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Effects of Copper Slag as Partial Replacement for Fine Aggregate in Geopolymer Concrete

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Abstract: *In recent years the rise of concrete production costs has always been a concern of concrete producers and consumers. Using industrial waste to replace cement and part of aggregate can reduce its cost and environmental pollution. In this study, an attempt has been done to use supplementary cementitious materials such as Flyash and GGBFS as replacement for the cement and industrial by product such as copper slag as partial replacement for fine aggregate in concrete. The strength, durability and bond strength characteristics of fly ash and GGBFS based geopolymer concrete with and without the fine aggregate replacement have been compared. The results indicated that geopolymer concrete with 40% copper slag as fine aggregate replacement showed an improvement of 17.5%, 13.94% and 22.72% in the 28th day compressive strength, splitting tensile strength and flexural strength respectively in comparison with the geopolymer concrete without copper slag, but in terms of durability of geopolymer concrete, it is found to be more water absorbent.*

Keywords – *Bond Strength, Copper Slag, Flyash, GGBFS, Geopolymer Concrete*

I. Introduction

Concrete made using geopolymer technology replaces cement completely in it and thereby reduces the CO_2 produced during the manufacture of cement which causes the environmental pollution. Geopolymers are formed by the alkaline activation of aluminosilicate material like Flyash, metakaolin, rice husk ash etc. The industrial by-products such as Flyash and GGBFS in combination are used to form geopolymer by replacing cement completely, which can be cured at ambient temperature.

Natural resources are depleting worldwide while at the same time the generated wastes from the industry are increasing substantially. Copper slag is a by-product obtained during matte smelting and refining of copper. Production of one tonne of copper generates approximately 2.2–3 tonnes of copper slag. Several researchers have investigated the possible use of copper slag as fine and coarse aggregates in concrete and its effects on the different mechanical and long-term properties of mortar and concrete (Tan et al 2000,Taeb et al 2002, Tang et al 2000, Zong et al 2003). Copper slag has been excluded from the listed hazardous waste category of the United States Environmental Protection Agency (USEPA). The United Nations (UN) Basel Convention on the Transboundary Movement of Hazardous Waste and its Disposal also ruled that copper slag is not a hazardous waste (Alter 2005). The chemical composition of copper slag depends on the type of furnace, the metallurgical production process, and the composition of the extracted ore.

From different studies carried out by the partial replacement of fine aggregate with copper slag in geopolymer concrete, the range of 40-50% of copper slag is found possible without much reduction in compressive strength. This paper presents an experimental study on the effects of copper slag as partial replacement for fine aggregate in geopolymer concrete. The main objective of this paper is to compare the strength and durability of geopolymer concrete with and without copper slag as fine aggregate.

II. Experimental Program

2.1 Materials

For geopolymer concrete siliceous pulverized fly ash obtained from Hi-Tech private limited, Tuiticorin, India, having a specific gravity of 2.2 and low calcium, ground granulated blast furnace slag of specific gravity 2.9 obtained from JSW Steel Limited, Salem, India, were used as the source material for the binder. Copper slag of specific gravity 3.9 obtained from Sterlite Industries Ltd (SIL), Tuiticorin, Tamil Nadu, India, were used for fine aggregate replacement. 97% purity sodium hydroxide (NaOH) pellets and sodium silicate (Na_2SiO_3) with 28.13% Na_2O, 28.13% SiO_2, and 40.74% H_2O were used. Coarse aggregate used were locally available crushed angular granite metal of 20 mm size having the specific gravity of 2.74 and for fine aggregate manufactured sand having the specific gravity of 2.6 were used.

III. Mix Proportions

3.1. Geopolymer mix

For studying the effect of copper slag as a replacement for fine aggregate in geopolymer concrete, 1:1.5:2.5 mix proportion was adopted. Flyash in combination with GGBFS in the ratio 50:50 was selected for geopolymer concrete under ambient curing condition on the basis of mortar cube tests with various ratio of Flyash and GGBFS.

Ratio of sodium silicate solution to sodium hydroxide solution by mass as 2.5, sodium hydroxide solution molarity as 8 M, and a ratio of activator solution to binder by mass as 0.35 are fixed for the present study. Different geopolymer concrete mixes GPC1 and GPC2 were prepared with 100% M-Sand and 40% copper slag plus 60% M-Sand combination respectively as fine aggregate. Fig. 1 gives the grading curve for both cases.

