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EXPERIMENTAL STUDY ON FLY ASH AND GGBS BASED GEOPOLYMER CONCRETE USING COPPER SLAG

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Abstract- Geopolymer concrete (GPC) is prepared by using industrial waste like fly ash (FA) and ground granulated blast furnace slag (GGBS) replacing ordinary Portland cement (OPC). Geopolymer concrete is the most economical and ecofriendly replacement to traditional concrete. The alkaline solutions used for polymerization of concrete are sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). A 10 Molarity solution is used for preparation of mix. In the present study different proportions of fly ash and GGBS are prepared as FA80 and GGBS20, FA90 and GGBS10 in percentages of total binding material and copper slag is replaced as fine aggregate in 0, 20, 40, 60, 80, 100%. The strength properties like compressive strength, split tensile strength and flexural strength are tested for 7, 28 and 90 days of ambient curing. The fresh concrete tests are also conducted. Comparing studies show that geopolymer concrete can be prepared at low cost comparing to that of OPC concrete and offers huge reduction in the carbon dioxide emissions.

Keywords: Geopolymer, fly ash, alkaline liquids, GGBS, copper slag, ambient curing.

I. INTRODUCTION

The use of concrete has been increasing in day to day life and it is the major building material used in the construction industry. The production of ordinary Portland cement (OPC) consumes natural resources and large amount of energy[1]. This leads to the emission of large amount of greenhouse gases into the atmosphere. It is found that one ton of cement production generates one ton of CO_2 emissions and it contributes nearly 6% of total emissions of CO_2 in the world[8]. To overcome these problems cement is replaced with supplementary materials which give equal strength to that of cement and ecofriendly[4]. The researchers have developed a new alternative binding materials for construction, which is eco-friendly and that leads to the new cement less binder called geopolymers, an alternative cementious material prepared from the combination of silica-alumina rich source material with alkali solution[6]. These includes the byproducts from industries such as fly ash, GGBS, silica fume, metakaolin, rice husk ash etc[2]. In the present study, fly ash and GGBS are used as binding materials. Fly ash is the byproduct of industries formed during the burning of coal at higher temperatures and GGBS is the byproduct from the blast furnace during manufacture of iron[4]. The chemical reaction take place between the source material and the alkaline liquid is called as polymerization process. Sodium silicate and sodium hydroxide are used as the alkaline liquids.

The use of sand in the concrete from river beds effects aquatic life, vegetation and reduces ground water level of surroundings[1]. In this study, copper slag is used as the replacement of sand which is the byproduct formed during matte smelting and refining copper[5]. The chemical composition of copper slag depends on the type of furnace, the metallurgical production process and the composition of the extracted ore[4]. This paper presents an experimental study on partial replacement of sand with copper slag at different proportions. The strength of concrete mainly depends on temperature and duration of curing. In the present study, ambient curing of geo polymer concrete is adopted.

II. MATERIALS AND ITS PROPERTIES

A. Fly Ash

Fly ash used in the present investigation belongs to class F fly ash and it is collected from Rayalaseema Thermal Power Plant (RTPP), Muddanur, Kadapa(dist), Andhra Pradesh. Specific gravity of fly ash is 2.2.

TABLE 1
PROPERTIES OF FLY ASH

SL.NO	Chemical composition	Fly ash (%wt.)
1	Silica	56.01
2	Aluminum oxide	28.10
3	Iron oxide	3.18
4	Calcium oxide	2.36
5	Magnesium oxide	0.38
6	Sulphur	1.64
7	Titanium oxide	1.75
8	Potassium oxide	0.73
9	Alkalies	0.61
10	Loss of ignition	0.40

B. Ground Granulated Blast Furnace Slag (GGBS:

GGBS is obtained from JSW steel plant, Nandyal, Kurnool(dist), Andhra Pradesh. Specific gravity of GGBS is 2.9.

TABLE 2
PROPERTIES OF GGBS

SL.NO	Chemical composition	GGBS(% wt.)
1	Calcium oxide	40
2	Silica	34
4	Aluminium oxide	12
5	Manganese oxide	7
6	Iron oxide	1.0

C. Copper Slag

Copper slag is the byproduct obtained from matte smelting and copper refining which can be used as a replacement of fine aggregate or cement. Production of one ton of copper produces 2.5 to 3 tons of copper slag[4]. It has higher density as impurities stay in the top layer and copper settles down in the smelter. The copper slag has specific gravity of 2.58.

