International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2015): 6.391

Acid Attack on Fly Ash and GGBS Blended Geopolymer Concrete using Different Fine Aggregates

J. Guru Jawahar[1], A. Bhavana[2]

[1]Professor, Department of Civil Engineering, Annamacharya Institute of Technology and Sciences, Andhra Pradesh, India

[2] P.G Student, Department of Civil Engineering, Annamacharya Institute of Technology and Sciences, Andhra Pradesh, India

Abstract: ***This investigation is mainly focused on the acid attack on class F fly ash (FA) and ground granulated blast furnace slag (GGBS) blended geopolymer concrete (GPC) using different fine aggregates. The GPC mixes (FA50-GGBS50) were manufactured with different fine aggregates viz. slag (SLAG), quarry dust (QD) and bottom ash (BA) at replacement levels of (SAND50-SLAG50, SAND50-QD50, SAND50-BA50) using sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solutions as alkaline activator. The compressive strength, weight and ultrasonic pulse velocity (UPV) values of GPC mixes were determined after 28 days of immersion in 3% sulphuric acid (H_2SO_4) after 28 days of ambient room temperature curing. The slag and quarry dust replaced GPC mixes performed better than bottom ash replaced mixes at ambient room temperature curing at all ages.***

Keywords: Geopolymer concrete, Fly ash, GGBS, Slag, Quarry Dust, Bottom ash

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 & 3]. 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. 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 greenhouse gases during polymerization process. Geopolymer can be produced by combining a pozzolanic compound or aluminosilicate source material with highly alkaline solutions [4]. Geopolymers are made from source materials with silicon (Si) and Aluminum (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 [5 & 6]. 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 aluminum 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 [6]. Palomo and Femandez-Jimenez [7] concluded that both curing temperature and curing time affects the compressive strength of GPC mixes. Gourley [8] stated that low calcium class F fly ash is more preferable than high calcium class C fly ash in the manufacturing of GPC. Bhikshma et al. [9] 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). 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 composite.

2. Experimental Study

The objective of this project is to study the compressive strength, weight and Ultrasonic pulse velocity (UPV) properties of fly ash and GGBS blended GPC mixes using slag, quarry dust and bottom ash as 50% sand replacement. These properties were determined before and after sulphuric acid attack.

2.1 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	*ClassF fly ash*	*GGBS*
Chemical composition		
% Silica(SiO_2)	65.6	30.61
% Alumina(Al_2O_3)	28	16.24
% Iron Oxide(Fe_2O_3)	3	0.584
% Lime(CaO)	1	34.48
% Magnesia(MgO)	1	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.

2.2 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 (H_2SO_4) 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.

3. 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/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, 517 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 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 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)*
		FA50-GGBS50
Coarse aggregate	20 mm	776
	10 mm	517
Fine aggregate		554
Fly ash (Class F)		204.5
GGBS		204.5
Sodium silicate solution		102
Sodium hydroxide solution		41 (10M)
Extra water		90
Alkaline solution/ (FA+GGBS) (by weight)		0.35
Superplasticizer		2.86

4. Results and Discussion

4.1 Performance of GPC before acid attack

Table 3 shows the compressive strength, weight and UPV values of GPC mixes (SAND50-SLAG50, SAND50-QD50, SAND50-BA50) at different curing periods before acid attack.

Table 3: Performance of GPC after acid attack

Mechanical property	Age (days)	Mix type (FA50-GGBS50)		
		SAND50-SLAG50	SAND50-QD50	SAND50-BA50
Compressive strength, f'c (MPa)	7	44.34	42.35	36.66
	28	70.44	54.86	45.34
Weight of specimen (kg)	28	8.14	8.08	7.67
UPV (m/s)	7	3102	2947	2123
	28	3687	3378	2376

From the results it is seen that the mix SAND50-BA50 has attained less compressive strength values when compared to those of the other two mixes after 7 and 28 days of curing. The mixes SAND50-QD50 and SAND50-SLAG50 have attained higher compressive strength values of 42.35 MPa and 44.34 MPa when compared to the mix SAND50-BA50 (36.66 MPa) after 7 days of curing. The mixes SAND50-QD50 and SAND50-SLAG50 have attained higher compressive strength values of 54.86 MPa and 70.44 MPa when compared to the mix SAND50-BA50 (45.34 MPa) after 28 days of curing. From the results, it is noted that the SLAG replaced GPC mixes have attained higher values of compressive strength at all ages. From the results, it is revealed that the increase in compressive strength was observed respectively in slag, quarry dust and bottom ash replaced GPC mixes as shown in 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. The mixes SAND50-QD50 and SAND50-SLAG50 have attained higher UPV values of 2947 m/s and 3102 m/s when compared to the mix SAND50-BA50 (2123 m/s) after 7 days of curing. The mixes SAND50-QD50 and SAND50-SLAG50 have attained higher UPV values of 3378 m/s and 3687 m/s when compared to the mix SAND50-BA50 (2376 m/s) after 28 days of curing.

From the results, it is revealed that the increase in UPV values was observed respectively in slag, quarry dust and bottom ash replaced GPC mixes 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 slag replacement increases the polymerization reactions which densifies mix and that leads to increase in the pulse velocity and compressive strength values.

