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REUSE OF INDUCTION FURNACE STEEL SLAG AS A REPLACEMENT OF COARSE AGGREGATE IN CONSTRUCTION

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Abstract: *The possibility of utilization of locally produced Induction Furnace (IF) steel slag as coarse aggregate in concrete blocks was explored. Steel slag was collected from a local steel plant. X-Ray Fluorescence (XRF) and X-Ray Diffraction (XRD) analysis were used to investigate the chemical composition and to identify the phases present respectively. Concrete specimens were made incorporating IF steel slag as coarse aggregate. A constant W/C ratio of 0.45 and a volumetric ratio of cement: sand: aggregate= 1:1.5:3 was maintained. The concrete specimens were made by incorporating 0%, 25% 50%, 75% and 100% slag aggregate. The concrete specimens were cured under water for 7 days, 14 days and 28 days and data were collected for compressive strength and splitting tensile strength. The results show that the compressive strength was* 3288-3699 *psi and the splitting tensile strength was 183-294 psi which indicate good possibility of the reuse of IF slag in construction materials.*

Keywords: Induction Furnace slag, Concrete, Coarse Aggregate, Construction Material.

1. INTRODUCTION

Concrete is a composite construction material consisting of aggregates bonded together by cement. With the increasing use of reinforced concrete in Bangladesh, the demand for the aggregates necessary for it has also increased. These aggregates take up 70-75% of the total volume of concrete and provide dimensional stability and wear resistance [1].

Two types of aggregates are used in concrete - fine aggregates like river sand or manufactured sand and coarse aggregates like limestone, stone or granite. Bangladesh has very limited availability of natural stones and traditional coarse aggregates like stone chips, while brick chips are very costly. Huge amount of stones are withdrawn from Sylhet every day and as a result the reserve of stones will be depleted in the near future which poses a great threat to us. Brick aggregates have become the main building material for the country's construction industry due to the scarcity of stone, despite brick production being associated with a lot of negative environmental impacts. It is necessary to find possible alternative resources that can be used as coarse aggregate in construction works to fulfill the future growth aspirations of Bangladesh's construction industry. In this aspect steel slag has become a viable option as a replacement for coarse aggregates in concrete production.

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.

Bangladesh has over 400 steel mills of different categories and sizes that produce over 4 million tons of steel annually. Almost all of these industries use induction furnaces which are responsible for about 3.2 million tons of steel production every year along with nearly 250 thousand tons of slag. Slag being considered a waste material is usually disposed in landfills that take up large areas near the industries. The use of these waste materials as a replacement for expensive aggregates in concrete has become an attractive option for Bangladesh. Successful reuse will result in the preservation of natural aggregates and a reduction in construction cost, while removing the necessity of landfills, which will free up a lot of land for the country.

Alizadeh R et al. [2] 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.

Tarek et al. [3] 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 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. [4] 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 that of dolomite concrete up to the temperature of 550°C. The compressive strength and modulus of elasticity of steel slag concrete was comparable with those of dolomite based mixture up to a temperature of 600°C beyond which it decreases.

Qurishee et al. [5] studied the strength of concrete using induction furnace slag as a replacement for its coarse aggregates and compared it with concrete with stone chips. They found that the compressive strength and tensile strength of concrete showed significant improvement up to 40% replacement by steel slag, while showing slight improvements varying from 6-20% beyond that 40% replacement.

Through the present work, the use of induction furnace slag as a replacement of coarse aggregates in concrete was investigated.

2. MATERIALS, METHODS AND EXPERIMENTAL DESIGN

2.1 Collection of Induction Furnace Slag

Induction furnace (IF) steel slag was collected from a local steel plant.

2.2 Preparation of the Samples of Slags

The steel slag was obtained in the form of boulders. 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

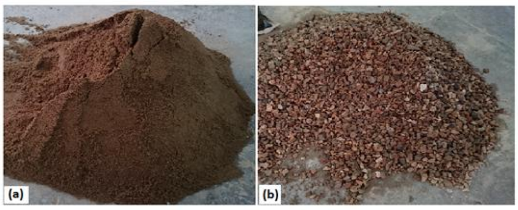

Fig. 2: (a) Fine aggregate (sand) sample in saturated surface dry (SSD) condition (b) Coarse aggregate (stone chips) sample in saturated surface dry (SSD) condition

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 Bholagonj [Fig.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 by using X-ray fluorescence (XRF) spectroscopy. Mineralogical composition was studied at room temperature (25^{o}C) using X-ray diffractometer (XRD).

2.7 Unit Weight Calculation

The unit weight is 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 the specification 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 IF 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 used. 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: (a) and (b) show sieve analyses conducted to determine gradation

2.11 Fresh Concrete Properties

Fresh concrete properties include slump and 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

Three specimens were tested on a hydraulic loading machine 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 Induction Furnace (IF) steel slag collected from a local steel industry was analyzed by x-ray fluorescence analysis using XRF-1800 SHIMADZU, Japan.