D. Alkaline liquid

Alkaline liquid used in this study includes the solution of sodium hydroxide and solution of sodium silicate. Sodium hydroxide (NaOH) generally available in the form of pellets or flakes, in the present study sodium hydroxide is used in the pellets form with 98% purity. Sodium hydroxide of 10M (Molarity) is used. Specific gravity and pH value of sodium hydroxide is 1.8 and 14 respectively. Sodium silicate is available in the liquid form. Chemical composition of sodium silicate is Na_2O – 14.7, SiO_2 – 31.4 and water – 53.9 by mass. Specific gravity of sodium silicate is 1.7.

E. Aggregates

Coarse aggregate used in this study are 10mm and 20mm size aggregates which are available from locally available crushed hard rocks. The specific gravity of coarse aggregate is 2.7.

The fine aggregate used in this study is obtained from locally available river sand which is passing through 4.75mm sieve size. The specific gravity and fineness modulus of sand is 2.625 and 2.79.

III. **METHODOLOGY**

A. Mix design of Geopolymer concrete

The mix design of geo-polymer is based on conventional concrete with some modifications. As the mix design of geo-polymer does not exist, we use trial and error method. In the design of geopolymer concrete mix, combined mass of coarse aggregate and fine aggregate are taken as 75% of mass of concrete[3]. In the case of conventional concrete it varies from 75% to 80% of total mass of concrete. Mass of concrete is taken as $2400kg/m^3$. Mass of coarse aggregate is taken as 70% of total mass of aggregate and mass of fine aggregate is taken as 30% of total mass of aggregate. Combined mass of Geopolymer binder and Alkaline liquid can be obtained by assuming the ratio of alkaline liquid to fly ash as 0.45. Mass of geopolymer binder, mass of fly ash and mass of alkaline liquid can be found. To obtain the mass of sodium hydroxide and sodium silicate solution, we take the ratio of sodium silicate solution to sodium hydroxide solution as 2. If necessary extra water can be added to mix to achieve workable concrete.

B. Preparation of alkaline solution

Alkaline solution is prepared by mixing of sodium hydroxide solution and sodium silicate solution. Sodium hydroxide solution is prepared before one day of casting of geopolymer concrete. Sodium hydroxide solution is prepared by mixing NaOH pellets of 10M consisting 10x40= 400gms with one litre of solution, where 40 is the molecular weight of NaOH. On the day of casting of geopolymer concrete, sodium silicate solution and sodium hydroxide solution are mixed properly and used.

C. Preparation of Geopolymer Concrete

Preparation of geopolymer concrete is explained in three steps as follows

Mixing:

During the mixing process of geopolymer concrete first the materials such as fly ash, GGBS, coarse aggregate and fine aggregates are mixed in dry condition about 3-4 minutes then alkaline solution of sodium hydroxide and solution of sodium silicate is added to the dry mix. The mixing process is done for about 6-8 minutes for proper binding of all the materials.

Casting:

After mixing, immediately geopolymer concrete mix is poured into moulds and tamping is done for proper compaction. Top surface of the mould is properly finished. Moulds used include cubes (150mmx150mmx150mm), cylinders (150mmx300mm) and beams (100mmx100mmx500mm).

Curing:

After 2 days, moulds are demoulded and kept for ambient curing. Curing is done for 7, 28 and 90 days and then tests are conducted.

IV. RESULTS AND DISCUSSIONS:

In these study mechanical properties of Geopolymer concrete is investigated by using different proportions of m-sand. Mechanical properties such as compressive strength, split tensile strength and flexural strength of geopolymer concrete are studied.

