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Comparison of Mechanical Properties of Induction Furnace Steel Slag and Electric Arc Furnace Steel Slag as a Replacement of Coarse Aggregate in Construction Materials

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Abstract

The utilization of Induction Furnace (IF) slag and Electric Arc Furnace (EAF) slag produced in Bangladesh as coarse aggregate in concrete has been investigated. EAF slag was collected from a steel mill in Chittagong and IF Steel slag was collected from a steel mill in Dhaka. 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 were used to prepare the concrete specimens. The concrete specimens were cured under water and tested at 7, 14 and 28 days for the determination of compressive strength and splitting tensile strength. A compressive strength of 2418-3578 psi could be achieved in case of the incorporation of IF slag while a compressive strength of 5076-5850 psi for the incorporation of EAF slag. We also found a splitting tensile strength of 183-298 psi for the incorporation of IF slag and a splitting tensile strength of 297-449 psi for the incorporation of EAF slag.

Keywords: Induction Furnace Slag, Electric Arc Furnace Slag, Coarse Aggregate, Compressive Strength, Tensile Strength.

1. Introduction

The management of waste materials has become one of the most challenging problems in Bangladesh, significantly affecting its economy and environment. One of these waste materials is slag, a byproduct of the steelmaking industry. For many years slag was considered a hazardous material and has been, generally, disposed of in landfills near the industries. A Steel Slag Coalition (SSC) formed in 1995 conducted an industry-wide Human Health and Ecological Risk Assessment (HERA) on iron and steel slag (NSA accessed Nov 2008). They concluded that iron and steel slag have no threats to human health or the environment when used in residential, agricultural, industrial and construction applications. Despite this, Bangladesh has no proper record of its slag utilization. Most developed countries like USA, Japan, Germany, France have almost 100% utilization of slag where it is used as a replacement for concrete aggregates, asphalt, roof aggregates, rail ballast, soil modifiers, fertilizers, etc. The largest man-made material on earth, concrete, has seen increasing demand in Bangladesh due to its fast-growing construction industry. Concrete requires a large number of good quality aggregates for its production as it takes up almost 70-75% of its total volume and directly affects its hardened properties [1].
Sylhet region in Bangladesh provides the largest amount of stones necessary for concrete production but the reserves are depleting at an alarming rate. Brick aggregates have thus become a strong alternative for stone chips, despite the significant negative environmental impacts of brick production. Crushed slag is an attractive replacement for the more scarce stone aggregates for concrete production. This utilization of an ever-increasing byproduct will financially help both the steel industry and the construction industry, not to the mention the environmental benefits of reducing landfills and natural resource depletion.
Tarek et al. [2] compared the physical and mechanical properties of lightweight, heavyweight and mixed weight induction furnace slag aggregates with those of common brick aggregates. The modulus of elasticity,

workability and tensile strength of concrete made with steel slag aggregates was higher and the absorption capacity of water was lower than concrete made with brick aggregates. The specific gravity of lightweight aggregates was similar to that of brick aggregates while that of heavyweight and mixed weight aggregates were higher. Qurishee et al. [3] 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. Andrews et al. [4] discussed the application of induction furnace slag and cupola furnace slag from different industries in Ghana as aggregate in concrete and as roadbed material. The chemical and mineralogical characterization results of the slag suggest that it cannot be used as aggregates for concrete without improving the CaO levels, however, it can be used as roadbed material. Alizadeh R et al. [5] studied the physical, chemical and mechanical properties of electric arc furnace slag as a possible replacement for coarse aggregates in concrete. They concluded that concrete incorporated with steel slag showed better results compared to conventional concrete. Juan et al. [6] produced concrete with good properties using oxidizing EAF slag as fine and coarse aggregate. The durability of the EAF slag was found to be acceptable, especially in the geographical region it was to be used, where winter temperature hardly fell below 0°C. The present work has investigated the use of induction furnace slag and electric arc furnace slag as a replacement of coarse aggregates in concrete.

2. Materials and Method

Preparation of the samples of slags

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

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. The cement properties and its chemical composition are shown in Table 1.

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.

Coarse aggregates

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

Chemical and mineralogical characterization of slag

The chemical compositions of the slag were determined using X-ray fluorescence spectroscopy. The mineralogical composition was studied at room temperature (25ºC) using X-ray diffractometer.

Unit weight

Unit weight is a function of initial ingredients of concrete, mix proportions, initial and final water content, air content, volume changes, and degree of consolidation. Unit weight values of aggregates are necessary for selecting a proportion of ingredients in the concrete mixtures. They may also be used for determining mass/volume relationships for conversions and calculating the percentages of voids in aggregates. The unit weight is measured in accordance with ASTM specification C29-97 R03. The rodding procedure was used for the determination of unit weight.

