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Utilization of Locally Produced Steel Slag as Building Material

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Abstract

An experimental program was carried out to investigate the possibilities of making non-fired brick by utilizing locally produced electric arc furnace slag and induction furnace slag. To assist the study, sample bricks were made with varying forming pressure, slag percentage and curing time to find out their effect on the mechanical properties i.e. compressive strength and water absorption capacity. Then the tested values were compared with traditional fired clay brick and the result shows superior values which indicates that EAF and IF slag could be a viable replacement for traditional fired clay brick. Such recycling could be a solution of ever increasing slag generation and disposal problem in our country. Another significant insight of the study is that, as we used the non-fired way in manufacturing, it helps in saving energy and natural resources as well as the environment.

Keywords: IF slag, EAF slag, non-fired brick, compressive strength, water absorption capacity.

1 Introduction

Brick has been used as construction material for over thousands of years due to its outstanding properties like great durability, good load bearing capacity, high strength, high thermal mass, low cost and so forth. But the conventional brick production process is energy intensive and put adverse effect on landscape and environment. This also cause impairment of natural resources. Studies have shown that, clay bricks, on average, have an embodied energy of approximately 2.0 kWh and release about 0.41 kg of carbon dioxide (CO_2) per brick [1,2]. So, for environmental protection along with consideration of sustainability in construction material, many researcher are studying utilization of waste material in production of brick. Kute and Deodhar [3] studied the compressive strength and water absorption capacity of bricks manufactured in laboratory using class F fly ash and clay. Ertugrul and Mustafa [4] studied the evolution of sewage sludge as construction material. They used sewage sludge along with fly ash and oven slag in various ratios as a substitute of clay in brick manufacture. Other than this, many more researches were held in developing bricks from wholly waste materials (like glass, plastic waste, coal ash, biomass ash, cigarette but, municipal waste, industrial waste etc.) without exploiting any sort of natural resources, in order to achieve sustainability [5].
Slag is a waste material generated in purifying metals, their casting and alloying. Consideration of using this waste as a construction material has been carried out since the last century. But it doesn't help in declining steel slag stockpiling & landfilling operations in steel producing countries mainly in the developing ones. Whereas in developed countries slag utilization rate is almost 100%. They use this waste as raw material in steel enterprise interior, aggregate of road and hydraulic construction, cement additive and concrete admixture, materials for waste water or gas treatment, construction materials, fertilizer in agriculture production and so on [7]. According to DoE (department of environment), in Bangladesh, every year 4.25 million tonne of slag just add up on the storage yard and within 2022 this amount will be 6.80 million tonne/year. So government has become concerned about utilizing this waste. And in that context, some recent studies are going on regarding utilization of this slag as concrete admixture.

Bangladesh Steel production mainly follows two routes: Induction furnace (IF) route & Electric arc furnace (EAF) route which results in two types of slag. The aim of this study is to evaluate the feasibility of recycling steel slag in clay brick production through laboratory test and validation. Locally produced IF and EAF slag along with lime, cement and gypsum were used for the production process followed by variation in composition, forming pressure and curing time. After production, compressive strength and water absorption capacity of the samples were tested to find their efficiency.

2 Materials, Method and Experimental Design

Materials and their preparation

The core element, IF and EAF slag were collected from local steel industries. The slag received from industry was in boulder form. To make it suitable for block preparation, it was broken down to a size enough for passing through 8 mesh sieve and then dried at 110˚C for 24 hour to remove moisture & volatile inorganic material. Other required elements i.e. Ordinary Portland Cement (OPC), quicklime (CaO) and gypsum (hydrated $CaSO_4$) were purchased from local market. Among them, lump of CaO was disintegrated by water addition.

