Preliminary Study on Geopolymer Concrete using Copper Slag and Vermiculite

Burri Yakshareddy[1*], J. Guru Jawahar[1], C. Sreenivasulu[1], C. Sashidhar[2]
[1]*Department of Civil Engineering, Annamacharya Institute of Technology & Sciences, Tirupati, India*
[2]*Department of Civil Engineering, Jawaharlal Nehru Technological University Anantapuram, India*

Abstract: **Geopolymer concrete (GPC) is becoming a sustainable concrete when comparing to ordinary Portland cement (OPC) concrete. This investigation is mainly focused on the preliminary study on fly ash (FA) and ground granulated blast furnace slag (GGBS) based GPC using copper slag (CS) and vermiculite (VM) as fine aggregate replacement at different levels (0%, 20% and 40%). The compressive strength and ultrasonic pulse velocity (UPV) values of GPC mixes (FA50-GGBS50) were determined after 7 and 28 days of ambient room temperature curing. In this study, sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solution is used as alkaline activator. Test results revealed that the increased replacement level of copper slag increased the GPC properties. Whereas, the increased replacement level of vermiculite decreased the GPC properties.**

Keywords: **Geopolymer concrete; fly ash, GGBS; compressive strength; ultrasonic pulse velocity; copper slag; vermiculite.**

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 (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]. Several efforts are in progress to supplement the use of Portland cement in concrete in order to address the global warming issues. In view of this, Davidovits proposed that geopolymer 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, rice husk ash etc [1]. The most common industrial by-products used as binder materials are fly ash (FA) and ground granulated blast furnace slag (GGBS) [2-4]. 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 [5-7]. 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. 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 concluded that GGBS and FA blended GPC mixes attained enhanced mechanical and durability properties at ambient room temperature itself [10-13]. Sujatha et al. [14] observed that geopolymer concrete columns exhibited high load carrying capacity, stiffness and ductility until failure. Anuradha et al. [15] noted that tensile strength of GPC made with river sand is higher than that of GPC made with manufactured sand. Research is being carried out to develop the GPC using different materials as fine aggregate replacement to save the natural resources. Sreenivasulu et al. observed that there was a significant increase in compressive strength with the increased granite slurry powder (GS) from 0% to 40% as sand replacement in all curing periods [16-19].

II. EXPERIMENTAL STUDY

Our objective was to determine the compressive strength and ultrasonic pulse velocity (UPV) of fly ash and GGBS based GPC using copper slag and vermiculite as replacement of sand at different levels (0%, 20% and 40%).

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 [20], class F fly ash produced from Rayalaseema Thermal Power Plant (RTPP), Muddanur, A.P, GGBS, copper slag (CS) and vermiculite (VM) obtained from the local suppliers were used in the manufacturing of GPC.

The alkaline liquid used was a combination of sodium silicate solution and sodium hydroxide solution. The sodium silicate solution (Na_2O= 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 8 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. Copper slag and vermiculite were used as fine aggregate replacements. 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, copper slag and vermiculite were 2.62 and 1%; 4.9 and 0%; 1.25 and 1.22% respectively.

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

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 [21]. 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 [22] prior to compression test.

III. MIX DESIGN

Based on the limited past research on GPC, the following proportions were selected for the constituents of the mixtures [23]. 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/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/m3 (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(Na2SiO3) solution-to-sodium hydroxide (NaOH) solution by mass as 2.5; the mass of sodium hydroxide 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) are mixed with water to make a solution with a concentration of 8 Molar. This solution comprises 32% of NaOH solids and 68% 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 = 0.32x41 = 13.12 kg, and water = 41 – 13.12 = 27.88 kg. Therefore, total mass of water = 57+27.88 = 84.88 kg, and the mass of geopolymer solids = 409 (i.e. mass of fly ash and GGBS) + 45 + 13.12 = 467.12 kg. Hence, the water-to-geopolymer solids ratio by mass = 84.88/467.12 = 0.18. Extra water of 42 litres is calculated on trial basis to get adequate workability. Superplasticizer (0.7% of geopolymer binders) was added to maintain adequate workability. The geopolymer concrete mixture proportions and fine aggregate proportions are shown in Table 2, Table 3 and Table 4.

