Proceedings of the
International Conference on Mechanical Engineering and Renewable Energy 2017
(ICMERE2017) 18 – 20 December, 2017, Chittagong, Bangladesh

ICMERE2017-PI-368

PROSPECT OF USING BANGLADESHI ELECTRIC ARC FURNACE STEEL SLAG AS A REPLACEMENT OF COARSE AGGREGATE IN CONSTRUCTION MATERIALS

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Abstract- *The possibility of utilization of Electric Arc Furnace (EAF) slag produced in Bangladesh as a coarse aggregate in concrete. Electric Arc Furnace slag has been explored. Samples of slag was collected from a steel plant in Chittagong. X-Ray Fluorescence (XRF) and X-Ray Diffraction (XRD) techniques were used to investigate the chemical composition and to identify the phases present respectively. A constant W/C ratio of 0.45 and a volumetric ratio of cement: sand: aggregate= 1:1.5:3 was maintained. The concrete specimen was made by incorporating 0%, 25% 50%, 75% and 100% slag aggregate. The concrete specimens were cured under water and tested at 7 days, 14 days and 28 days for compressive strength and splitting tensile strength. The results show that the compressive strength was 5076-5850 psi and the splitting tensile strength was 285-440 psi which indicate good possibility of the reuse of EAF slag in construction materials.*

Keywords: Electric Arc Furnace slag, Concrete, Coarse Aggregate and Construction Material

1. INTRODUCTION

The American Society for Testing and Materials (ASTM) defines steel slag as a non-metallic product, consisting essentially of calcium silicates and ferrites combined with fused oxides of iron, aluminium, manganese, calcium and magnesium that are developed simultaneously with steel in basic oxygen, electric arc or open hearth furnaces. Out of the 4 million metric tons of steel produced annually in Bangladesh, about 1.0 million tons of steel is made using an electric arc furnace in only one industry out of a total of 400 steel mills. With a slag production of about 145 kg per ton of steel this plant produces 270 thousand tons of slag annually. Slag being considered a waste material in our country it is used in landfills near the industrial area. The management of slag is gradually becoming a challenge for the country.

Concrete is a composite construction material consisting of cement, aggregate and water, in which, the cement acts as a binder for the aggregates. The aggregates make up about 70-75% of the total volume of the concrete [1] and are of two types - coarse aggregates such as limestone, stone or granite and fine aggregates such as river sand or manufactured sand. Bangladesh has very limited availability of natural resources and yet huge amounts of stone are withdrawn from Sylhet every day for their use in construction. This natural reserve of stone will be depleted in the near future, posing a huge problem for the country's construction sector. Brick aggregates have thus become a more frequently used material for the country's construction industry despite brick production being associated with a lot of negative environmental impacts. The use of steel slag as a replacement for coarse aggregates like brick chips and stone in concrete is being considered as a more viable option [2-4]. This will help preserve our natural reserves of stone while also freeing up lands which otherwise would have to be used as landfills for slag.

Tarek et al. [2] compared the physical and mechanical properties of lightweight, heavyweight and mixed weight slag aggregates with that of common brick aggregates. The modulus of elasticity, workability and tensile strength of concrete made with steel slag aggregates were higher and the absorption capacity of water was lower than concrete made with brick aggregates. The specific gravity of lightweight aggregates were similar to that of brick aggregates while that of heavyweight and mixed weight aggregates were higher.

Netinger et al. [3] observed the effects of high temperature (up to 800°C) on the properties of concrete with 60% aggregates being replaced by steel slag. Dolomite based concrete mixture was studied as a reference mixture and the results revealed that the mechanical properties of concrete made with steel slag aggregate are comparable to those of dolomite concrete up to temperatures of 550°C. The compressive strength and modulus of elasticity of steel slag concrete was comparable with dolomite based mixture up to a temperature of 600°C beyond which it decreased.

Alizadeh et al. [4] studied the physical, chemical and mechanical properties of electric arc furnace slag as a possible replacement for natural aggregates in concrete. They concluded that concrete incorporated with steel slag showed better results compared to conventional concrete.

This research focused on studying the use of replacing coarse aggregates in concrete using electric arc furnace slag.

2. MATERIALS, METHODS AND EXPERIMENTAL DESIGN

2.1 Collection of Electric Arc Furnace Slag

In Bangladesh, at present only one steel industry uses Electric Arc Furnace (EAF) to produce steel reinforcing bars. Samples of slag for this study was collected from this plant.