Specific gravity and absorption of fine and coarse aggregate

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.

Concrete mix design

Coarse aggregates of both IF and 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 used. The natural aggregate was replaced by both slags 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, 14 and 28 days for the determination of compressive strength and splitting tensile strength.

Gradations

Sieve analysis was done according to ASTM C 136. The results of the percentage passing each screen for the steel slag were compared to the curves of the natural aggregates it was to replace.

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). Three specimens were tested at each age, following ASTM C39, on a hydraulic loading machine. The compressive strength was determined by dividing the ultimate applied load by the cross-sectional area of the cylinder. The type of fracture of the specimen and the compressive strength was also recorded and compared with ASTM C39.

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 inches (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.

3. Results and discussions

Unit weight

The unit weight of the ingredients used in concrete is shown in Table 2. The unit weight of electric arc furnace slag was higher than that of induction furnace slag.

Table 1. Unit weight of concrete ingredients

Sample	**Unit Weight (kg/ft^3)**	**Unit Weight (kg/m^3)**
Cement	29.70	1050
sand	40.18	1420
stone	39.63	1400
IF (Coarse aggregate)	28.16	995
EAF (Coarse aggregate)	46.29	1635

Specific gravity and absorption capacity

Table 3 indicates that the specific gravity of EAF slag is more than of IF slag but the absorption of IF slag is the highest among all the materials used in concrete.

Table 2. Specific gravity and absorption capacity of concrete materials

Properties	**Fine aggregate (Sand)**	**Coarse aggregate (Stone chips)**	**IF coarse aggregate**	**EAF coarse aggregate**
Apparent specific gravity	2.65	2.66	2.91	3.62
Bulk specific gravity (OD basis)	2.54	2.6	2.77	3.47
Bulk specific gravity (SSD basis)	2.58	2.62	2.81	3.51
Absorption capacity (%)	1.61	0.83	1.67	1.17

X-Ray Fluorescence (XRF) results

The major components of the induction furnace slag sample were: Fe_2O_3 and SiO_2. Significant amounts of Al_2O_3 and MnO were also present. In contrast, the arc furnace slag contained a larger amount of CaO. A comparison of the major components of mixed induction furnace slag and arc furnace slag can be seen in Table 4.

This variation in the CaO content of the two types of slag is due to the practice of making steel through these two different routes. In arc furnace steelmaking lime (CaO) is added as a slag former and thus EAF slag contains a significant amount of CaO. The induction furnaces used for making steel in Bangladesh is generally silica lined. Silica is an acidic oxide and therefore care is taken so that during the process of making steel in induction furnaces the lining does not come in contact with any basic oxide. CaO is a strong base and is particularly harmful to the lining of induction furnaces. The addition of any lime in induction furnace steelmaking is effected later in ladle refining (LRF) furnaces. The lining of electric furnaces is different in chemical nature permitting additions of basic oxides during steel making process. This difference in furnace lining of electric arc furnaces offers some technical advantages to making of steel in electric arc furnaces. The composition of the sample is compared with different IF slag and EAF slag used in other research work which is also shown in Table 4. 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.

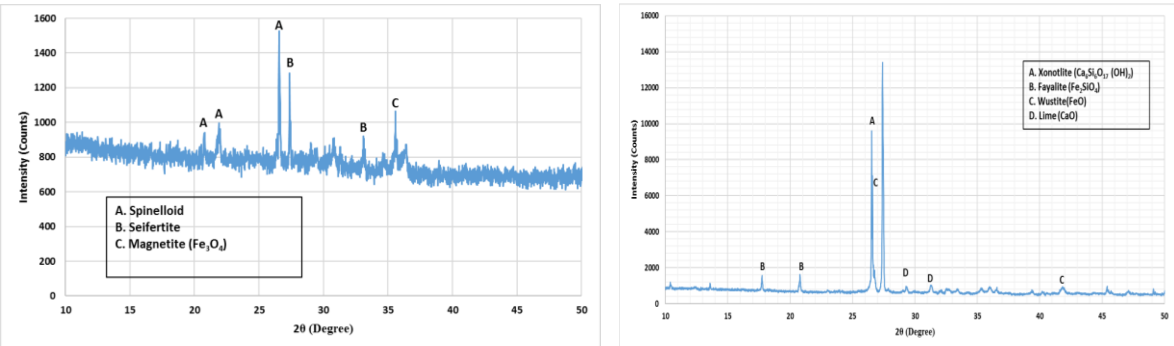
Table 3. Comparison of the compositions of slag generated through the two different route

	SiO_2	Fe_2O_3	MnO	Al_2O_3	CaO
IF slag sample	40.01	23.29	9.73	7.85	12.80
IF slag [7]	48.54	25.89	7.62	8.45	3.91
IF slag [8]	55.82	13.09	-	16.35	2.86
EAF slag sample	19.9	19.9	5.1	6.3	35.5
EAF slag [9]	16.1	16.1	4.5	7.6	29.5
EAF slag [10]	14.1	14.1	5	6.7	38.8

X-Ray Diffractometric (XRD) analysis

The x-ray diffraction patterns of the different types of slag recorded by using EMPYREAN PANalytical, Netherlands are shown in Figure 1. It is evident that spinelloid phase (Fe_3O_4-Fe_2SiO_4) is predominant in the x-ray diffraction pattern of induction furnace slag. 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. This is in good agreement with the x-ray fluorescence analysis results.