(a) (b) (c) (d)

Fig. 1: (a) as received IF slag (b) pulverized IF slag (c) as received EAF slag (d) pulverized EAF slag

Mixing

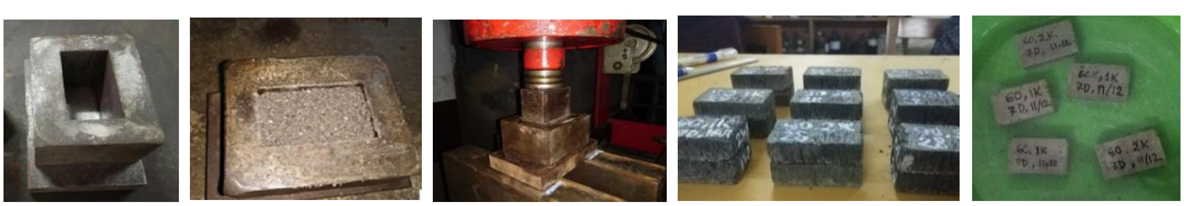
The requisite quantities of the materials i.e. slag, lime, gypsum and cement was calculated. To control the block density and uniformity, weigh batching and thorough mixing of dry materials was done. For block preparation, every time 100gm of sample was used (excluding gypsum) & 14% water was mixed. Design parameters maintained in our work are shown in *Table 01*.

Table 01: Design parameter for brick production

Types of slag	Compositional Variation					Pressure Variation (psi)	Curing time Variation (days)
	Slag	Cement	Lime	Gypsum (excluding 100gm)	Water content		
IF slag & EAF slag	60%	20%	10%	2%	14%	1000	7
	80%	10%				2000	14
	90%	0%				3000	28

Production of brick

Hydraulic press machine was used for compressing the block. Generally the single acting ram generates a compaction pressure in the range of 1000-3000 psi. This process consists of compressing the wet mix after it has been placed in the mould, through static compression to get constant volume blocks. The compressed block is then removed and the ejected samples were weighed, cured and labelled according to their mix and design. Inner dimension of the mould was 6.0cm×3.5cm. For compression test 3 sample was prepared for each variant and for water absorption test 2 sample was prepared for each variant. So a total of 270 sample were prepared.



(a) (b) (c) (d) (e)

Fig. 2: (a) mould (b) sample preparation (c) compression (d) manufactured brick (e) curing

Test methods

To evaluate the sample brick properties, test conducted to find out their compressive strength and water absorption capacity. Compression test was carried out in a universal compression testing machine where brick sample was placed and load is applied until the block crushes. Compressive strength was determined by dividing the load value with load surface area. For water absorption test, after curing the bricks were kept in oven for drying at 110˚C for 24 hour and then immersed in clean water again for 24 h. Using the weight difference in these two cases, water absorption capacity was calculated.

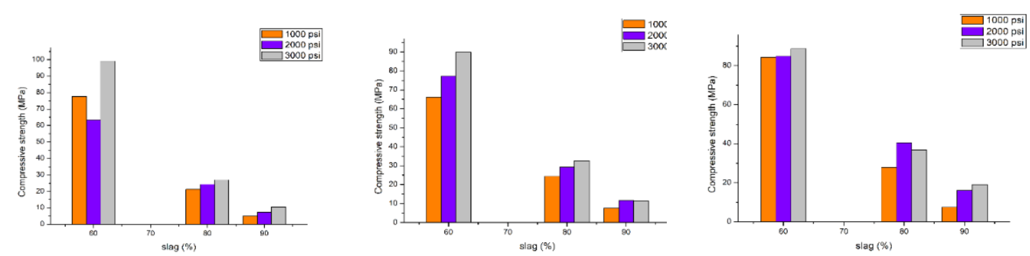
3 Result and discussion

Characterization of slag

The XRF and XRD results were adopted from the work of Raihan et al [08]. The XRF result shows that major components of the induction furnace slag sample are: Fe_2O_3 and SiO_2 with significant amounts of Al_2O_3, MnO and CaO. Having spinelloid (Fe_3O_4-Fe_2SiO_4) as a predominant phase in XRD result shows a good agreement with this XRF result. 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. Whereas in case of electric arc furnace slag, major elements are: Fe_2O_3 and CaO that also agrees with XRD result having xonotlite (calcium silicate compound) as a predominant phase. This variation happens because induction furnaces used for making steel in Bangladesh is generally silica lined and during the production process in arc furnace steel, lime (CaO) is added as a slag former which results in high silica and calcium oxide content in their respective field.