2.2 Preparation of the Slag samples

The steel slag was obtained in the form of boulders. As received samples of slag were crushed. The crushed samples were sieved to obtain required size fractions for further study.

Fig. 1: Coarse slag sample in saturated surface dry (SSD) condition

Fig. 2: (a) Fine aggregate (sand) sample in saturated surface dry (SSD) condition (b) Coarse aggregate (stone chips) sample in saturated surface dry (SSD) condition

2.3 Ordinary Portland Cement (OPC)

The cement used in this project was collected from Fresh Cement. This is Type I Portland cement as classified by ASTM C150. Its chemical composition is shown in Table 1.

Table 1: Cement Composition

Chemical	Percentage (%)
SiO_2	24.09
Fe_2O_3	3.56
Al_2O_3	6.68
CaO	56.70
MgO	1.56
SO_3	4.91
K_2O	0.97
Na_2O	0.15
TiO_2	0.99
P_2O_5	0.13
MnO	0.11

2.4 Fine Aggregates

The fine Aggregate used for the research was Sylhet natural sand. This aggregate has absorption of 1.61%. The Bulk Specific Gravity of the fine aggregate was 2.54 while its SSD Specific Gravity was 2.58.

2.5 Coarse Aggregates

The coarse aggregates used in this research were obtained from Bolagonj (Fig. 5.2(b)). The absorption of these coarse aggregates was 0.83%. The Bulk Specific Gravity was 2.60 with an SSD Specific Gravity of 2.62.

2.6 Chemical and Mineralogical Characterization of slag

The chemical compositions of the slags were determined using X-ray fluorescence (XRF) spectroscopy. Mineralogical composition was studied at room temperature (25^{o}C) using an X-ray diffractometer (XRD).

2.7 Unit Weight Calculation

The unit weight was measured in accordance to ASTM specification C29-97 R03. The Rodding procedure was used for the determination of unit weight.

2.8 Determination of Specific Gravity and Absorption of Fine and Coarse aggregate

The measured water absorption rate and specific gravity of aggregate is routinely used in design and construction of pavement materials and structures worldwide. Most of the aggregates are porous in which some pores are permeable and some impermeable. The presence of these pores is very important for defining specific gravity of aggregates. The absorption capacity in aggregate is important in determining the net water-cement ratio in the concrete mix.

The specific gravity and absorption of coarse and fine aggregate were determined according to ASTM C128-01.

2.9 Concrete Mix Design

The slag aggregates were tested for fineness modulus, specific gravity, absorption capacity and unit weight. Coarse aggregates of EAF slag were used. Concrete specimens were made with a constant Water/Cement (W/C) ratio of 0.45. A volumetric ratio of Cement: Sand: Aggregate = 1:1.5:3 was maintained. The natural aggregate was replaced by coarse slag by 0%, 25% 50%, 75% and 100%. After mixing, the workability of the concrete was measured by slump test. The concrete specimens were cured under water and tested at 7 days, 14 days and 28 days for compressive strength and splitting tensile strength. The results were analyzed to determine practical applications.

Fig. 3: Concrete cylindrical specimen after casting

2.10 Gradations

The initial visual examination of the steel slag samples suggested that they consisted of a mixture of both fine and coarse aggregates. Sieve analysis was done according to ASTM C 136.

Fig. 4: Sieve analyses conducted to determine gradation

2.11 Fresh Concrete Properties

Fresh concrete properties include slump, unit weight. The slump of the concrete was tested following ASTM C143. The unit weight of the mixture was tested according to ASTM C29-97 R03. The specific gravity and absorption of coarse aggregate were determined according to the specification ASTM C127-01.

Fig. 5: Slump test being conducted on the concrete sample

2.12 Hardened Concrete Properties

To determine the hardened properties of concrete, the Compression test (ASTM C 39) and Splitting tensile test (ASTM C 496) were conducted. Concrete is much stronger in compression than in tension and so the compressive strength of concrete is an important property of the concrete. It is very difficult to directly measure the tensile strength of concrete; therefore, the splitting tensile test, an indirect method, was adopted.

