Original Research Article

THE MECHANICAL AND PHYSICAL CHARACTERISTICS OF STEEL DUST BRICKS

ABSTRACT

This work investigates thermal and mechanical properties of bricks produced from particles of electric arc furnace (EAF) hazardous fumes with a view to enhancing safe disposal and reduce the current prohibitive cost of handling. Test samples are prepared from the as-received steel-dust and sieved to 53-106 µm size range, mixed with 10-35 wt% bentonite content and rammed in a cylindrical mould. The samples are first allowed to cool in air at ambient temperature (32^0C) for 24 hours and then heated in a muffle furnace at 6.7^0C per minute to sinter at 1000^0C with 10-60 minutes. Relevant refractory property tests of the steel-dust bricks namely; bulk density, porosity, cold crushing strength (CCS), refractoriness, linear shrinkage and wear resistance are carried out and their results analyzed. Based on their performance ratings, the EAF steel-dust brick containing 15wt% bentonite and held for 30 minutes during sintering possess the highest ranking of 4.2/5.0 while bricks with 25,30 and 35 wt% bentonite at 50, 60 and 40 minutes holding time respectively exhibit 3.8/5.0 ranking. The refractory properties of the bricks are significantly influenced by the combination of the proportion of fine particle size (106µm), amount of bentonite added and the sintering holding time. Steel-dust bricks can be useful as thermal insulator in non-ferrous reactors and allied devices.

Keywords: Steel-dust, brick, sintering, thermal properties, wear resistance

INTRODUCTION

A material is classified as "refractory" based on the capacity to retain its physical shape and chemical stability at elevated temperatures. Refractory materials such as clay bricks, ceramic fiber, insulating bricks, etc., are made in varying combinations and shapes for different applications (BEE, 2005). According to Bhatia (2011), refractories are not valued only by the

cost of material, but also by the nature of the job and their performance in a particular situation. In the metallurgical industry, refractory materials are employed in the internal linings of furnaces, kilns, reactors and other vessels for holding and transporting molten metal and slag. In the non-metallurgical industries, refractories are mostly installed on fired heaters and hydrogen reformers. Most of this equipment operates under high pressure and temperature which can vary from very low to very high (approximately 482.22°C- 1593.33°C). In addition to performing these tasks at elevated temperatures, refractory materials may also be required to bear mechanical loads and transfer heat.

The availability and processing of raw materials for the production of refractories could be highly energy intensive, which in turn affects cost of production (Hemrick et al., 2005). This has placed a high demand on refractory manufacturers to explore the use of alternative raw materials other than the conventional ones. The steel industry is in the forefront of this effort with steel dust bricks as potential alternative cost effective refractory. The electric arc furnace (EAF) technology employs the manufacture of steel with the generation of dust between 15 – 25kg dust per ton of liquid steel produced (Popovici, 2009). The EAF dust is listed hazardous (NICE[3], 1999) and contains zinc (15-35%) with some toxic metals such as lead, cadmium and chromium. Several dust samples from different industrial furnaces are also observed by Scanning Electron Microscopy (SEM) and analyzed by Energy Dispersive Spectrometry (EDS). From morphological survey, two categories of particles are distinguished. These are large particles, with sizes ranging from a few dozen to a few thousand µm and finer particles, lower than 20 µm. The process of fine steel dust formation in the furnace involves vaporization, reaction with oxygen and deposition on condensed nuclei (Sofilic et al., 2005).

With the aim of preventing improper handling of this hazardous waste and stopping the increase in environmental pollution, mineralogical composition of several specimens of EAF dust is examined by Holloway and Etsel (2007). It is concluded that EAF dusts generated during processing of steel differ essentially from one another by their physical and chemical characteristics. However, there is no general model of solution approach for EAF recovery and disposal. A study has shown that the residual lead content of ferrous metal scrap can be controlled by EAF operators to some extent (EPA, 2009). However, the most feasible and cost effective method of managing lead in scrap is to reduce the amount of lead in products that can

potentially enter the ferrous metal scrap stream. Sresty, (1990) devised a high temperature (1000-1100°C) reduction of iron, lead, zinc and calcium oxides present in the furnace dust.

