Performance of Fly Ash and GGBS Based Geopolymer Concrete in Acid Environment

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Abstract: **Geopolymer concrete (GPC) is becoming a sustainable concrete when comparing to ordinary Portland cement (OPC) concrete. This investigation is mainly focused on performance of fly ash (FA) and ground granulated blast furnace slag (GGBS) based GPC in acid environment. The compressive strength, weight and ultrasonic pulse velocity (UPV) values of GPC mixes (FA100-GGBS0; FA50-GGBS50; FA0-GGBS100) were determined after 28 days of immersion in 3% sulphuric acid (H_2SO_4). In this study, sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solution is used as alkaline activator. Specimens were cast and cured for different curing periods at ambient room temperature and then studied the performance of GPC in acid environment. Test results revealed that the increased level of GGBS increased the compressive strength and ultrasonic pulse velocity values of GPC at all curing periods. The percentage of reduction in weight, compressive strength and pulse velocity values is decreased with the increased replacement of GGBS.**

Keywords: **Geopolymer concrete; fly ash, GGBS; compressive strength; ultrasonic pulse velocity; acid environment.**

I. INTRODUCTION

Concrete is the most widely used construction material after water 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 (CO2) to the atmosphere that significantly contributes to greenhouse gas emissions. It is estimated that one ton of CO2 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 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. 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 [5]. Geopolymers are made from source materials with silicon (Si) and Aluminium (Al) content and thus cement can be completely replaced by the materials such as fly ash and ground granulated blast furnace slag which are 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 and durability properties of the geopolymer concrete.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. Guru Jawahar and Mounika concluded that GGBS and FA blended GPC mixes attained enhanced mechanical properties at ambient room temperature itself [10]. 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. Sreenivasulu et al. observed that there was a significant increase in compressive strength with the increase in percentage of granite slurry powder as sand replacement from 0% to 40% in all curing periods [13 & 14]. Vijai et al. [15] developed an expression to predict 28-day compressive strength, splitting tensile strength and flexural strength of steel fibre reinforced geopolymer concrete composites.

II. EXPERIMENTAL STUDY

Our objective was to determine the compressive strength, weight and ultrasonic pulse velocity (UPV) of fly ash and GGBS based GPC before and after sulphuric acid attack.

Materials

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 [16], 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: Properties of geopolymer binders

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	2.13	2.9
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 (Na2O= 13.7%, SiO2=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.

Test Methods

Compressive strength test was conducted on the cubical specimens for all the mixes after 7 and 28 days of curing as per IS 516 [17]. Three cubical specimens of size 150 mm x 150 mm x 150 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. Ultrasonic pulse velocity test was conducted on GPC specimens as per ASTM C 597-02 [18] prior to compression test. Resistance of concrete specimens against external acid attack was evaluated as per ASTM C 267-01 [19]. Each specimen of concrete was weighed on completion of initial ambient curing period of 28 days. Then the specimens were immersed in 3% sulphuric acid (H2SO4) solution. During this test the changes in the weight, UPV and compressive strength values of GPC specimens were determined after 28 days of immersion the specimens in 3% sulphuric acid solution.

III. MIX DESIGN

Based on the limited past research on GPC, the following proportions were selected for the constituents of the mixtures [20]. 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, 517 kg/m3 (40%) of 10 mm aggregates, and 554 kg/m3 (30%) of fine aggregate to meet the requirements of standard grading curves. 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 90 litres is calculated on trial basis to get adequate workability. Superplasticizer was added to maintain adequate workability. The geopolymer concrete mixture proportions are shown in Table 2.

Table 2: GPC mix proportions

Materials		Mass (kg/m^3)		
		FA100-GGBS0	FA50-GGBS50	FA0-GGBS100
Coarse aggregate	20 mm	776	776	776
	10 mm	517	517	517
Fine aggregate		554	554	554
Fly ash (Class F)		409	204.5	0
GGBS		0	204.5	409
Sodium silicate solution		102	102	102

Sodium hydroxide solution	41 (10M)	41 (10M)	41 (10M)
Extra water	90	90	90
Alkaline solution/ (FA+GGBS) (by weight)	0.35	0.35	0.35
Superplasticizer	2.86	2.86	2.86

IV. RESULTS AND DISCUSSION

Performance of GPC before acid attack

Table 3 shows the compressive strength, weight and UPV values of GPC mixes (FA100-GGBS0; FA50-GGBS50; FA0-GGBS100) at different curing periods before acid attack.