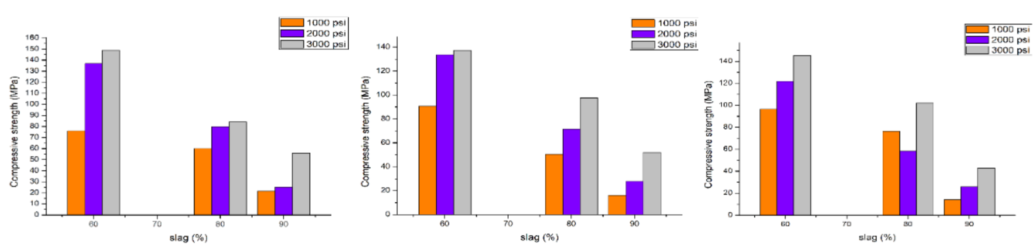
Compressive Strength

Change in compressive strength with variation in slag type, composition and pressure is shown in figure 04 and 05. The fig. shows that, with increasing slag percentage compressive strength decreases. This happens because major portion of strength is obtained by the hydration reaction of cement. The higher the cement content, the greater the reaction, thus the strength [09]. For this reason, 60-30 slag- cement composition gave the highest strength value and 90% slag brick showed the least. In absence of cement, only the pozzolona reaction of slag [06] is responsible for strength. Incremental change in other variables i.e. pressure and curing time, both helped in increasing compressive strength. Increase in pressure causes higher strength value as denser compact forms with higher pressure. And increase in curing time leads to higher strength as it gets more time for hydration reaction.



(a) (b) (c)

Fig. 3: compressive strength for IF slag brick for curing time of (a) 7 days (b) 14 days (c) 28 days



(a) (b) (c)

Fig. 4: compressive strength for EAF slag brick for curing time of (a) 7 days (b) 14 days (c) 28 days

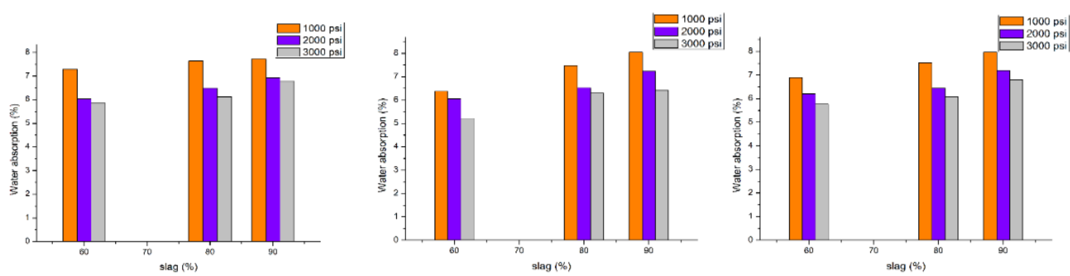
According to ISS: 1077-1970: Compressive Strength of first class brick is 105 kg/cm^2 (~10.3 MPa), 2nd class brick is 70 kg/cm^2 (~6.86 MPa) and for common building brick is 35 kg/cm^2 (~3.43 MPa). So, in comparison with the conventional brick, strength value of the IF slag brick, is higher than conventional structural brick. 60-30 and 80-10 combination of slag and cement showed greater strength value than that of 1st and 2nd class brick. In case of no cement, thus for 90% slag, low pressure- low curing time (1k-7Days) was not enough to beat the strength of 1st and 2nd class brick. Low pressure- high curing time (1k- 14/28 days) combination gave strength value higher than 2nd class brick. And high pressure-high curing time (2k/3k- 14/28days) combination gave strength value higher than 1st class brick.

