MECHANICAL PROPERTIES OF FLY ASH AND GGBS BLENDED GEO POLYMER CONCRETE USING DIFFERENT FINE AGGREGATES

P. Ukesh Praveen[1], Dr. J. Guru Jawahar[2], K. Sai Abhinav[3], C. Sashidhar[4]

[1]*P.G Student, Department of Civil Engineering, Annamacharya Institute of Technology and Sciences, Andhra Pradesh, India*
[2]*Professor, Department of Civil Engineering, Annamacharya Institute of Technology and Sciences, Andhra Pradesh, India*
[3]*P.G Student, Department of Civil Engineering, Annamacharya Institute of Technology and Sciences, Andhra Pradesh, India*
[4]*Professor, Department of Civil Engineering, Jawaharlal Nehru Technological University Anantapur, Andhra Pradesh, India*

Abstract - *This project mainly aims at the study of effect of class F fly ash (FA) and ground granulated blast furnace slag (GGBS) on the mechanical properties of geopolymer concrete (GPC) at replacement level of (FA50-GGBS50) and replacement of fine aggregate with slag, quarry dust, bottom ash at levels of (SAND50-SLAG50, SAND50-QD50, SAND50-BA50) using sodium silicate (Na2SiO3) and sodium hydroxide (NaOH) solutions as alkaline activator. The replacement of sand with slag and quarry dust in GPC mixes enhanced the mechanical properties at ambient room temperature curing at all ages.*

***Key Words*: Geopolymer concrete, Fly ash, Quarry Dust, Slag, Bottom ash, Compressive Strength, Split Tensile Strength**

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). Sujatha et al. [10]

observed that geopolymer concrete columns exhibited high load carrying capacity, stiffness and ductility until failure. Anuradha et al. [11] noted that tensile strength of GPC made with river sand is higher than that of GPC made with manufactured sand. Vijai et al. [12] 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 mechanical properties of fly ash and GGBS blended GPC mixes using slag, bottom ash and quarry dust as 50% sand replacement and at ambient room temperature curing. 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 [13]. 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 [14]. Three cylindrical specimens of size 150 mm x 300 mm were cast and tested for each age and each mix.

3. MIX DESIGN

Based on the limited past research on GPC, the following proportions were selected for the constituents of the mixtures [15]. 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 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. The geopolymer concrete mixture proportions are shown in Table 1.

Table 1: GPC mix proportions

Materials		Mass (kg/m^3) FA50-SLAG50
Coarse aggregate	20 mm	776
	10 mm	517
Fine aggregate		554
Fly ash (Class F)		409
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

Table 2 shows the compressive strength of GPC mixes with mix type of fly ash and GGBS (FA50-GGBS50) and replacement of fine aggregates at levels of (SAND50-SLAG50, SAND50-QD50, SAND50-BA50).

Table 2: Compressive strength of GPC

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
	14	54.51	48.2	38.7
	28	70.44	54.86	45.34
	56	76.84	68.33	48.66
	112	88.95	77	55.03

It was observed that there was a significant increase in compressive strength with the mix proportion of (FA50-GGBS50) and replacement of sand with percentage of SAND50-SLAG50 and SAND50-QD50 in all curing periods as shown in Fig. 1. It can be concluded that the increase in replacement level of sand with 50% of slag and 50% quarry dust enhances strength improvement in geopolymers. The GPC with mix type of (FA50-GGBS50) and replacement of SAND50-SLAG50 sample exhibited compressive strength values of 44.34 MPa, 54.51 MPa, 70.44 MPa, 76.84 MPa and 88.95 MPa and replacement of SAND50-QD50 sample exhibited compressive strength values of 42.35 MPa, 48.2 MPa, 54.86 MPa, 68.33 MPa and 77 MPa after 7, 14, 28, 56 and 112 days of curing respectively at ambient room temperature as shown in Table 2.