There is attendant health and economic issues raised by the present management of EAF dust as discussed above. In light of this, there is need to design a process that is sufficiently attractive economically, technically and environmentally friendly for the use of this waste. This study therefore, is aimed at producing refractory bricks from steel dusts generated from pyrometallurgical reactor. The successful production of bricks from this waste will reduce its harmful effect on the environment and stem the burden of handling cost and disposal. This study is limited to analysis of the EAF steel dust from Delta steel plant, Ovwian-Aladja, Delta state, Nigeria.

EXPERIMENTAL METHODOLOGY

Materials

The EAF steel dust used for this study is obtained from Delta Steel Company (DSC), an integrated steel plant located in Ovian-Aladja, Delta State of Nigeria. The plant utilizes a fume extraction system for the filtration of its furnace off-gases. Size of as-received dust ranged between 53-106 µm and the chemical composition as obtained from atomic absorption spectrophotometry (AAS) analysis is shown in Table 1. Table 2 gives the steel dust –bentonite mixes. The foundry bentonite is obtained from a local standard foundry in Lagos,Nigeria.

Table 1: Chemical analysis of EAF Dust

Element	Al_2O_3	CaO	Fe_2O_3	PbO	MgO	MnO	SiO_2	ZnO
Composition(wt %)	21.4	0.32	64.35	0.04	0.17	0.06	13.21	0.45

Table2: Steel dust-bentonite mixes

Samples	A	B	C	D	E	F
Steel dust (wt %)	90	85	80	75	70	65
Bentonite (wt %)	10	15	20	25	30	35

The foundry sodium-bentonite type used has ability to form thixotrophic gels with water . It has ability to absorb large quantities of water with an accompanying increase in volume 12-15 times its dry bulk and a high cation exchange capacity. It cation exchange capacity allows the mineral to bind with inorganic cations. The bentonite exhibits good green strength along with high hot and dry strengths which helps preventing cracking in form bricks. As shown in Table 2, varying content (wt%) of bentonite is thoroughly mixed with the steel dust with addition of 0.268g of water per gram of mixture to make it plastic enough for the production of green cylindrical samples by ramming. The Ridsdale-Dietert A.F.S standard rammer is used to prepare the standard A.F.S test samples. This yields samples having 3.65cm diameter and length which ranged between 1 and 15cm depending on the tests to be carried out. The samples are then subjected to open air drying for 24 hours before sintering in the furnace at 1000°C and at 6.67^{o}C/min heating rate. The sintering period for each steel dust-bentonite sample, ranges from 10, 20, 30, 40, 50 and 60 minutes after which the sample is removed to cool in still air.

Cold crushing strength test CCS)

Cold crushing strength test is carried out on 15x3.65cm^2 sintered bricks using a compressive strength tester at a crushing load of 10kN for 60 minutes**.** The load is applied axially by turning the hand wheel at a uniform rate until failure occurs. The sample crushing strength is evaluated by dividing the maximum compressive load (kN) by cross sectional area of brick (m^2).

Refractoriness test

Sample bricks of 6x3.65cm^2 are placed in a muffle furnace with maximum operating temperature of 1200°C and the samples are heated continuously at the rate of 7°C/min till fracture occurs.The operating temperature and sintering time employed are 1005°C and 60 minutes respectively while the temperature at which each brick crumbled is recorded.

Thermal shock resistance test

Bricks (6x3.65cm^2) prepared for thermal shock resistance test are carried out by placing them in a furnace maintained at 900°C and left for 10 minutes. Each brick is removed and cooled in air for 10 minutes after which it is returned to the furnace for another period of 10 minutes. This

cycle of heating and cooling is repeated until the test samples crumbled and the number of cycles sustained by each brick before fracture is recorded.

Apparent porosity measurement (AP)

The boiling water method is used to determine the bricks apparent porosity. Each sample brick is weighed dry and completely immersed in boiling water. The saturated brick is finally cooled by suspension in cold water. The apparent porosity is calculated using, the expression

$$AP(\%) = \frac{Wa - Wb}{Wc - Wb} x100 \qquad (1)$$

Where Wa is the weight of dry brick in air, Wb is the weight of the saturated brick in water and Wc is the Weight of the saturated brick in air.

Bulk density measurement (B)

The samples' bulk density is measured directly by the ratio of weight of 6x3.65 cm^2 brick (g) to its volume (cm^3):

$$B = \frac{W}{V} x100 \qquad (2)$$

W and V are the sample weight and volume respectively.

