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# POSSIBILITY OF MAKING NON-FIRED BRICKS FROM INDUCTION FURNACE STEEL SLAG AND ELECTRIC ARC FURNACE STEEL SLAG GENERATED IN BANGLADESH

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***Abstract:*** *Production of light weight structural bricks using Electric Arc Furnace (EAF) steel slag and Induction Furnace (IF) steel slag, as the major ingredient has been investigated. The compressive strength of the prepared non-fired bricks suggests that it is possible to produce good quality light weight non-fired structural bricks from both EAF slag and IF slag. Findings of this research indicate promising result that slag can be used as a construction material. Such recycling of slag can help manage the ever-increasing volume of slag generated in steel plants and help construction industry by reducing the burden of importing huge building materials and ensure a cleaner environment.*

**Keywords:** EAF slag, IF slag, non-fired bricks, recycling

## 1. INTRODUCTION

The brick sector in Bangladesh contributes about 1% of gross domestic product and generates employment for about 750,000 people. The brick sector has grown rapidly in the last decade; led by continuous economic expansion since the 1990s and the subsequent construction boom [1]. Statistics reflects that Bangladeshi construction industry is developing at a rate of about 5.28% over the last couple of years. Brick is at the root of every infrastructure development project. According to DoE (Department of Environment) and BBMOA (Bangladesh Brick Making Owners Association) new 1930 brick kilns were established at the time frame of 2011-2015.

Because of the lack of stone aggregates and other alternative building materials, the clay in Bangladesh’s Ganges River delta provides abundant raw materials for bricks, which have underpinned the country’s civil construction in building, road pavement, irrigation, bridges, and other essential infrastructure, and as aggregate in concrete mix.

The brick sector is directly contributing to economy. However, it is now considered as one of the most concerning sectors as it reduces agricultural land, causes deforestation, air pollution and greenhouse gas (GHG) emission.

In 2011, available market data indicate that there are 4,880 brickfields in Bangladesh, 92% of which are polluting fixed chimney kilns. The brick sector grew at an average rate of about 5.6% per year during 1995–05, and is estimated to be currently growing at 7%–8% per annum. The available data also indicate that the brick sector in Bangladesh burns about 203 tons of coals and emits about 576 tons of $CO_2$ per 1 million bricks manufactured [1]. With about 17 billion bricks produced annually, the industry's annual $CO_2$ emissions are estimated to be 9.8 million tons [1]. In the capital city of Dhaka, the north Dhaka cluster of brickfields contributes about 40% of the fine particulate pollution in the city during the operating season (November to April).

Another major concern of the current red bricks (clay fired) production is the consumption of agricultural top soil. Generally traditional brick making process requires the upper layer (6 inch – 24 inch) of the agricultural field - known as top soil. Research conducted by research organizations estimated that over 100 core cubic-feet agricultural top soil is required by this sector . UN estimated that everyday about 690 acres of agricultural land is truing as nonagricultural land over the country . If such land transformation continuities national food security will face a huge strife to satisfy the demand of future population.

On the other hand, steel mills of different categories and sizes, currently produce about 250,000 tons/yr of steelmaking slag in Bangladesh. With the progress of economy, the per capita consumption of steel, presently estimated as 25 kg, will increase leading to generation of higher volumes of slag. The disposal of this huge slag is a great concern. In most cases landfill is the main disposal solution practiced in Bangladesh, resulting in environmental pollution.

In Bangladesh two types of steel slag is produced - Induction Furnace (IF) slag and Electric Arc Furnace (EAF) slag. They differ in chemical composition and in properties. This research focuses on the possibility of recycling both types of slags as structural bricks.

## 2. MATERIALS AND METHODS

Steel slag (both IF and EAF), sand and hydrated lime mixtures with gypsum as a binder were used to make the bricks. The samples of steel slag collected from different industries. The ingredients like hydrated lime and gypsum were collected from the local market. Process variables like the composition of the mix and curing conditions were maintained constant, the forming pressure was the only variable. Finally, the compressive strengths of the bricks produced under these conditions were determined.

Brick specimens were produced under the conditions given in Table 1. In total eighteen bricks were made for the testing purpose. Before making a brick, each ingredient of the raw materials was dried in a muffle furnace at 110℃ for 24 hours. Required amount of each ingredient was weighed, 14% moisture was added and the components were mixed thoroughly.