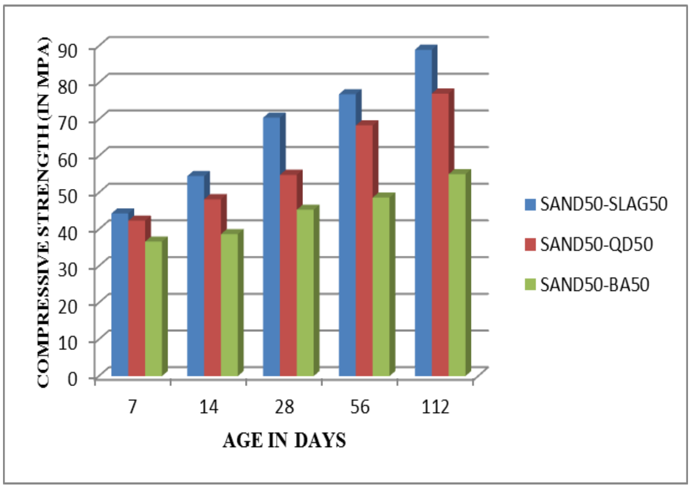

Figure 1. Compressive strength versus age

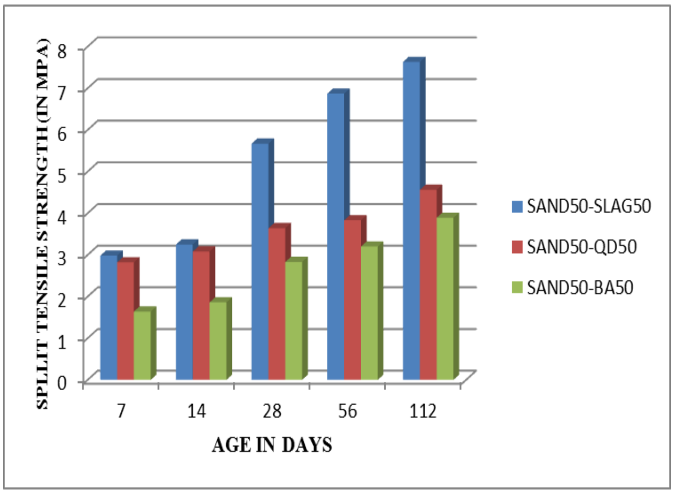

Figure 2. Split tensile strength versus age

Table 3 shows the splitting tensile strength (STS) of GPC mix of (FA50-GGBS50) with different fine aggregates as sand replacement SAND50-SLAG50, SAND50-QD50 and SAND50-BA50 at different curing periods. It was observed that there was a significant increase in splitting tensile strength with the replacements of SAND50-SLAG50 and SAND50-QD50 in all curing periods as shown in Fig. 2. It can be concluded that the increase in replacement level of sand with slag and quarry dust improves the microstructure of GPC thus leads to enhancement of splitting tensile strength of GPC. The GPC mix of (FA50-GGBS50) and replacement of sand as SAND50-SLAG50, SAND50-QD50 and SAND50-BA50 samples 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 3.

Table 3: Splitting tensile strength of GPC

Mechanical property	Age (days)	Mix type: (FA50-GGBS50)		
		SAND50-SLAG50	SAND50-QD50	SAND50-BA50
Splitting tensile strength, fct (MPa)	7	2.98	2.82	1.64
	14	3.25	3.08	1.86
	28	5.67	3.64	2.83
	56	6.87	3.83	3.20
	112	7.63	4.56	3.89

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 [16, 17 & 18]. 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. 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.
2. The replacement of sand with slag and quarry dust in GPC mixes enhanced the 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 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] Sujatha T, Kannapiran K, Nagan S. Strength assessment of heat cured geopolymer concrete slender column, Asian Journal of Civil Engineering, 13 (2012) 635-646.
[11] 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.
[12] 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.
[13] IS 516 (1991). Methods of tests for strength of concrete, Bureau of Indian Standards, New Delhi, India.
[14] IS 5816 (1999). Splitting tensile strength of concrete method of test, Bureau of Indian Standards, New Delhi, India.
[15] 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.
[16] Siddiqui KS. Strength and Durability of Low-Calcium Fly Ash-based Geopolymer Concrete. Final Year Honours Dissertation, The University of Western Australia, Perth, 2007.
[17] Guru Jawahar J., Mounika G. Strength properties of fly ash and GGBS based geopolymer concrete. Asian Journal of Civil Engineering, 2016, 17(1), pp 127-135.ISSN 1563-0854
[18] 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, 2016, 17(5), pp 537-550.ISSN 1563-0854

BIOGRAPHIES

"P. Ukesh Praveen pursuing M.Tech in Structural Engineering, performing research in the areas of High Strength Performance Concrete using different admixtures and eco-friendly materials"

"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."

"K.Sai Abhinav pursuing M.Tech in Structural Engineering, performing research in the areas of Fibre reinforced Concrete"

"Dr.C. Sashidhar is a Professor in the department of Civil Engineering, JNTUA, Anantapuramu. He received M.Tech and Ph.D from J.N.T.University, Hyderabad. His research interests include FRC, SIFCON, HPC, Non Destructive Test Evaluation and Earth Quake Engineering. He has co – authored more than 40 scientific and technical publications"