Permanent linear change

Permanent linear change is measured in terms of the bricks' diameter before and after sintering. After measuring the bricks' diameter using an electronic digital stainless hardened veneer caliper model no G04086472 made by HUAWEI, it is air dried for 24 hours and sintered at 1000°C for 10 and 60 minutes. On cooling to room temperature, the diameter of the fired bricks is taken and the linear shrinkage is calculated using the expression,

$$LS(\%) = \frac{Dd - Fd}{Dd} x100 \qquad (3)$$

Where Dd is dried diameter and Fd is fired diameter.

Wear rate

The rate at which the bricks wear off during service is determined using 6x3.65 cm^2 sample bricks. Each brick is initially weighed and held on a 100 grit abrasive paper, worn on an electrically powered rotating wheel for 60 seconds after which the final weight is measured. The wear rate is measured using the expression:

$$Wearrate = \frac{Weightloss}{time} \qquad (4)$$

RESULTS AND DISCUSSION

Cold crushing strength

The test brick samples withstood the crushing load without crumbling at 95.6MPa maximum load capacity of the crushing machine. This implies that the magnitude of load or time (or both) set are insufficient to cause failure of bricks.

Refractoriness

All the brick mixes possess adequate refractoriness as none crumbled below 1005°C on sintering for an hour.

Thermal shock resistance

Each brick shows no visual macro observable incipient cracks after seven cycles.

Apparent Porosity (AP)

Sintering between 30 - 60 minutes at the maximum sintering temperature, according to Eisenmann (2000), is recommended for most materials for sufficient bond formation and growth. Figure 1 below shows the influence of sintering time on the apparent porosity of steel dust – bentonite bricks. Sample brick of 10wt% bentonite (sample A) sintered for 60 minutes has the highest AP of 47%. This implies that the refractory will possess the least strength, allow penetration of molten metal, fluxes and slags which will eventually lead to degradation of its structure (Bhatia, 2011; Yan, 2011). Refractories of this nature will be good insulating materials owing to the high volume of air that can be trapped in the pores. On the other hand, sample F sintered for 40 minutes possess the least magnitude of AP (1.13%) and can therefore, best function in hotter zones. Fluctuations in the rise and fall of bricks' AP with increase sintering time could be as a result of the varying composition of bentonite and/or the magnitude of the sintering temperature employed.

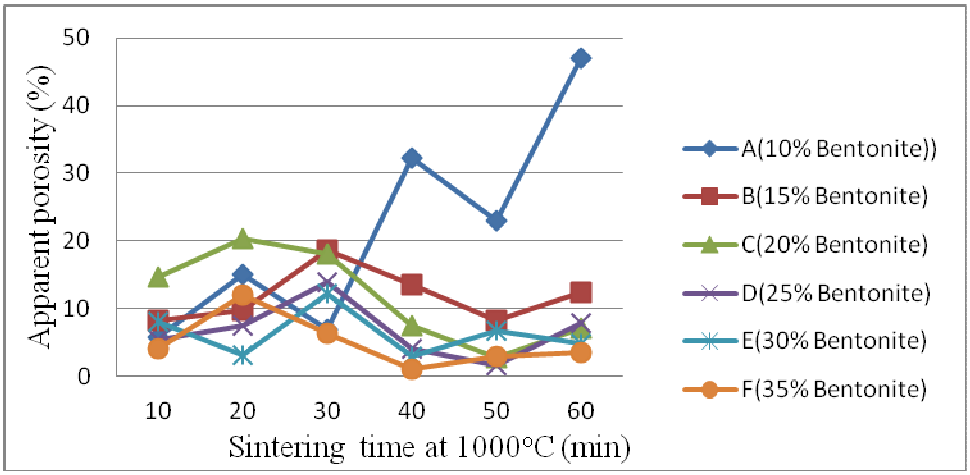

Figure 1: Apparent porosity of sample bricks with sintering time

Bulk Density

Figure 2 shows fluctuations in the bulk densities of sample bricks at varying bentonite compositions and sintering time. Decrease in brick's porosity and appreciable contact made between steel dust and bentonite may be responsible for the increase in the bulk density of sample bricks and vice-versa (Elngar et al., 2009). Sintering for 30 minutes increases the bulk

density of sample brick B to 4.01 g/cm^3, which is of the highest magnitude, hence, possessing the highest volume stability (UNEP, 2006). All the samples show decrease in bulk density when sintered between 10 and 20 minutes except for those containing 25 and 30wt% bentonite. Sample bricks C and F follow similar trend though the former has reduce magnitudes.