A. Compressive Strength

Compressive strength test is performed on cubes of size 150*150*150mm in compressive testing machine with curing period of 7, 28 and 90 days. Three specimens are casted and tested for each mix. The compressive strength for different proportions are as follows:

Fig. 1: Compressive strength testing machine

TABLE 3

COMPRESSIVE STRENGTH FOR FA90 AND GGBS10

Mix id	% Replacement of copper slag	Compressive strength (N/mm^2)		
		7 Days	28 Days	90 Days
M1	0%	25.03	36.66	44.39
M2	20%	28.31	41.43	48.54
M3	40%	30.05	44.72	52.40
M4	60%	29.27	42.57	49.93
M5	80%	28.56	41.33	47.67
M6	100%	26.71	38.36	45.82

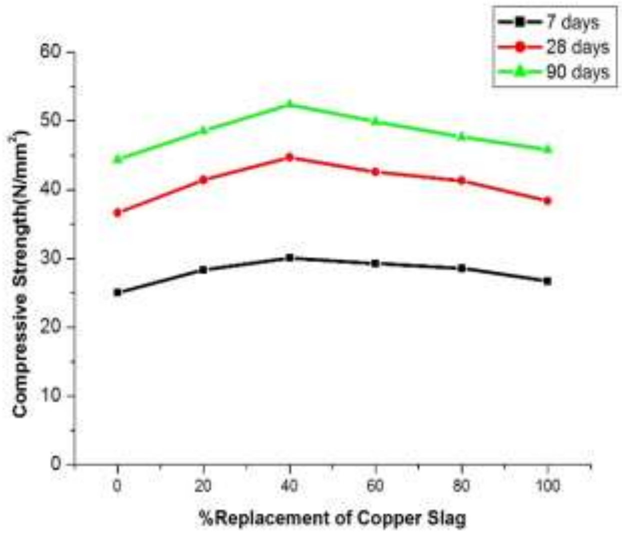

Fig. 1: Compressive strength for FA90 and GGBS10

TABLE 4
Compressive strength for FA80 and GGBS20

Mix id	% Replacement of copper slag	Compressive strength (N/mm^2)		
		7 Days	28 Days	90 Days
M1	0%	28.08	42.14	49.62
M2	20%	30.65	46.36	54.15
M3	40%	32.30	50.15	57.55
M4	60%	31.05	48.65	56.0
M5	80%	30.15	47.20	54.55
M6	100%	29.23	45.47	51.66

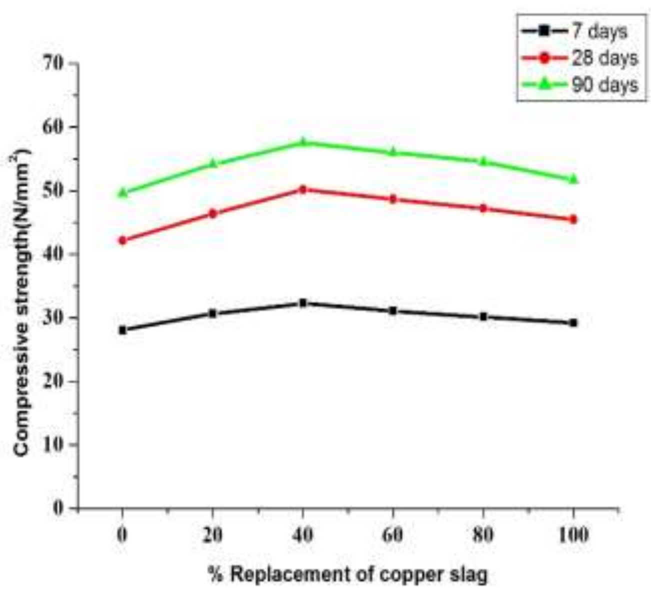

Fig 2: Compressive strength for FA80 and GGBS20

B. Split Tensile Strength

Split tensile strength test is performed on cylinders of diameter 150mm and length 300mm in compressive testing machine with curing period of 7, 28 and 90 days. Three specimens are casted and tested for each mix. The split tensile strength for different proportions are as follows:

Fig 3: Split tensile strength

TABLE 5
SPLIT TENSILE STRENGTH FOR FA90 AND GGBS10

Mix id	% Replacement of copper slag	Split tensile strength (N/mm^2)		
		7 Days	28 Days	90 Days
M1	0%	2.051	3.156	3.58
M2	20%	2.26	3.47	3.94
M3	40%	2.38	3.63	4.22
M4	60%	2.32	3.58	4.15
M5	80%	2.28	3.51	4.07
M6	100%	2.17	3.35	3.84

