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Strength of Geopolymer Concrete by Replacement of Fine Aggregate with Waste Steel Slag

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Abstract

The increased production of Portland cement causes great concern to environment because of its high carbon foot print. Geopolymer concrete is a new invention in the world of concrete in which cement is totally replaced by industrial waste and byproducts like fly ash. Geopolymer concrete is environment-friendly material for construction because of its reduced carbon foot print and also it is found to be durable. In this study, strength and durability characteristics of geopolymer concrete are studied with partial replacement of waste steel slag obtained from steel plants. Steel slag is impregnated in varying percentages of 5–15% instead of fine aggregate in geopolymer concrete prepared with sodium silicate and sodium hydroxide used in a ratio of 1.8:2.5, and various properties obtained were analyzed.

Keywords: *Geopolymer, fly ash, steel slag, fine aggregate*

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INTRODUCTION

In environmental aspect, waste from steel industries causes bountiful hazards to the environment and to human health. Geopolymer concrete is a new material that does not need the presence of Portland cement as a binder. Instead, the material such as fly ash (FA) is activated by alkaline liquids to produce the geopolymeric binder. The contribution of cement industry to the CO_2 emissions is about 5% of the global CO_2 emissions and one ton of CO_2 is released in the atmosphere from one ton production of Portland cement [1].

The geopolymer technology is proposed by Davidovits and gives considerable promise for application in concrete industry as an alternative binder to Portland cement. In terms of reducing global warming, geopolymer technology could reduce CO_2 emission in to the atmosphere, caused by cement and aggregate industries about 80% [2–5]. The main benefit of geopolymeric cement is reduction in environmental impacts to move toward sustainable development which is defined as the optimum usage with correct and efficient operation of basic and natural resources for providing the requirements of the future generation. In India, about 2,069,738 thousands of metric ton of CO_2 was emitted in the year 2010 [6–8]. Several studies have been carried out to reduce the use of Portland cement in concrete to address global warming issues. These include utilization of supplementary cementing materials such as FA, silica fume, granulated blast furnace slag, rice-husk ash and metakaolin, and the development of alternative binders to Portland cement [9]. The survey shows that total production of FA in the world is about 780 million ton per year after 2010. In India, more than 100 million ton of FA is produced annually, out of which 17–20% FA is utilized either in concrete as a part replacement for cement or workability improving admixture or in stabilization of soil [10].

Geopolymer-based materials are attractive because of their excellent mechanical properties, high early strength, high durability, freeze-thaw resistance, low chloride diffusion rate, abrasion resistance, thermal stability and fire resistance that can be achieved. Due to their lower Ca content, they are more resistant to acid attack than Portland cement-based materials. A further advantage of geopolymers compared to epoxy adhesives is related to their inorganic silico-aluminate nature, which makes these materials more similar to the concrete support from a chemical and physical point of view. In fact, so far, good mechanical and physical properties of geopolymer composite systems have been obtained by controlling the curing conditions in terms of high temperature and/or controlled pressure [11]. The curing temperature or the temperature at which the initial reaction takes place plays a vital role in the development of strength and can be achieved by curing it above ambient temperature [12]. The utilization of fly ash, especially in concrete production, has significant environmental benefits, viz, improved concrete durability, reduced use of energy, diminished greenhouse gas production, reduced amount of fly ash that has to be disposed in landfills, and saving of the other natural resources and materials.[13] In recent years, the Iron and Steel industry has played a vital role in the development of the country's economy as India has turned out to be the 5th largest producer of crude steel in the world with the total finished steel (alloy + non-alloy) production for sale of 47.30 million tonne (MT) during April – December 2010. India is expected to be the 2nd largest producer by the year 2015-16 .With such pace of development, the industry is also adding up to the industrial solid waste (ferrous + non-ferrous)every year [14] Concrete exposed to marine environment is subjected to several types of aggressive agents: mechanical agents, such as waves and tides, and erosion due to the effects of the waves; chemical attacks due to the action of chlorides present in seawater and sulfates, and climatic agents due to the variations of temperature.[15]

METHODOLOGY

Material Selection

Materials used in this study were chosen according to the standard specification. FA was obtained from a local power station. Chemical composition of FA is shown in Table 1. Coarse aggregate used in this experiment is of maximum size 10–12 mm. Specific gravity of steel slag is 2.68 and fineness modulus of steel slag is 2.86 with a fineness modulus of 2.3 forming zone II as per Indian standard (IS 383-1970). Coarse aggregate and fine aggregate specific gravity was found to be 2.63 and 2.78 respectively. Sodium hydroxide was used in the form of flakes, and commercial grade Sodium hydroxide and sodium silicate were used in this study; 640 g sodium hydroxide flakes were dissolved in 1 L of water to make 16 M solution of NaOH.