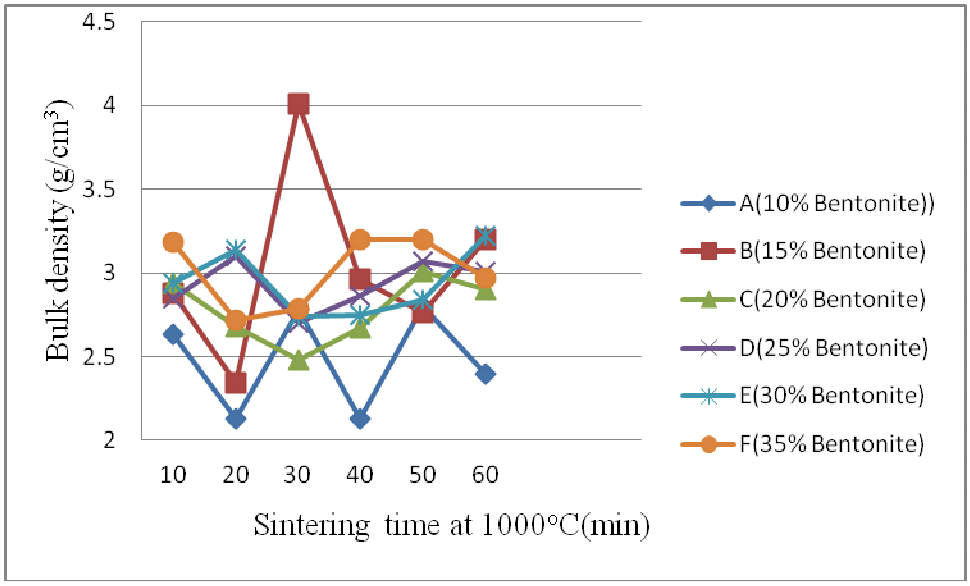

Figure 2: Bulk densities of sample bricks with soaking time

Permanent linear change

Permanent linear change of sample bricks follows the same trend as their shrinkage increase between 10 and 20 minutes of sintering (Figure 3). Beyond this time, there is non-uniform variation in their dimensional changes as both bentonite content and soaking time increase. In comparison among sample bricks B-F, sintering for 60 minutes shows a higher event of sintering, as bricks possessed the largest percent shrinkage at this time while the lowest value (4.34gcm^{-3}) is obtained at 40 minutes with sample brick A.