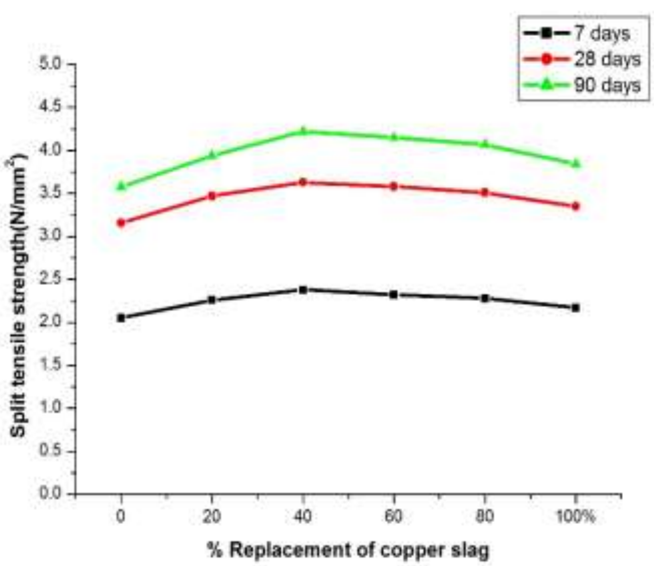

Fig 3: Split tensile strength for FA90 and GGBS10

TABLE 6
SPLIT TENSILE STRENGTH FOR FA80 AND GGBS20

Mix id	% Replacement of copper slag	Split tensile strength (N/mm^2)		
		7 Days	28 Days	90 Days
M1	0%	2.28	3.77	4.22
M2	20%	2.41	4.08	4.57
M3	40%	2.60	4.36	4.98
M4	60%	2.54	4.25	4.76
M5	80%	2.42	4.13	4.60
M6	100%	2.36	3.98	4.41

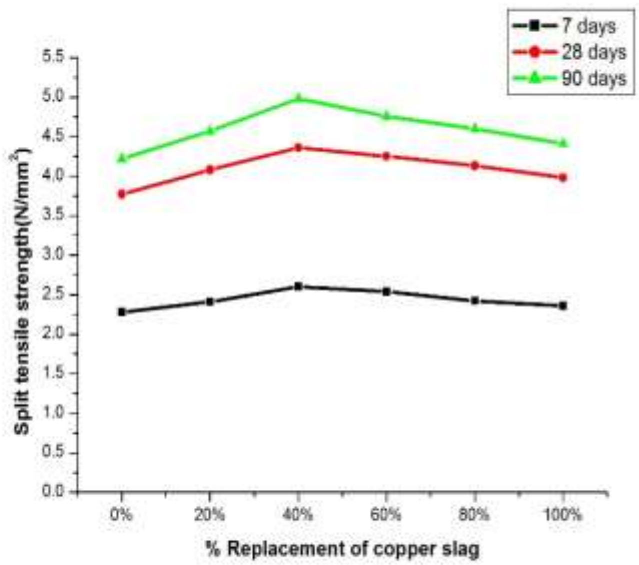

Fig 4: Split tensile strength for FA80 and GGBS20

C. Flexural Strength

Flexural strength test is conducted on beams of size 500*100*100mm with curing period of 7, 28 and 90 days. Three specimens are casted and tested for each mix. The flexural strength for different proportions are as follows:

Fig 5: Flexural strength

TABLE 7
FLEXURAL STRENGTH FOR FA90 AND GGBS10

Mix id	% Replacement of copper slag	Flexural strength (N/mm^2)		
		7 Days	28 Days	90 Days
M1	0%	3.76	4.81	5.54
M2	20%	4.18	5.60	6.27
M3	40%	4.62	5.82	6.82
M4	60%	4.45	5.65	6.51
M5	80%	4.35	5.57	6.32
M6	100%	3.98	5.19	5.85