On the other hand, the diffraction pattern of electric arc furnace slag showed, instead, a predominant phase containing CaO. A weak diffraction line of free CaO could also be identified. Moreover, the spinelloid phase (Fe_3O_4-Fe_2SiO_4) predominant in the x-ray diffraction pattern of induction furnace slag was absent in the pattern of EAF slag. This makes electric furnace slag qualitatively different from induction furnace slag.



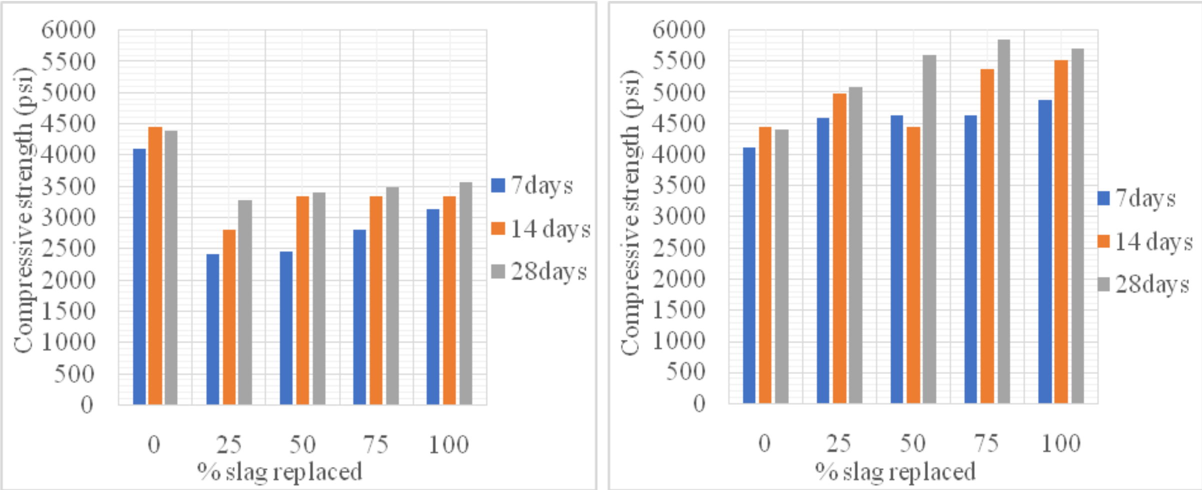
(a) (b)

Fig. 1. X-ray diffraction (XRD) patterns of (a) IF slag and (b) EAF slag

Compressive strength

Figure 2 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. For IF coarse aggregate, the strength of the concrete specimens was almost the same as the replacement of slag from 25% to 100% with the numerical values ranging from 3288 psi to 3578 psi.

The compressive strength of samples incorporated with EAF slag in varied ratios by weight showed superior numerical values compared to the concrete with no slag in it. Again, increasing the amount of the ratios of slag increased 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 incorporation also showed a comparable value of 5705 psi. This shows that concrete with steel slag aggregates achieves similar strength compared to conventional concrete.



(a) (b)

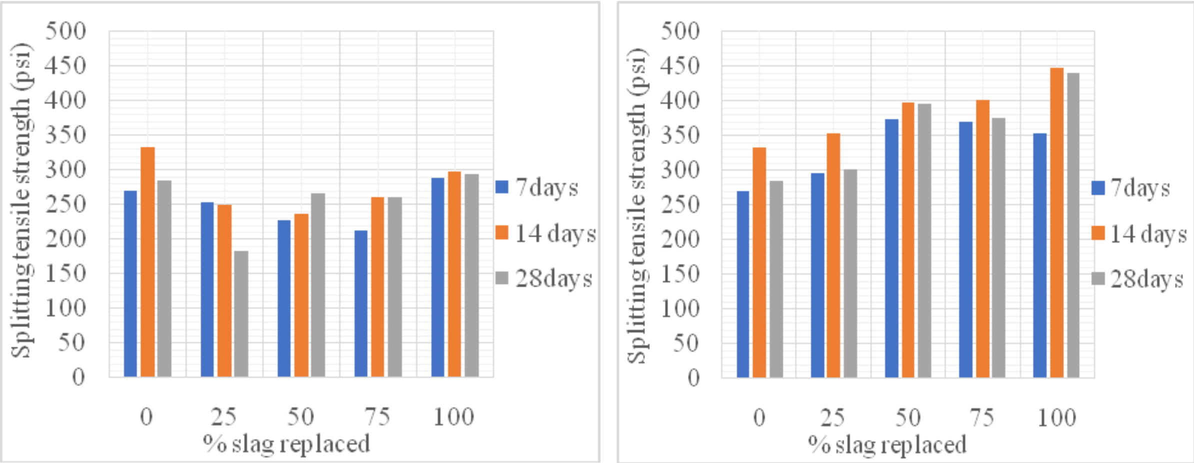
Fig. 2. Comparison of compressive strength of (a) IF coarse aggregate and (b) EAF coarse aggregate