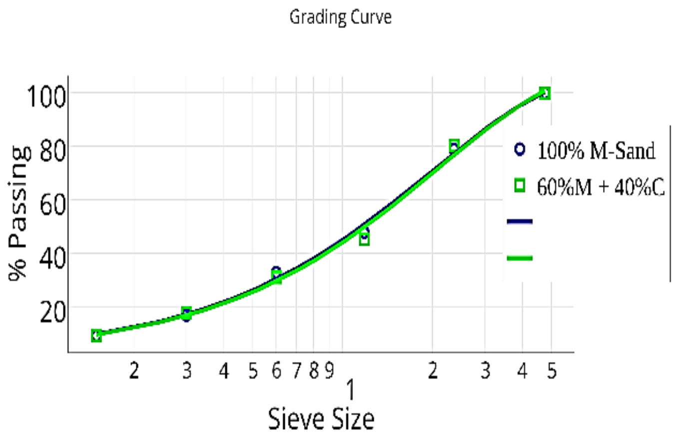

Fig. 1 Grading Curve

3.2. Mixing and casting of geopolymer concrete

NaOH pellets were dissolved in distilled water and thoroughly mixed with Na_2SiO_3 one day prior to the casting. Fly ash, GGBFS and aggregates were mixed homogeneously and then the prepared alkaline solutions were added to it. The mixing of total mass was continued until the mixture become homogeneous and uniform in colour. The required test specimens were casted as per IS specifications.

3.3. Curing Conditions

The casted specimens were allowed to set for 24 hours and then removed from the moulds which were wrapped in polythene sheets and kept at ambient temperature till testing.

IV. Tests and Results

4.1. Compressive strength

The compressive strength of geopolymer concrete cubes GPC1 and GPC2 at 7^{th} day and 28^{th} day, according to IS 516-1959 are shown Fig. 2. 17.5% increase in the compressive strength was observed for geopolymer concrete with 40% copper slag as replacement for fine aggregate due to high toughness of copper slag.

Fig. 2 Compressive Strength Results

4.2. Split tensile strength

One of the indirect tension test methods for concrete is split tension test. On testing the cylindrical specimens, the average tensile strength values for GPC1 & GPC2 were obtained as 3.04 and 3.46 N/mm^2

respectively. An increase of 13.9% tensile strength was observed with 40% copper slag replacement in geopolymer concrete as fine aggregate.

4.3. Flexural strength

The beam specimens of size 100 × 100 × 500 mm were tested for flexural strength of geopolymer concrete as per IS 516-1959. The average flexural strength for GPC1 and GPC2 were obtained as 5.50 & 6.75 N/mm^2 respectively. 40% copper slag replacement for fine aggregate increases the flexural strength by 22.72% over geopolymer concrete with 100% M Sand as fine aggregate.

4.4. Modulus of elasticity

The modulus of elasticity is essentially the measurement of the stiffness of a material. Knowledge of the modulus of elasticity of high strength concrete is very important in avoiding excessive deformation, providing satisfactory serviceability, for cost-effective design as well as a fundamental factor for determining modular ratio. The average value of modulus of elasticity for GPC1 and GPC2 determined by means of an extensometer were 20526.17 and 20607.63 N/mm^2 respectively.

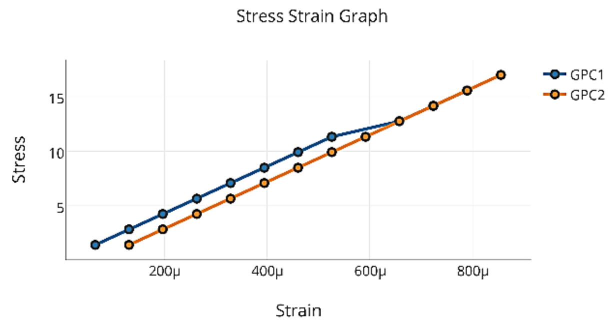

Fig. 3 Stress Vs Strain Graph

4.5. Pull out test for the determination of bond strength

The pull out test was done as per IS 2770-1967- Part-1 for 100 mm cube specimens containing 12 mm dia reinforcement. The failure was marked by splitting of the cover and slipping of the reinforcement. The nominal bond strength was calculated as follows:

Where, P = pull at failure, = bar diameter and L = length of embedment. The load Vs slip is as shown in Fig. 4.The specimen GPC2 failed at an earlier stage compared to GPC1 during pull out test.