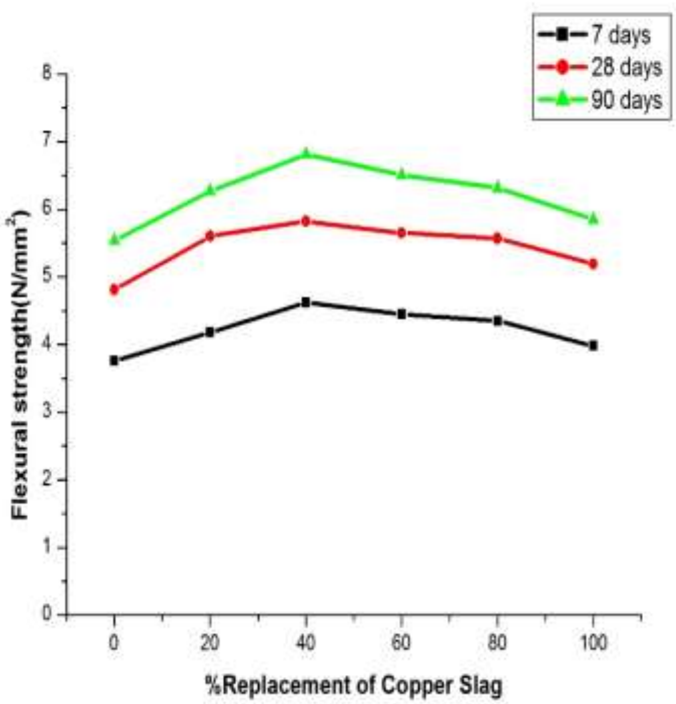

Fig 5: Flexural strength for FA90 and GGBS10

TABLE 8
FLEXURAL STRENGTH FOR FA80 AND GGBS20

Mix id	% Replacement of copper slag	Flexural strength (N/mm^2)		
		7 Days	28 Days	90 Days
M1	0%	3.90	5.28	5.95
M2	20%	4.28	5.75	6.40
M3	40%	4.49	6.33	6.85
M4	60%	4.38	6.10	6.67
M5	80%	4.28	5.82	6.51
M6	100%	4.06	5.58	6.27

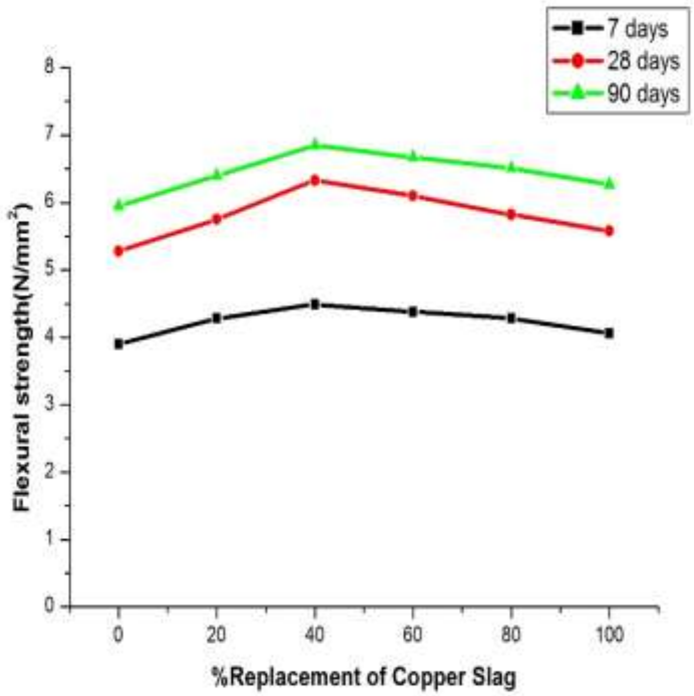

Fig 6: Flexural strength for FA80 and GGBS20

V. CONCLUSIONS

After performing the above tests on fly ash and GGBS based geopolymer concrete with replacement of river sand with copper slag, the following conclusions are made

- Geopolymer concrete (GPC) is cost-effective and ecofriendly.
- GPC reduces environmental effect by replacing ordinary portland cement (OPC) with industrial byproducts.
- The environmental benefits of geopolymer concrete are increased due to the utilization of copper slag which reduces the demand for sand mining.
- Copper slag can be used as a replacement of fine aggregate and strength gained is more than that of nominal geopolymer concrete.
- The compressive strength is maximum at 40% replacement of fine aggregate with copper slag.
- The split tensile strength is maximum at 40% replacement of fine aggregate with copper slag.
- The flexural strength is maximum at 40% replacement of fine aggregate with copper slag.
- The strength of 100% replacement of fine aggregate with copper slag achieved greater strength than nominal geopolymer concrete.
- It has been found that with increase in the percentage of GGBS, the strength of concrete proportionately increased.

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