Casting and Curing

Cubes of dimension 150 × 150 × 150 mm were casted and de-molded after 24 h. The specimens were cured in room temperature during curing period.

Test Procedure

Compressive strength test was performed on concrete using a digital compressive testing machine of 2000 kN capacity. The specimen was tested at ages of 7, 14 and 28 days. During the test, concrete cube was loaded with 5.8– 6.2 kN/s.

Table 1: *Chemical Composition of Fly Ash.*

Chemical composition	(%)
SiO_2	54.02
Al_2O_3	22
Fe_2O_3	9.3
CaO	2.62
MgO	2.4
SO_3	0.88
K_2O	1.14
Na_2O	2.12

DESIGN OF MIX PROPORTIONS

FA was used in this study as a base binder material. Class F FA was used in the mix proportions. FA to alkaline activator ratio was 0.5 and the sodium silicate to sodium hydroxide ratio varied between 1.8 and 2.5 with molarity of 16. The fine aggregate was replaced by 5, 10, and 15% of waste steel slag. The waste steel slag was crushed and sieved in 1.18 mm IS sieve. Sodium hydroxide solution was prepared in laboratory before 24 h to make concrete. Concrete ingredients were mixed in laboratory by using hand mix. Aggregate and binding material was dry-mixed thoroughly in the mixer. Pre-mixed alkaline activator solution was gradually poured into the mixer. Proper mixing gives good results. Concrete is filled in mold and vibrated using needle vibrator. Samples were de-molded 24 h after casting.

Table 2: *Details of Geopolymer Concrete Mix Proportion.*

Mix	FA (kg/m^3)	CA (kg/m^3)	FA (kg/m^3)	FA/activator solution	Steel slag (%)	Steel slag (kg/m^3)	NaOH (kg/m^3)	Na_2SiO_3 (kg/m^3)
M1	383	1187	546	0.45	0	0	43.52	123
M2	383	1187	546	0.45	0	0	34.92	136.93
M3	383	1187	518.7	0.45	5	27.3	43.52	123
M4	383	1187	491.4	0.45	10	54.6	43.52	123
M5	383	1187	464.1	0.45	15	81.9	43.52	123
M6	383	1187	491.4	0.45	5	54.6	34.92	136.93
M7	383	1187	491.4	0.45	10	54.6	34.92	136.93
M8	383	1187	464.1	0.45	15	81.9	34.92	136.93

CA: Coarse aggregate; FA: Fine aggregate; NaOH: Sodium hydroxide solution;
Na_2SiO_3: Sodium silicate solution

RESULTS AND DISCUSSION

A total of eight mixes of geopolymer concrete were designed to study this admixture on the compressive strength of geopolymer concrete. The results are compared in Table 3. By increasing the steel slag value, the compressive strength of concrete decreased at the mix of M_8. Sodium silicate to sodium hydroxide ratio of 2.5 gives higher compressive strength value for M_7 mix. The entire mix of concrete used FA as alkaline activator solution in the ratio of 0.45. In conventional geopolymer, concrete gives strength in 28 days at 21.78 N/mm^2. Using WSS, the compressive strength in 28 days is 25.56 N/mm^2. The strength is nearly increased to about 85% which is a considerable increase in strength.