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 (8M)
Extra water		42
Alkaline solution/ (FA+GGBS) (by weight)		0.35
Superplasticizer		2.86

Table 3: Sand and copper slag proportions

Fine aggregate	Weight (kg/m^3)		
	0%	20%	40%
Sand	554	347	140
Copper slag	0	207	414

Table 4: Sand and vermiculite proportions

Fine aggregate	Weight (kg/m^3)		
	0%	20%	40%
Sand	554	502	450
Vermiculite	0	52	104

IV. RESULTS AND DISCUSSION

Compressive strength

Table 5 shows the compressive strength values of GPC mixes at different curing periods using copper slag and vermiculite as fine aggregate replacement.

Table 5: Compressive strength of GPC

Compressive strength (MPa)	Age (days)	
	7	28
100%Sand	29.08	53.33
20%CS	38.41	65.61
40%CS	45.56	75.85
20%VM	26.12	47.32
40%VM	23.89	41.78

From the Table 5, it is seen that the mix 100%Sand has attained compressive strength values of 29.08 MPa and 53.33 MPa respectively after 7 and 28 days of curing. It is observed that the mix 20%CS has attained more compressive strength values of 38.41 MPa and 65.61 MPa respectively after 7 and 28 days of curing when compared to those of the 100%Sand. Similarly, the mix 40%CS has attained more compressive strength values of 45.56 MPa and 75.85 MPa respectively after 7 and 28 days of curing when compared to those of the mixes 100%Sand and 20%CS. The percentage increase in the compressive strength values of the mix 20%CS was observed to be 32% and 23% respectively after 7 and 28 days of curing when compared to 100% Sand mix. The percentage increase in the compressive strength values of the mix 40%CS was observed to be 56% and 42% respectively after 7 and 28 days of curing when compared to 100%Sand mix. From the results, it is revealed that the GPC mixes have attained higher values of compressive strength with the increased percentage of copper slag (CS) as shown in Fig. 1. Hence, it is to be pointed out that the increase in CS replacement increases the polymerization reactions which densifies mix and that leads to increase in the compressive strength values. It can also be said that alkali activation of CS was significantly increasing with the increased replacement of CS.

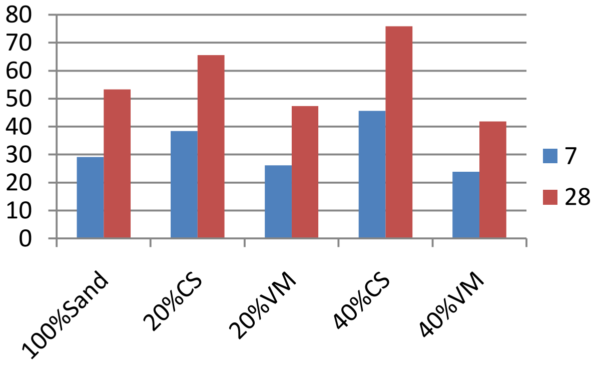

Figure 1. Compressive strength versus age

From the Table 5, it is observed that the mix 20%VM has attained less compressive strength values of 26.12 MPa and 47.32 MPa respectively after 7 and 28 days of curing when compared to those of the 100%Sand. Similarly, the mix 40%VM has attained less compressive strength values of 23.89 MPa and 41.78 MPa respectively after 7 and 28 days of curing when compared to those of the mixes 100%Sand and 20%VM. The percentage decrease in the compressive strength values of the mix 20%VM was observed to be 10% and 11% respectively after 7 and 28 days of curing when compared to 100%Sand mix. The percentage decrease in the compressive strength values of the mix 40%VM was observed to be 17% and 22% respectively after 7 and 28 days of curing when compared to 100%Sand mix. From the results, it is revealed that the GPC mixes have attained lower values of compressive strength with the increased percentage of vermiculite (VM) as shown in Fig. 1. Hence, it is to be pointed out that the increase in VM replacement decreases the polymerization reactions and leads to decrease in the compressive strength values. It can also be said that alkali activation of VM was not that much significant when compared to CS.

Ultrasonic pulse velocity

Table 6 shows the ultrasonic pulse velocity (UPV) values of GPC mixes at different curing periods using copper slag and vermiculite as fine aggregate replacement.