Mechanical property	Age (days)	Mix type		
		FA100-GGBS0	**FA50-GGBS50**	**FA0-GGBS100**
Compressive strength, f'_c (MPa)	7	8.79	38.12	50.4
	28	11.08	52.5	57.6
Weight of specimen (kg)	28	7.3	7.73	8.09
UPV (m/s)	7	300	2443	3198
	28	350	3304	3558

From the results it is seen that the mix FA100-GGBS0 has attained very less compressive strength values when compared to those of the other two mixes after 7 and 28 days of curing. The mixes FA50-GGBS50 and FA0-GGBS100 have attained higher compressive strength values of 38.12 MPa and 50.4 MPa when compared to the mix FA100-GGBS0 after 7 days of curing. The mixes FA50-GGBS50 and FA0-GGBS100 have attained higher compressive strength values of 52.5 MPa and 57.6 MPa when compared to the mix FA100-GGBS0 after 28 days of curing. From the results, it is noted that the GGBS blended GPC mixes have attained higher values of compressive strength in early ages itself i.e., after 7 days of curing as in the case of FA50-GGBS50 and FA0-GGBS100.Similarly, the mixes FA50-GGBS50 and FA0-GGBS100 have attained higher values of compressive strength at all ages. From the results, it is revealed that the GPC mixes have attained higher values of compressive strength with the increased percentage of GGBS. Hence from the Fig. 1, it is concluded that 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 Siddique [21]. Weights of GPC mixes after 28 days of curing are also tabulated in Table 3.From the results it is observed that FA100-GGBS0 mix has attained very poor pulse velocity values when compared to those of the other two mixes. The pulse velocity values increased from 300 m/s to 2443 m/s at 50% GGBS replacement and 300 m/s to 3198 m/s at 100% GGBS replacement after 7 days of curing. Similarly, the pulse velocity values increased from 350 m/s to 3304 m/s at 50% GGBS replacement and 350 m/s to 3558 m/s at 100% GGBS replacement after 28 days of curing. From the results it is clearly observed that the pulse velocity values increased with the increased replacement of GGBS at all curing periods. It is also noted that the pulse velocity values increased with the increase in curing period. From the Table 3, it is to be said that the compressive strength values are in line with the pulse velocity values. Hence, it is revealed that the increase in GGBS replacement increases the polymerization reactions which densifies mix and that leads to increase in the pulse velocity and compressive strength values.

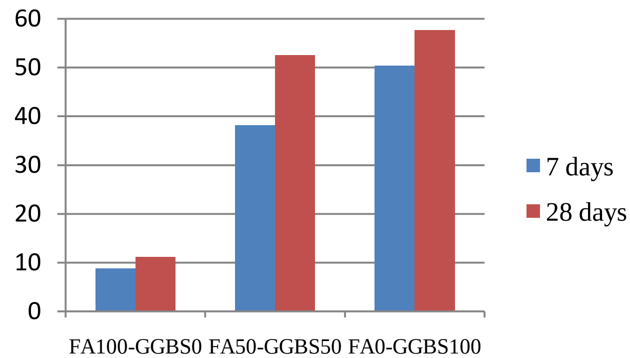

Figure 1. Compressive strength versus age

Performance of GPC after acid attack

Table 4 shows the initial values of weight, compressive strength and pulse velocity before acid attack after 28 days of curing and the corresponding loss of weight, compressive strength and pulse velocity values after acid attack of GPC mixes (FA100-GGBS0; FA50-GGBS50; FA0-GGBS100) after 28 days of immersion the specimens in 3% sulphuric acid solution after 28 days of curing.

Table 4: Performance of GPC after acid attack

Property		Mix type		
		FA100-GGBS0	**FA50-GGBS50**	**FA0-GGBS100**
Weight (kg)	Initial	7.3	7.73	8.09
	After aid attack	6.89	7.55	7.97
Loss of weight (%)		5.62	2.33	1.48
Compressive strength (Mpa)	Initial	11.08	52.5	57.6
	After aid attack	7.35	44.61	51.24
Loss of compressive strength (%)		33.66	15.03	11.04

Ultrasonic pulse velocity (m/s)	Initial	350	3304	3558
	After aid attack	210	3006	3280
Loss of pulse velocity (%)		40	9.02	7.81

From the Table 4, it is clearly observed that the loss of weight, compressive strength and pulse velocity values are very high in FA100-GGBS0 mix when compared to those of the other two mixes. The percentage of reduction in weight, compressive strength and pulse velocity values is decreased with the increased replacement of GGBS. It is believed that increased replacement level of GGBS is increasing the polymerization and hence densifying the concrete which refines the pore structure. This improved pore structure and polymerization is contributed to resistance to external sulphuric acid attack.

V. CONCLUSIONS

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

1. The increased level of GGBS increased the compressive strength and ultrasonic pulse velocity values of GPC at all curing periods.
2. During acid resistance tests, the percentage of reduction in weight, compressive strength and pulse velocity values is decreased with the increased replacement of GGBS.
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 for the use of constructions.

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