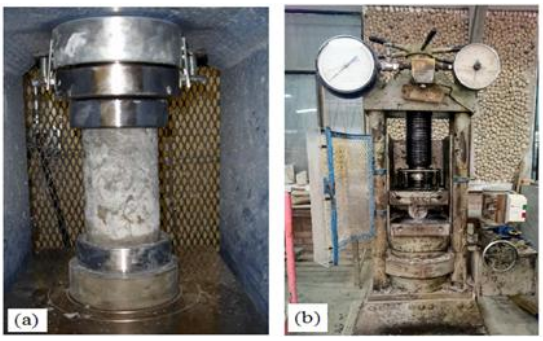

Fig. 6: (a) Compression test conducted on a concrete specimen with steel slag aggregates (b) Splitting tensile Test conducted on concrete specimen

2.13 Compressive Strength of Concrete

The concrete specimens were tested for compressive strength at 7, 14 and 28 days. Specimens were made following ASTM C192 and stored in the water curing tank following ASTM C511. The cylindrical specimens prepared for the research were made with a diameter of four inches (102 mm) and a height of eight inches (203 mm).

Fig. 7: Concrete specimen after compressive strength test

Compressive strength was determined on a hydraulic loading machine on three specimens at each age, following ASTM C39. The type of fracture of the specimen and the compressive strength was also recorded and compared with ASTM C39.

2.14 Splitting Tensile Strength of Concrete

The splitting tensile strength of the concrete specimens was tested at 7, 14 and 28 days. The four inches (102 mm) and eight inch (203 mm) cylindrical specimens were molded at the same time as compressive strength specimens. The specimens were tested on a hydraulic loading machine following ASTM C 496.

Fig. 8: Concrete specimen after splitting tensile strength test

3. RESULTS AND DISCUSSION

The results presented here are the average results when more than one sample of mixtures was tested.

3.1 X-Ray Fluorescence (XRF) Results

The sample of Electric Arc Furnace (EAF) steel slag was analyzed by x-ray fluorescence analysis using XRF-1800 SHIMADZU, Japan.

The major components (Table 2) in the EAF slag sample in Bangladesh were: CaO, Fe_2O_3 and SiO_2. Significant amounts of Al_2O_3, MnO and MgO were also present. The difference in the actual content of oxides in the samples from reference values may be related to the difference in the quality and composition of the raw materials used and the practice of alloy addition during the process of making steel.

Table 2: Comparison of compositions of EAF steel slag

	CaO	Fe_2O_3	SiO_2	Al_2O_3	MnO	MgO
Slag sample	35.5	26.5	19.9	6.3	5.1	4.4
Slag sample [5]	29.5	32.6	16.1	7.6	4.5	5
Slag sample [6]	38.8	20.3	14.1	6.7	5	3.9
Slag sample [7]	35.7	26.6	17.5	6.3	2.5	6.5

3.2 X-Ray Diffractometric Analysis

The x-ray diffraction pattern of EAF steel slag by using EMPYREAN PANalytical, Netherlands is shown in Fig**. 9.** The diffraction pattern of EAF steel slag showed a predominant phase containing CaO. A weak diffraction line of free CaO could also be identified.

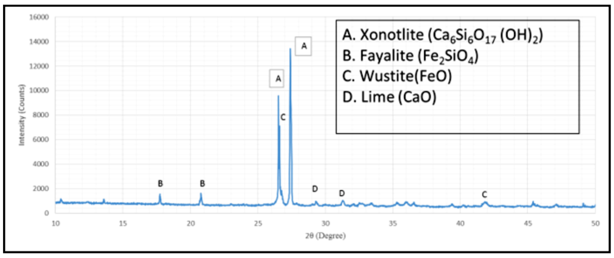

Fig. 9: XRD pattern of EAF slag

3.3 Workability

The workability of concrete (measured by slump) made with EAF steel slag is shown in Fig.10. EAF coarse slag shows same slump value for 0%, 25% and 50% coarse aggregate replacement and same value for 75% and 100% coarse aggregate replacement. All values are indicators of good workability compared to reference value (0% coarse aggregate replacement).