Splitting tensile strength

The splitting tensile strength of the concrete specimens was determined at 7, 14 and 28 days following ASTM C 496. It may be noted that the specimens, in the form of cylinders with a diameter of 4 inches (102 mm) and a length of 8 inches (203 mm), were molded at the same time as the compressive strength specimens.

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.

In IF coarse aggregate replacement, the maximum values were obtained for 100% slag incorporation and no slag incorporation in 14 days. For 7 days curing, the values were found to be more or less consistent. For 14 days, an increasing trend was observed as well as for the gradual 28 days replacement of slag except for concrete with no slag replacement. In case of EAF slag replaced, the maximum values were obtained for 100% slag replaced in 14 days and 28 days respectively, but all the slag replaced samples showed superior values than the concrete with no slag. The normal strength found for splitting tensile strength of concrete is 200-700psi after 28 days water curing. The strength of both IF and EAF coarse slag made concrete indicates that both of them can be used as a replacement of natural coarse slag aggregates in concrete.



(a) (b)

Fig. 3. Comparison of splitting tensile strength of (a) IF coarse aggregate and (b) EAF coarse aggregate

4. Conclusion

a) Slag produced in EAF steelmaking contains a greater amount of lime, while the slag generated in induction furnace are almost free from lime.
b) The compressive strength of the concrete specimens incorporated with IF coarse slag was almost the same for the incorporation of 25% to 100% slag and the highest value was 3699 psi.
c) The compressive strength of samples incorporated with EAF slag in varied ratios by weight shows superior numerical values compared to the concrete with no slag in it. The highest strength attained was 5850 psi.
d) Concrete with steel slag aggregates achieves similar strength compared to normal strength concrete (3000-6000 psi). Incorporation of EAF slag showed a more encouraging result.

5. Acknowledgement

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6. References

[1] Troxel G.E, Davies H.E and Kelly J.W, Composition and properties of concrete (New York, McGraw Hill Books Company, 1968)

[2] Tarek U. Mohammed, Md N. Rahman, Aziz H. Mahmood, Tanveer Hasan, and Shibly M. Apurbo (2016), "Utilization of steel slag in concrete as coarse aggregate", 4th international conference on Sustainable Construction Materials and Technologies, Las Vegas, USA, SCMT4.

[3] M. A. Qurishee, I. T. Iqbal, M. S. Islam & M. M. Islam (2016), "Use of slag as coarse aggregate and its effect on mechanical properties of concrete", 3rd International Conference on Advances in Civil Engineering, 21-23 December, CUET, Chittagong.

[4] A. Andrews, E. Gikunoo, L. Ofosu-Mensah, H. Tofah and S. Bansah (2012), "Chemical and mineralogical characterization of Ghanaian foundry slag", Journal of minerals and material characterization and engineering, Vol.11, No.2, pp 183-192.

[5] Alizadeh R, Chini M, Ghods P, Hoseini M, Montazer and Shekarchi M (2003), "Utilization of electric arc furnace slag as aggregates in concrete", 6th ACI international conference on recent advances in concrete technology, Bucharest, Romania, pp 451-464.

[6] J. M. Manso, J. J. Gonzalez and J. A. Polanco (2004), "Electric arc furnace slag in concrete", ASCE Journal of materials in civil engineering, Vol.16, No.6, pp 639-645.

[7] J. Zuno-Silva1, A. Bedolla-Jacuinde, J.M. Martínez-Vázquez, A. Pérez-Perez, y T. Quintero-Azuara, "Laboratory scale study of uncommon degradation SiO_2 refractories used on induction furnaces", *Nova Scientia*, vol.6 no.11 León abr., 2014.

[8] M. Barra, E. V. Ramonich, and M. A. Munoz, "Stabilization of soils with steel slag and cement for application in rural and low traffic roads," in *Proceedings of the Beneficial Use of Recycled Materials in Transportation Application*, pp. 423–432, RMCR University of Durham, Arlington, Va, November 2001.