The major components of the induction furnace slag sample were: Fe_2O_3 are SiO_2. Significant amounts of Al_2O_3, and MnO were also present. The composition of the sample is compared with different IF slag samples used in other researches which is shown in Table 2. The differences in the actual content of oxides in the samples from different sources 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 the compositions of IF steel slag

	SiO_2	Fe_3O_4	MnO	Al_2O_3	CaO
Slag sample	40.01	23.29	9.73	7.85	12.80
Slag sample [6]	48.54	25.89	7.62	8.45	3.91
Slag sample [7]	55.82	13.09	-	16.35	2.86

3.2 X-Ray Diffractometric (XRD) Analysis

The x-ray diffraction patterns of the different types of slag by using EMPYREAN PANalytical, Netherlands are shown in Fig. 9. It is evident that spinelloid phase (Fe_3O_4-Fe_2SiO_4) is predominant in the x-ray diffraction pattern of induction furnace slag. This is in good agreement with the x-ray fluorescence analysis results. Free lime or a phase containing lime could not be identified in the diffraction patterns of induction furnace slag. This is because either these phases are not present or the quantity of any such phase is below the detection limit of x-ray diffractometry.

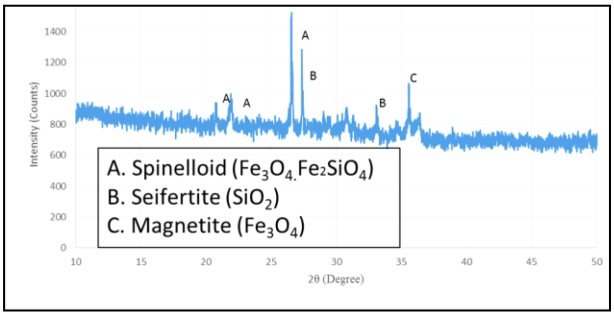

Fig. 9: X-Ray Diffraction pattern of IF slag

3.3 Compressive Strength for Concrete Specimens

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.

In case of concrete with no slag, the values of compressive strength for 7, 14 and 28 days are 4109 psi, 4448 psi and 4399 psi respectively. It is evident from the graph (Fig. 10) that, the compressive strength of concrete samples containing IF coarse slag has lower values than the concrete samples with no slag. The strength of the concrete specimens was almost the same for the replacement of slag from 25% to 100% with the numerical values ranging from 3288 psi to 3578 psi after 28 days water curing.

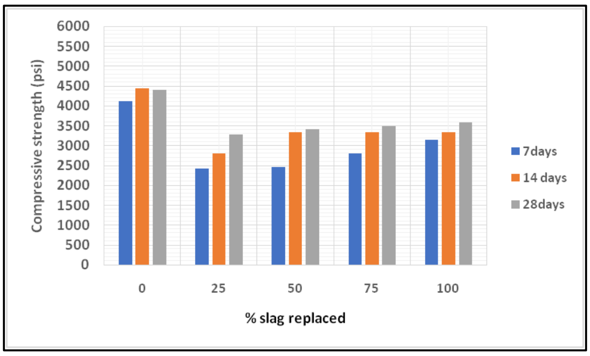

Fig. 10: Compressive strength of IF coarse aggregate

The normal strength of concrete is in the range of 2500-6000 psi. The strength of IF coarse slag aggregate is found to be 3288-3699 psi which indicates that IF coarse aggregate can be used as a replacement of coarse aggregate in concrete.

3.4 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). Figure shows the 7 days, 14 days and 28 days splitting tensile strength on concrete specimens. In IF coarse aggregate replacement, the maximum values were obtained for 100% slag replacement and no slag replacement in 7 days and 14 days respectively. For 7 days curing, the values were found to be more or less consistent. For 14 days, an increasing trend was observed for the gradual replacement of slag except for concrete with no slag replacement.

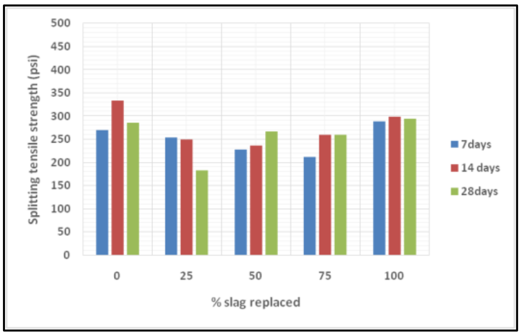

Fig. 10: Splitting tensile strength of IF coarse aggregate.

The normal strength found for splitting tensile strength of concrete is 200-700 psi after 28 days water curing. The strength of IF coarse slag aggregate is found to be 183-294 psi which also indicates that IF coarse slag can be used as a replacement of fine aggregate in concrete.

5. CONCLUSION

The following is the summary of the findings:

Compressive strength of concrete samples containing 100 percent slag IF fine slag attained the highest value of 3699 psi after 28 days.

The compressive strength of the concrete specimens containing 25% to 100% IF slag was almost the same with the numerical values ranging from 3288 to 3699 psi.

Concrete with steel slag aggregates achieves similar strength compared to normal strength concrete (2500-6000) psi. It can be concluded that incorporation of IF slag in concrete is a possibility.

6. ACKOWLEDGEMENT

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