In case of EAF slag based brick, for all combination, strength value is higher than that of all class of conventional brick. Even the lowest value of strength (90% slag -1000psi- 28 days) is 14.25MPa which is higher than that of first class brick. So this type of brick can be good replacement for the conventional one.

Among the two types of slag, brick based on EAF slag always showed superior value due to the presence of high amount of CaO in it. Presence of CaO helps in enhancing the hydraulic property of cement [06].

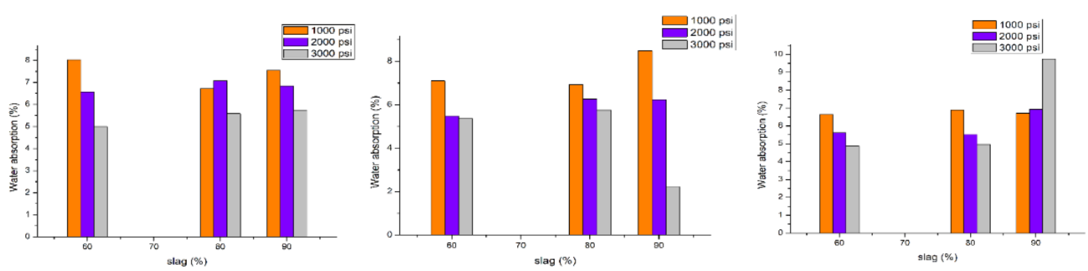
Water Absorption Capacity

The water absorption capacity of slag bricks for variations in composition, forming pressure and curing time are shown in figure 06 and 07. The figure represents an increase in water absorption capacity and a decrease with respect to increase in pressure and curing time respectively. It happens as the porosities tend to squeeze with higher pressures and with increase in curing time, block gets more time in hydration reaction thus more CSH gel formed which reduce the capillary spaces and results in lower water absorption [09].



(a) (b) (c)

Fig. 5: water absorption capacity for IF slag brick for curing time of (a) 7 days (b) 14 days (c) 28 days



(a) (b) (c)

Fig. 6: water absorption capacity for EAF slag brick for curing time of (a) 7 days (b) 14 days (c) 28 days

According to ISS: 1077-1970: water absorption capacity of first class brick is less than 15 percent. For 2nd class brick it is less than 20 percent. And for common building brick it is within 22-25 percent. So, in comparison with conventional clay brick, in all cases water absorption capacity of both IF and EAF slag based brick is lower than that of conventional clay brick. To use brick as building materials, low water absorption capacity is necessary to eliminate damping or water penetration problems, thus to increase durability but a minimum of water absorption (10%) is needed for accompanying construction process. Because if it is too dry, then it will fail making bond with concrete due to insufficient water for hydraulic reaction, which will affect the strength of construction. Whereas in this study, for IF slag based brick, highest value of water absorption is 8.04% and for EAF slag based brick it is 8.43%. This can be altered by lowering the forming pressure and shape of manufactured brick.

4 Conclusion

Core intention of our study was to find a viable replacement for conventional clay brick. Findings and observations of the study can be concluded as follows:

- Slag bricks irrespective of slag types and combination, always have higher strength value than conventional burnt clay brick. In case of EAF, all combination showed superior strength than the conventional one. But in case of IF slag based brick, 3 combinations showed lower value than 1st class brick and 1 combination showed lower value than 2nd class brick. In variation of composition, higher amount of slag results into the chemical instability so that decreases compressive strength. And increasing pressure & curing time increases compressive strength.

- The water absorption of slag brick was lower than the burnt clay brick. Effect of slag composition and curing time was insignificant on water absorption capacity.

- This was a non-fired brick making process. So produced brick can be helpful in the reduction of CO_2 emission.

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