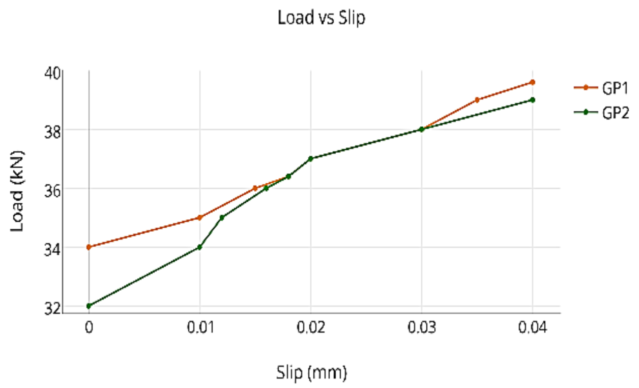

Fig. 4 Load Vs Slip

4.6. Water absorption percentage

Water absorption is calculated by measuring the increase in mass as a percentage of dry mass. Saturated water absorption test was conducted at the age of 28 days on 100 mm cubes in accordance with IS. 2185- 1979.

$WaterAbsorption=$

Where = weight of specimen at fully saturated condition and = weight of oven dry specimen. For good concrete the increase in masses should be less than 10% by initial masses. The results show that geopolymer concrete with copper slag replacement shows higher water absorption capacity due to its more porous nature.

4.7. Sorptivity test

This test method is used to determine the rate of absorption (sorptivity) of water by measuring the increase in the mass of a specimen resulting from absorption of water as a function of time when only one surface of the specimen is exposed to water. This test is based on the method that developed by Hall who called the phenomenon "water sorptivity." The initial sorptivity, defined in accordance with ASTM C1585-04, includes data measured from 1 minute up to 6 hours.

and

where I is the cumulative absorbed volume after time t per unit area of inflow surface (mm^3/mm^2), M_t the change in specimens mass at the time t, ρ the density of fluid and A the cross-sectional area in contact with fluid. The results show an increase in sorptivity value at 6 hrs for geopolymer concrete with copper slag replacement.

Fig. 5 Sorptivity Result

4.8. Density

The density of concrete is the measurement of concrete's solidity or the measure of its unit weight. Understanding concrete density is an important part of knowing the possibilities and limitations of what concrete can be used for. The results show that the density of geopolymer concrete increased by 4.25% on partial replacement of fine aggregate with copper slag. Addition of copper slag increases the density of concrete thereby increasing the self-weight, so that it can be used for high density concrete production.

4.9. Economic Feasibility

Geopolymer concrete (GPC) manufactured using industrial waste like fly ash, GGBS and copper slag is considered as an eco-friendly construction material, because it solve the problems of lack of natural aggregate in various construction sites and reduce environmental problems related to aggregate mining and waste disposal. It also helps in reducing the cost of the concrete production. Furthermore, low drying shrinkage, low creep, excellent resistance to sulphate attack and good acid resistance offered by the fly ash and GGBFS based geopolymer concrete might yield additional economic benefits when utilized in infrastructure applications.

When the strength and cost for the different mixes are compared it can be concluded that geopolymer concrete with copper slag shows improved strength characteristics and helps in reducing the cost for production. By keeping the values of GPC1 as unity the ratio difference in the parameters for GPC2 are plotted. Fig. 6 shows the parametric comparison (CS = Compressive Strength, FS = Flexural Strength, TS = Tensile Strength, BS = Bond Strength, WA = Water Absorption Percentage, S = Sorptivity) of geopolymer concrete with and without copper slag replacement.

Fig. 6 Parametric Comparison Results

V. Conclusions

Based on the experimental investigations carried out on Fly ash-GGBFS based geopolymer concrete with 40% copper slag replacement for fine aggregate under ambient temperature curing, the results in comparison with 100%M Sand as fine aggregate can be concluded as,

1. The compressive strength, split tensile strength and flexural strength increases by 17.5%, 13.94% and 22.72% respectively due to the partial replacement of fine aggregate by copper slag.
2. The water absorption capacity and sorptivity increases due to the porous nature of copper slag.
3. The density increases by 4.25% and hence suitable for high density concrete.
4. Modulus of elasticity and bond strength values of geopolymer concrete reduces by 0.4% and 4.1% respectively when copper slag replaces fine aggregate by 40%.
5. The utilization of copper slag reduces the cost for production of geopolymer concrete there by achieving both environmental and economic benefits.

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