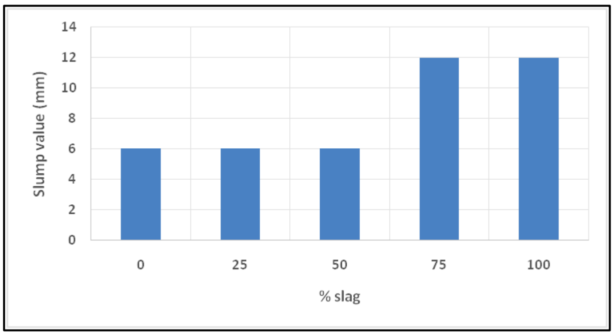

Fig. 10: Workability of coarse aggregate replacement by EAF steel slag

3.4 Compressive Strength for Concrete Specimen

Most properties of concrete are directly related to its compressive strength. The compression test on the concrete specimens was carried out according to ASTM C39. Cylindrical samples, 4 inches in diameter and 8 inches in height, were properly molded and cured. The specimens were loaded at a control rate in the compression machine.

Fig. 11 provides the compressive strength of concrete for 7, 14 and 28 days. In case of concrete with no slag replacement, the values of compressive strength for 7, 14 and 28 days are 4109 psi, 4448 psi and 4399 psi respectively.

The compressive strength of samples replaced with slag in varied ratios by weight shows superior numerical values compared to the concrete with no slag in it. Again, it is evident that, increasing the amount of the ratios of slag increases the compressive strength of the concrete. The highest strength was attained for 75% slag replacement with a value of 5850 psi. Concrete samples with 100% slag replaced also showed a comparable value of 5705 psi. The normal compressive strength of concrete is in the range of 2500-6000 psi. The strength of EAF coarse slag aggregate is found to be 5076-5850 psi which indicates that concrete with steel slag aggregates achieves similar strength compared to conventional concrete.

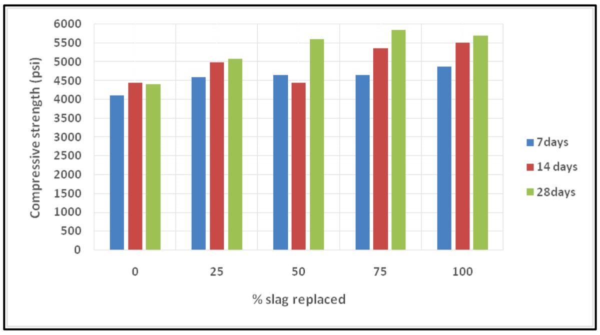

Fig. 11: Compressive strength of EAF coarse aggregate.

3.5 Splitting Tensile Strength

The splitting tensile test is an indirect way of estimating the tensile strength of cylindrical concrete specimens. Since the concrete is much weaker in tension than in compression, the failure would be at a much lower load than in compression. The cylinders were tested according to ASTM C 496.

The specimens were molded at the same time as the compressive strength specimens. Cylinders were molded with a diameter of 4 inches (102 mm) and a length of 8 inches (203 mm). Fig. 12 shows the 7 day, 14 day and 28 day splitting tensile strength on concrete specimens. The maximum values were obtained for 50% and 100% replacement by slag, but all the samples with replaced slag showed superior values than the concrete with no slag.

The normal strength found for splitting tensile strength of concrete is 200-700 psi after 28 days water curing. The strength of EAF slag aggregate was found to be 300-440psi which also indicates that EAF coarse slag can be used as a replacement of coarse aggregate in concrete.

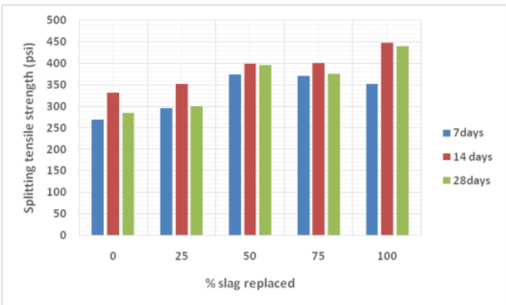

Fig. 12: Splitting tensile strength of coarse slag aggregate

5. CONCLUSION

The compressive strength of concrete samples containing slag in varied ratios by weight shows superior numerical values compared to concrete with no slag in it. The highest strength attained was 5850 psi. This shows that concrete with steel slag aggregates achieves similar strength compared to normal strength concrete (2500-6000) psi. It can be concluded that incorporation of EAF slag in concrete is a definite possibility.

6. ACKOWLEDGEMENT

This research project was funded by Department of Environment (DoE), Government of the Peoples' Republic of Bangladesh. The authors also acknowledge the facilities provided by Bangladesh University of engineering and Technology (BUET), Dhaka to carry out this research work.

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