Table 1: Test parameters

| Slag Type | Bricks code | Sand wt% | Slag (IF) wt% | Lime wt% | Gypsum wt% | Forming Pressure(psi) | Curing process | Other Parameters |
|---|---|---|---|---|---|---|---|---|
| IF | 01 | 20 | 70 | 10 | 2 | 1000 | Under water | 14% moisture added; Pressure applied for 15 sec |
| | 02 | 20 | 70 | 10 | 2 | 1000 | | |
| | 03 | 20 | 70 | 10 | 2 | 1000 | | |
| | 01 | 20 | 70 | 10 | 2 | 2000 | | |
| | 02 | 20 | 70 | 10 | 2 | 2000 | | |
| | 03 | 20 | 70 | 10 | 2 | 2000 | | |
| | 01 | 20 | 70 | 10 | 2 | 3000 | | |
| | 02 | 20 | 70 | 10 | 2 | 3000 | | |
| | 03 | 20 | 70 | 10 | 2 | 3000 | | |
| EAF | 01 | 20 | 70 | 10 | 2 | 1000 | Under water | 14% moisture added; Pressure applied for 15 sec |
| | 02 | 20 | 70 | 10 | 2 | 1000 | | |
| | 03 | 20 | 70 | 10 | 2 | 1000 | | |
| | 01 | 20 | 70 | 10 | 2 | 2000 | | |
| | 02 | 20 | 70 | 10 | 2 | 2000 | | |
| | 03 | 20 | 70 | 10 | 2 | 2000 | | |
| | 01 | 20 | 70 | 10 | 2 | 3000 | | |
| | 02 | 20 | 70 | 10 | 2 | 3000 | | |
| | 03 | 20 | 70 | 10 | 2 | 3000 | | |

To ensure uniform size of the bricks a known weight of mixture was used each time to fill the mould cavity. Dimension of the mould cavity (Figure 1) was 6 X 3.5 cm. A hydraulic press (Figure 2) was used to apply pressure for a period of 15 Seconds. The bricks were then ejected (Figure 3) and finally cured. Curing was done by immersing the bricks in water (Figure 4).

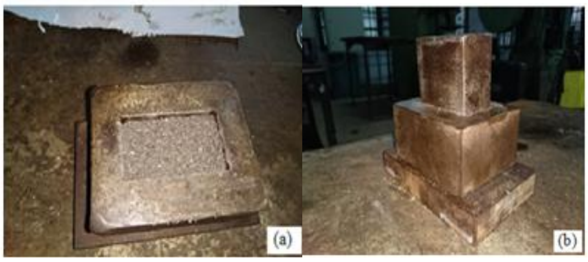



Fig. 1: (a) Brick samples in mould (b) Mould ready for pressing

### 2.1 Compressive strength

Compressive strength was determined by applying load on the specimen by using a Universal Testing Machine (UTM). Load was applied on an area measuring 6mm X 3.5 mm [The size of one face of the entire brick].

(a) (b)

Fig. 2: (a) Hydraulic Press (b) Brick samples in the hydraulic press.

Fig. 3: Green Slag-Sand-Lime-Gypsum bricks

Fig. 4: Water curing of brick samples

## 3. RESULTS AND DISCUSSIONS

### 3.1 X-Ray Fluorescence (XRF) Results

The samples of steel slag were analyzed by X-Ray Fluorescence (XRF) 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 $Al_2O_3$, MnO and CaO 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 2.

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 steel making 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 for 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.