Table 3: *Compressive Strength for Various Mixes.*

Mix	Compressive strength (N/mm^2)			Morality	Steel slag (%)	Ratio
	7 days	14 days	28 days			
M1	6	8	17.97	16 M	0	1.8
M2	7.89	16.35	21.78	16 M	0	2.5
M3	10.84	13.56	16.56	16 M	5	1.8
M4	12.43	15.35	18.56	16 M	10	1.8
M5	15.28	16.35	18	16 M	15	1.8
M6	16.28	17.34	22	16 M	5	2.5
M7	15.32	21.42	25.56	16 M	10	2.5
M8	14.56	16.44	21.33	16 M	15	2.5

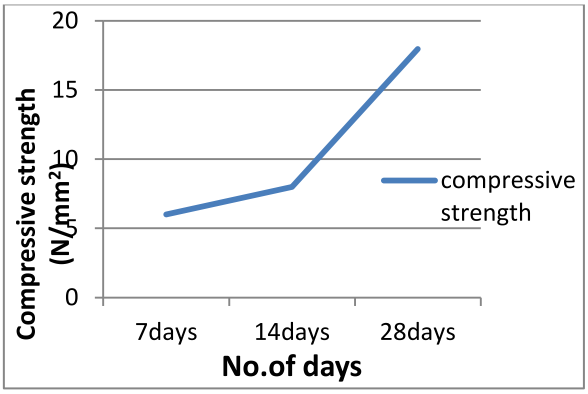

Fig. 1: *Compressive strength in 16 M Activator Solution Ratio 1.8 Ratio for M1 Mix.*

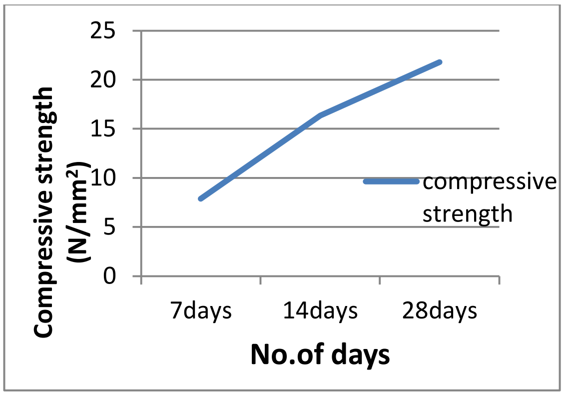

Fig. 2: *Compressive Strength in 16M and Activator Solution Ratio 2.5 Ratio for M2 Mix.*

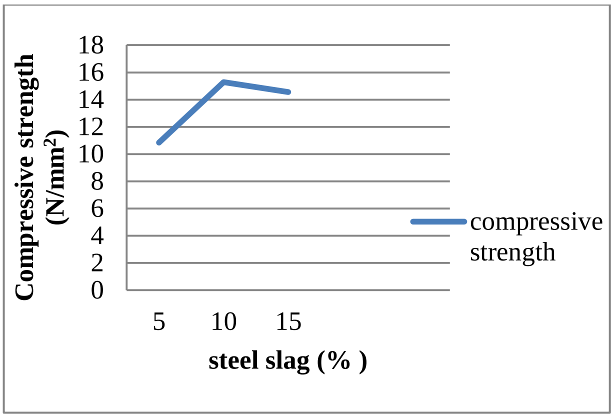

Fig. 3: *Compressive Strength in 7 days 16 M Activator Solution Ratio 1.8 Ratio for M3 Mix.*

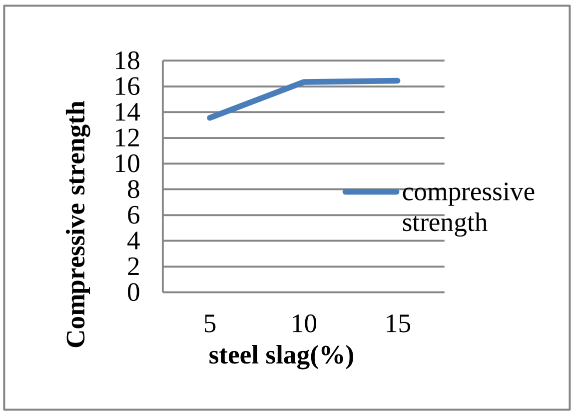

Fig. 4: *Compressive Strength in 14 days 16 M and Activator Solution Ratio 1.8 Ratio for M4 Mix.*