Table 6: Ultrasonic pulse velocity of GPC

Ultrasonic pulse velocity (m/s)	Age (days)	
	7	28
100%Sand	3842	4012
20%CS	4043	4238
40%CS	4155	4428
20%VM	3660	3856
40%VM	3440	3672

From the Table 6, it is seen that the mix 100%Sand has attained UPV values of 3842 m/s and 4012 m/s respectively after 7 and 28 days of curing. It is observed that the mix 20%CS has attained more UPV values of 4043 m/s and 4238 m/s respectively after 7 and 28 days of curing when compared to those of the 100%Sand. Similarly, the mix 40%CS has attained more UPV values of 4155 m/s and 4428 m/s respectively after 7 and 28 days of curing when compared to those of the mixes 100%Sand and 20%CS. From the results, it is revealed that the GPC mixes have attained higher values of UPV with the increased percentage of copper slag (CS) as shown in Table 6. Hence, it is concluded that the increase in CS replacement increases the polymerization reactions which densifies mix and that leads to increase in the compressive strength and UPV values.

From the Table 6, it is observed that the mix 20%VM has attained less UPV values of 3660 m/s and 3856 m/s respectively after 7 and 28 days of curing when compared to those of the 100% Sand. Similarly, the mix 40%VM has attained less UPV values of 3440 m/s and 3672 m/s respectively after 7 and 28 days of curing when compared to those of the mixes 100%Sand and 20%VM. From the results, it is revealed that the GPC mixes have attained lower values of UPV with the increased percentage of vermiculite (VM) as shown in Table 6. Hence, it is concluded that the increase in VM replacement decreases the polymerization reactions and leads to decrease in the compressive strength and UPV values.

V CONCLUSIONS

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

1. The increase in CS replacement increases the polymerization reactions which densifies mix and that leads to increase in the compressive strength and UPV values.
2. It can be said that alkali activation of CS was significantly increasing with the increased replacement of CS.
3. The increase in VM replacement decreases the polymerization reactions and leads to decrease in the compressive strength and UPV values.
4. It can be said that alkali activation of VM was not that much significant when compared to CS.
5. 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]. 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) 584-592.

[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) 32-39.

[5]. Davidovits J. Geopolymers: Inorganic Polymeric New Materials, Journal of Thermal Analysis, 37 (1991) 1633-1656.

[6]. Davidovits J. Global Warming Impact on the Cement andAggregate Industries, World Resource review, 6 (1994) 263-278.

[7]. Palomo SA, Grutzeck MW, Blanco MT. Alkali-activated fly ashes – A cement for the future, Cement and Concrete Research, 29 (1999) 1323-1329.

[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) 1141–1145.

[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]. 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]. J. Guru Jawahar, D. Lavanya, C. Sashidhar. Performance of fly ash and GGBS based Geopolymer concrete in acid environment, International Journal of Research and Scientific Innovation, 3(8) (2016) 101-104.

[12]. J. Guru Jawahar, A. Bhavana. Acid attack on fly ash and GGBS blended Geopolymer concrete using different fine aggregates, International Journal of Science and Research, 5(8) (2016) 1012-1015.

[13]. P. Venkata Kiran, J. Guru Jawahar, C. Sashidhar and C. Sreenivasulu. Flexural studies on fly ash and GGBS blended reinforced geopolymer concrete beams, International Journal of Research and Scientific Innovation, 4(3) (2017) 91-95.

[14]. Sujatha T, Kannapiran K, Nagan S. Strength assessment of heat cured geopolymer concrete slender column, Asian Journal of Civil Engineering, 13 (2012) 635-646.

[15]. 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.

[16]. Sreenivasulu C, Guru Jawahar J, VijayaSekhar 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.

[17]. 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.

[18]. Sreenivasulu Chitrala, Guru Jawahar Jadaprolu, Sashidhar Chundupalli. Study and predicting the stress-strain characteristics of geopolymer concrete under compression, Case Studies in Construction Materials, 8 (2018) 172-192.

[19]. Sreenivasulu C, Guru Jawahar J, Sashidhar C. Predicting compressive strength of geopolymer concrete using NDT techniques, Asian Journal of Civil Engineering, 1 (2) (2018), https://doi.org/10.1007/s42107-018-0036-1

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

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

[22]. ASTM C 597-02, Standard test methods for pulse velocity through concrete. ASTM International, West Conshohocken, USA, 2002.

[23]. Hardjito, D. and Rangan, B. V. (2005), Development and Properties of Low-Calcium Fly Ash-based Geopolymer Concrete, Research Report GC1, Faculty of Engineering, Curtin University of Technology, Perth, available at espace@curtin or www.geopolymer.org.