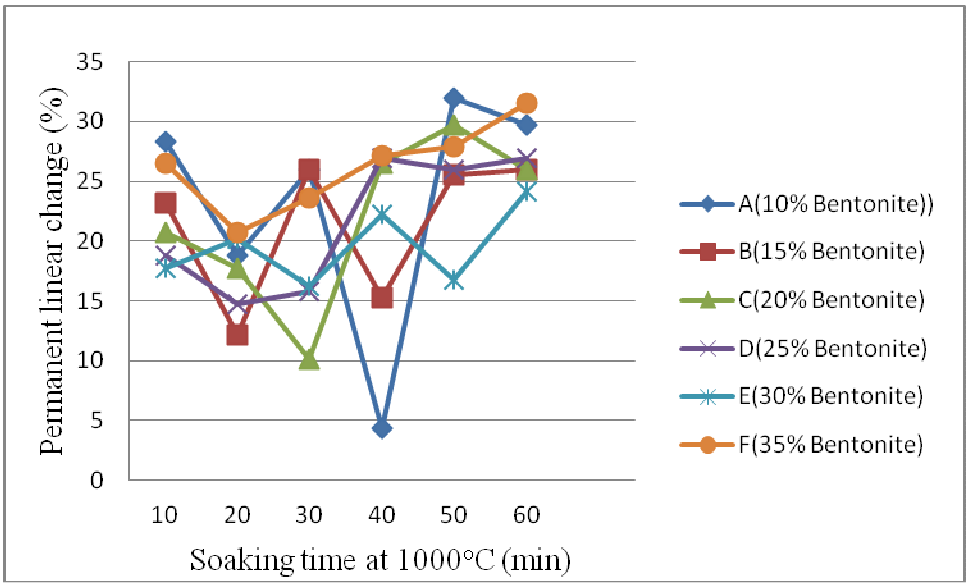

Figure 3: Permanent linear change of sample bricks with sintering time

Wear Resistance

In Figure 4, brick sample A offers the highest wear rate of $1.5gs^{-1}$ when sintered for 10 minutes. Apart from this sample, wear rate of sample bricks are small ($< 1s^{-1}$). Sintering samples A, C and D for 60 minutes has culminated to their lowest wear rate of $0.02gs^{-1}$.

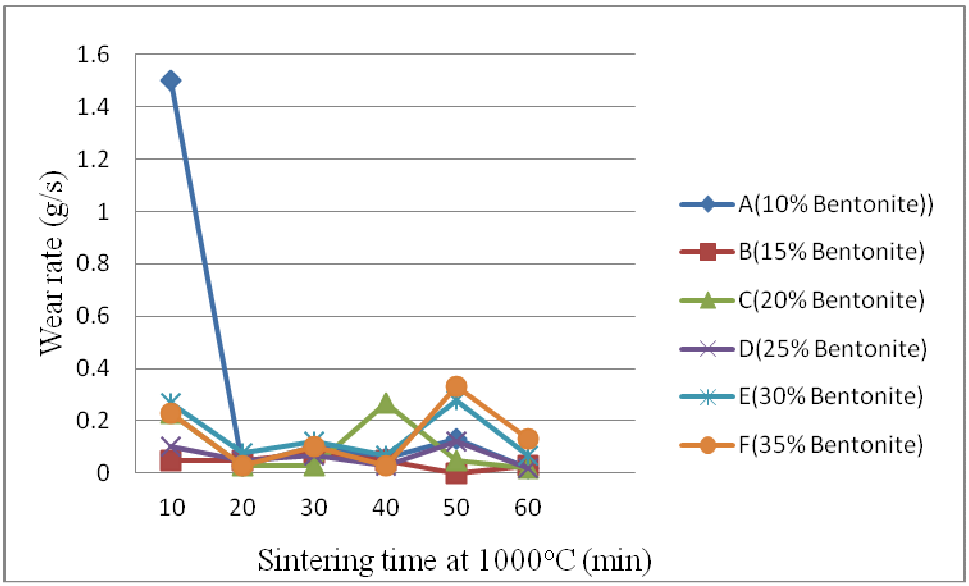

Figure 4: Wear rates of sample bricks with sintering time

CONCLUSION

The feasibility of using EAF dust as a refractory material has been studied. The refractory properties of steel dust are found to be strongly influenced by the amount of bentonite content and the sintering time at 1000°C. Information from the study can be summarized as follows:

1) Steel dust bricks containing between 10 and 35wt% bentonite exhibit the minimum cold crushing strength (CCS) of 95.6MPa as each brick passed on compression at 10kN for 60 minutes. This magnitude of CCS is fairly higher than alumina-based castable refractories (93MPa) in which calcium aluminide cement is used as a binder (Kalpakli, 2008).
2) All the brick mixes possess adequate refractoriness as none crumbled below 1005°C on sintering for an hour. These bricks can therefore preserve molten metals up to this temperature during transportation or processing.
3) Bulk densities of steel dust bricks (2.13-4.01g/cm^3) are comparable to that of alumina-zirconia bricks (2.28-3.12g/cm^3) (Prakash et al., 2011).
4) Addition of 35wt% bentonite to steel dust (sample F) and sintered at 1000°C for 40 minutes results in the least apparent porosity of 1.13%. This brick sample mix also demonstrates a good bulk density of 3.2g/cm^3.

The above analysis of the brick refractory performances shows that sample B (85 wt % steel dusts, 15 wt % bentonite) mix which is sintered for 30 minutes has the highest ranking of 4.2/5. Thus, one of the reliable ways of safe handling of EAF dust would be in the production of refractory bricks. However, the bentonite content and sintering time employed will depend on the service condition(s) to which the refractory brick would be subjected.

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