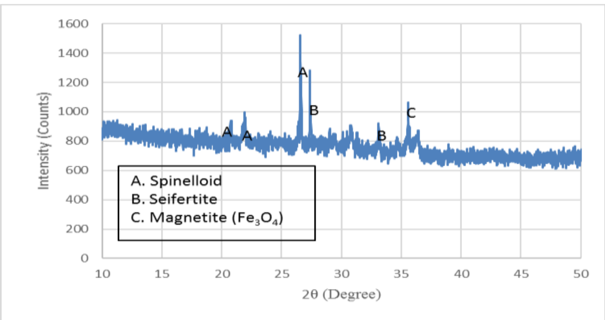
Table 2: Comparison of the compositions of slag generated through the two different routes

| | $SiO_2$ | $Fe_2O_3$ | MnO | $Al_2O_3$ | CaO |
|---|---|---|---|---|---|
| **IF slag sample** | 40 | 23.3 | 9.7 | 7.9 | 12.8 |
| **IF slag reference 1** | 48.5 | 25.9 | 7.6 | 8.5 | 3.9 |
| **IF slag reference 2** | 55.8 | 13.1 | - | 16.4 | 2.9 |
| **EAF slag sample** | 19.9 | 19.9 | 5.1 | 6.3 | 35.5 |
| **EAF slag reference 1** | 16.1 | 16.1 | 4.5 | 7.6 | 29.5 |
| **EAF slag reference 1** | 14.1 | 14.1 | 5 | 6.7 | 38.8 |

### 3.2 X-Ray Diffractometric (XRD) Analysis

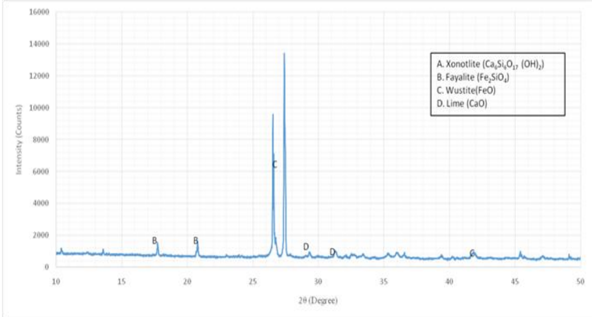
The x-ray diffraction patterns of the different types of slag by using EMPYREAN PANalytical, Netherlands are shown in Figure 5. It is evident that spinelloid phase ($Fe_3O_4$-$Fe_2SiO_4$) is predominant in the x-ray diffraction pattern of induction furnace slag. This is in good agreement with the x-ray 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.

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)

Fig. 5 (a): X-ray diffraction patterns of EAF slag




(b)

Fig. 5 (b): X-ray diffraction patterns of IF slag

### 3.3 Effect of Brick forming Pressure on the Compressive Strength

The results are presented in Figure 6. It is evident that, with increasing pressure applied during shaping the bricks, there is a rise in the magnitude of the compressive strength in both the cases of incorporation of induction furnace slag and electric arc furnace in the brick. However, the bricks with electric arc furnace slag exhibit superior compressive strength value.

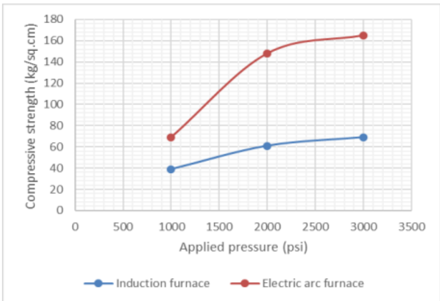



Fig. 6: Comparison of compressive strength values of bricks formed at different forming pressures

The compressive strength of generally used burnt bricks are (i) 35kg/sq.cm for ordinary bricks, (ii) 70 kg/sq.cm for the second-class bricks, (iii) 105 kg/sq.cm for the first-class bricks [6].

The bricks under this study were not burnt bricks, they were cured bricks. The manufacture of the bricks involved no $CO_2$ emission and this is a definite advantage. Thus, the results obtained (70 kg/sq.cm for induction furnace slag bricks and 165 kg/sq. cm for electric arc furnace slag) so far show a possibility of using slag in the manufacture of structural bricks also. However, there are so many aspects of investigation and it is possibly too early to make a definite comment.

## 4. CONCLUSION

The bricks under this study were not burnt bricks, they were cured bricks. The manufacture of the bricks involved no $CO_2$ emission. Compressive strength were 70 kg/sq.cm for induction furnace slag bricks and 165 kg/sq. cm for electric arc furnace slag bricks whereas the compressive strength of generally used burnt bricks are

(35-105) kg/sq.cm for ordinary bricks. So it can be concluded that incorporation of slag (both IF and EAF) in building materials is a definite possibility.

## 5. ACKOWLEDGEMENT

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