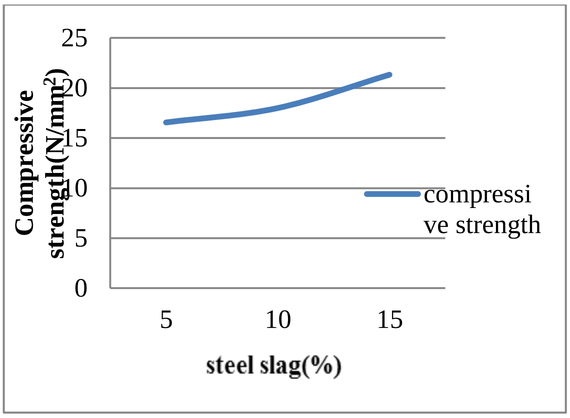

Fig. 5: *Compressive Strength in 28 days 16 M Activator Solution Ratio 1.8 ratio for M5 Mix.*

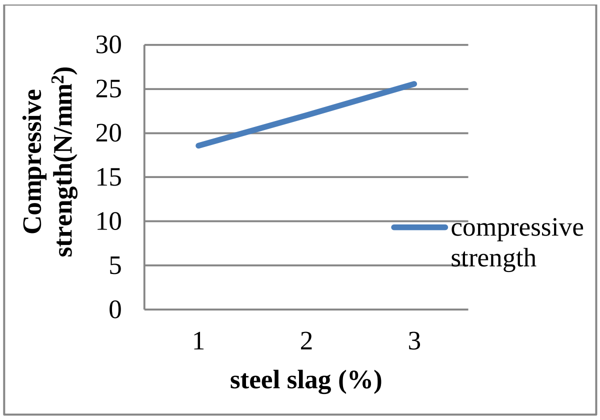

Fig. 6: *Compressive Strength in 16 M and Activator Solution Ratio 2.5 Ratio for M6 Mix.*

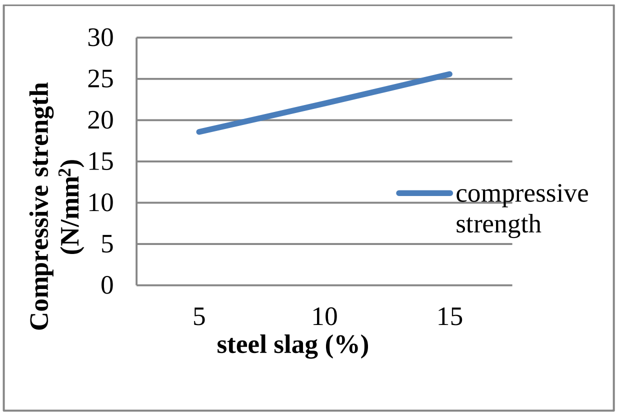

Fig. 7: *Compressive Strength in 14 days16M Activator Solution Ratio 2.5 Ratio for M7 Mix in 28 days.*

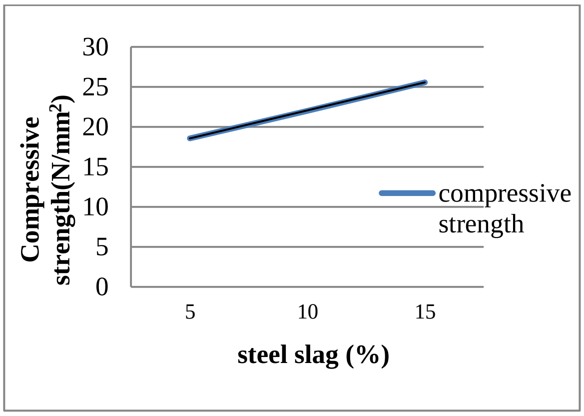

Fig. 8: *Compressive strength in 16 M and activator Solution Ratio 2.5 Ratio for M8 Mix.*

CONCLUSIONS

- ✓ When compared with conventional geopolymer concrete, the addition of 10% steel slag replacement with fine aggregate increases the compressive strength at 28 days curing.
- ✓ 16 M NaOH and 2.5 silicates to sodium hydroxide ratio gives good result.
- ✓ This is economical than conventional geopolymer concrete.

- ✓ The compressive strength for steel slag geopolymer concrete after doing ambient curing is 85% higher than conventional concrete.
- ✓ The binding property is more efficient in steel slag geopolymer concrete.

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