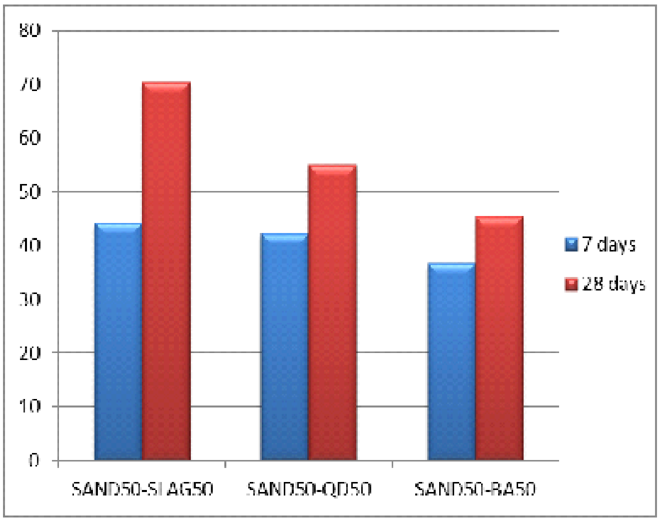

Figure 1: Compressive strength versus age

4.2 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 (SAND50-SLAG50, SAND50-QD50, SAND50-BA50) 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 (FA50-GGBS50)		
		SAND50-SLAG50	SAND50-QD50	SAND50-BA50
Weight (kg)	Initial	8.14	8.08	7.67
	After aid attack	8.09	7.96	7.46
Loss of weight (%)		0.61	1.49	2.74
Compressive strength (Mpa)	Initial	70.44	54.86	45.34
	After aid attack	66.24	48.64	39.22
Loss of compressive strength (%)		5.96	11.34	13.49
Ultrasonic pulse velocity (m/s)	Initial	3687	3378	2376
	After aid attack	3502	3119	2120
Loss of pulse velocity (%)		5.02	7.67	10.77

From the Table 4, it is clearly observed that the loss of weight, compressive strength and pulse velocity values are high in SAND50-BA50 mix when compared to those of the other two mixes. The percentage of reduction in weight, compressive strength and pulse velocity values is decreased respectively in slag, quarry dust and bottom ash replaced GPC mixes. It is believed that slag replacement 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. 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 [10 & 21]. 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 increase in compressive strength, weight and UPV values has been observed respectively in bottom ash, quarry dust and slag replaced GPC mixes.
2. During acid resistance tests, the percentage of reduction in weight, compressive strength and pulse velocity values is decreased respectively in bottom ash, quarry dust and slag replaced GPC mixes.
3. Keeping in view of savings in natural resources and sustainability, GPC can be recommended as an innovative construction material for the use of constructions.

References

[1] Davidovits J. Geopolymers: Man-Made Geosynthesis and the 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) 163-171.
[3] 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) 32-39.
[4] Davidovits J. Geopolymers: Inorganic Polymeric New Materials, Journal of Thermal Analysis, 37 (1991) 1633-1656.
[5] Davidovits J. Global Warming Impact on the Cement andAggregate Industries, World Resource review, 6 (1994) 263-278.
[6] Palomo SA, Grutzeck MW, Blanco MT. Alkali-activated fly ashes – A cement for the future, Cement and Concrete Research, 29 (1999) 1323-1329.
[7] Palomo SA, Femandez-Jimenez A. Alkaline activation of fly ashes: NMR study of the reaction products, *Journal of the American Ceramic Society*, 87 (2004) 1141–1145.
[8] 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.
[9] 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) 841-853.
[10] Guru Jawahar J, Mounika G. Strength properties of fly ash and GGBS based geopolymer concrete, Asian Journal of Civil Engineering, 17(1) (2016) 127-135.
[11] Sujatha T, Kannapiran K, Nagan S. Strength assessment of heat cured geopolymer concrete slender column, Asian Journal of Civil Engineering, 13 (2012) 635-646.
[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) 353-364.
[13] Sreenivasulu C, Guru Jawahar J, Vijaya Sekhar Reddy M, Pavan Kumar D. Effect of Fine Aggregate Blending on Short-Term Mechanical Properties of Geopolymer Concrete, Asian Journal of Civil Engineering, 17(5) (2016) 537-550.
[14] 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(2) (2015) 83-91.
[15] 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) 377–385.
[16] ASTM C 618:2003. Standard specification for coal fly ash and raw or calcined natural pozzolan for use in concrete.
[17] IS 516 (1991). Methods of tests for strength of concrete, Bureau of Indian Standards, New Delhi, India.
[18] ASTM C 597-02, Standard test methods for pulse velocity through concrete. ASTM International, West Conshohocken, USA, 2002.
[19] ASTM C 267-01, "Standard Test Methods for chemical resistance of mortars, grouts and monolithic surfacing and polymer concretes." ASTM International, West Conshohocken, USA.
[20] 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.
[21] Siddiqui KS. Strength and Durability of Low-Calcium Fly Ash-based Geopolymer Concrete. Final Year Honours Dissertation, The University of Western Australia, Perth, 2007.

Author Profile

Dr. J. Guru Jawahar has 19 years of experience (11 years in industry and 8 years in teaching). He obtained his B. Tech from Sri Venkateswara University, Tirupati. He obtained his M. Tech and Ph. D from Jawaharlal Nehru Technological University College of Engineering, Anantapur with the specialization of Structural Engineering. He has 20 publications His research interests include self-compacting concrete, geopolymer concrete and advanced construction materials. He has life membership in Indian Society for Technical Education. He also has Six Sigma Green Belt and many other certificates.

A. Bhavana pursuing M. Tech in Structural Engineering, performing research in the areas of Geopolymer concrete using various eco-friendly materials"