixes with fine aggregate and slag blending(FA100-SLAG0; FA50-SLAG50; FA0-SLAG100) at different curing periods.

Table 9: Flexural strength of GPC

Mechanical property	Age (days)	Mix type		
		FA100-SLAG0	FA50-SLAG50	FA0-SLAG100
Flexural strength, f_{cr} (MPa)	28	3.76	4.89	5.29
	56	3.81	5.12	5.65
	112	3.87	5.34	6.08

It was observed that there was a significant increase in flexural strength with the increase in percentage of slag from 0% to 100% in all curing periods as shown in Fig. 3. It can be concluded that the increase in slag replacement level refines the pore structure of GPC thus improves the flexural strength of GPC. The GPC with 100% slag sample exhibited splitting tensile strength values of 5.29 MPa, 5.65 MPa and 6.08MPa after 28, 56 and 112 days of curing respectively at ambient room temperature as shown in Table 9.

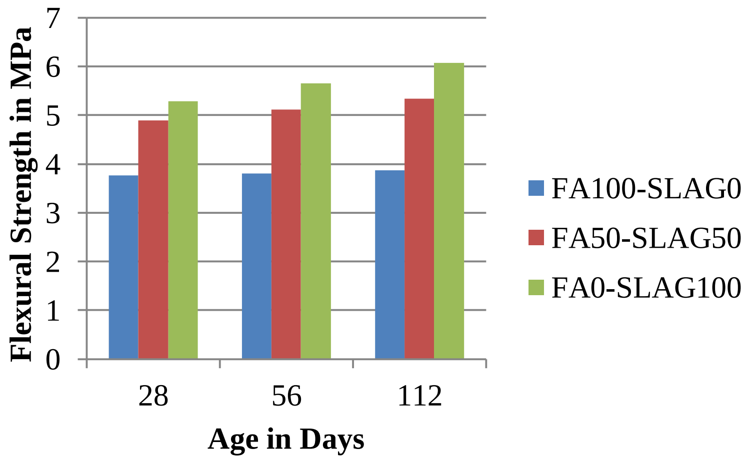

Figure 3.Flexural strength of mixes

From the results it is revealed that flyash and slag blended GPC mixes attained enhanced mechanical properties at ambient room temperature curing itself without the need of heat curing. 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:

1. The increased level of slag replacement increased the mechanical properties of FA based GPCmixes at ambient room temperature curing itself without the need of heat curing as in the case of only FA based GPC mixes.
2. For 50% and 100% slag replacement, FA and GPC mixes attainedenhanced mechanical properties at ambient room temperature curing at all ages.
3. Keeping in view of savings in natural resources, sustainability, environment, production cost, maintenance cost and all other GPC properties, it can be recommended slag as an alternative to sand for the use of constructions.

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