INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X
Impact factor: 4.295
(Volume 3, Issue 6)
Available online at www.ijariit.com

Characterization and Reuse Avenues of BOF Slag as Flux Material in Sinter

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Abstract: The present study "Characterization and Reuse avenues of BOF Slag as a flux material in sinter" are focused on waste utilization for a sustainable growth and development. In an integrated steel plant, approximately 2-4 tonnes of wastes (including solid, liquid and gas) are generated for every tonne of steel produced. Among all the wastes, slag generated at iron making and steel making units are a key area of concern. With increasing capacities, the mechanism for disposal of large quantities of slag that get generated have gained traction as the environmental issues that it could evoke could become critical for steel makers. Over the last few years, with better understanding process there is a significant reduction in the volume of slag generated. However, slag generation remains inevitable and emphasis on its recycling remains one of the most serious concerns that need to be solved. Blast furnace granulated slag is a glassy aggregate and used as raw material for pozzolanic cement. But BOF granulated slag is crystalline and less glassy phase compared to BF slag, so 100 % utilization as pozzalanic cement manufacture is limited. Hence, alternate reuse avenues are under study at research or implementation level. The present topic is selected to study the reuse avenues of BOF Slag as a flux material in sinter.

Keywords: Aggregate, BOF/LD Slag, Sintering, Granulation, Recyclable Material, etc.

INTRODUCTION

Industrialization in the name of growth has loaded tremendous pressure on the environment. Industrialization & environment in independent India tried to run hand to hand. But knowingly or unknowingly, industrialization ran faster without caring for the environment to win the race. In these days, the disposal of industrial waste or by-products has become more complicated and expensive as a result of the increasing environmental standards and shortages of suitable disposal locations. In the consideration of conserving and extending the resources of quality natural raw materials and increase in environmental awareness, attention is now being focused on the recycling of industrial waste streams or byproducts (Kalyoncu et al., 1999). Reuse of waste in integrated steel plants is important with regard to environmental and economic consideration.

Integrated steel plants generate large amounts of solid wastes which are mainly blasted furnace and steel furnace slags, dust, sludges, mill scales, used refractories, etc. Studies and research on metal and waste recycling have shown that as a result of slag processing and usage in different applications, massive stoke piles of such wastes are disappearing and the land occupied by these by-products and waste streams can be reclaimed for other purposes (Zunkel and Schmitt, 1996). These wastes contain some valuable resources and elements such as iron, zinc, lead, calcium, etc., which can be recovered and reused within steel-making process or can be used as raw materials elsewhere (Shen and Forssberg, 2003; Proctor et al., 2000).

Slag is a combined product of unwanted gangue minerals of ore and flux minerals resulting from the separation of a metal from its ore. Its chemistry and morphology depend on the metal being produced and the solidification process used.

Granulated blast furnace granulated slag (250-400 kg/tHM) mostly used as a primary raw material for Portland slag cement. BOF slag (90 to110kg/ton of crude steel) principal uses include: Blending with many other products such as granulated slag, fly ash and lime to form pavement material and skid resistant asphalt aggregate, rail ballast asphaltic concrete aggregate, soil conditioner, hard stand areas and unconfined construction fill.

MATERIAL & METHODS

The present study focus used as a flux in iron ore sintering. The BOF slag collected from one of the integrated steel plants of Kalinganagar Industrial complex, Duburi, Odisha. Approximately 10 to 12 tonnes of dry slag is generated in each heat. This slag is tapped to a metallic pot from where it is sent to slag granulation unit. Hot slag is sprayed with high speed water jet where hot slag is converted into slag granules and some portions remained as lumpy slag. The shape and size of Lumpy and granulated slag sample collected is given in figure 1 & 2.

Characterization and analysis of BOF slag samples are done by utilizing various physico-chemical methods. The different phases present in powder samples were investigated by X-ray diffraction using an X-ray Diffractometer (Phillips, PW3710) using Ni-filtered CuK_{α} radiation at a scan speed of 2° min^{-1}.
The chemical composition of BOF slag was analyzed by XRF (Phillips, Axios 4 kW). The major components like CaO, MgO, Al2O3, FeO, and SiO2 were cross checked by wet chemical methods (Vogel 1978) for comparison. The hardness of BOF slag was measured by Mohr's scale.

Physical Appearance: Lumpy BOF Slag

Figure 1: Image of BOF slag in Lumpy Form

The Mohr' Scale of Hardness of Lumpy BOF slag remains between 6 (Orthoclase) and 7 (Quartz). Bulk specific gravity is 2.98. The sizes of lumpy BOF slag vary from 10mm to 100mm.

Physical Appearance: Granulated BOF Slag

Figure 2: Image of Granulated BOF slag

Table 1: Chemical Composition of BOF SLAG (%)

CaO	MgO	SiO_2	FeO	MnO	P_2O_5	TiO_2	Cr_2O_3	SO_3	BASICITY-1	BASICITY-2
48.48	6.84	14.14	24.59	2.45	1.89	0.84	0.124	0.099	3.43	3.91

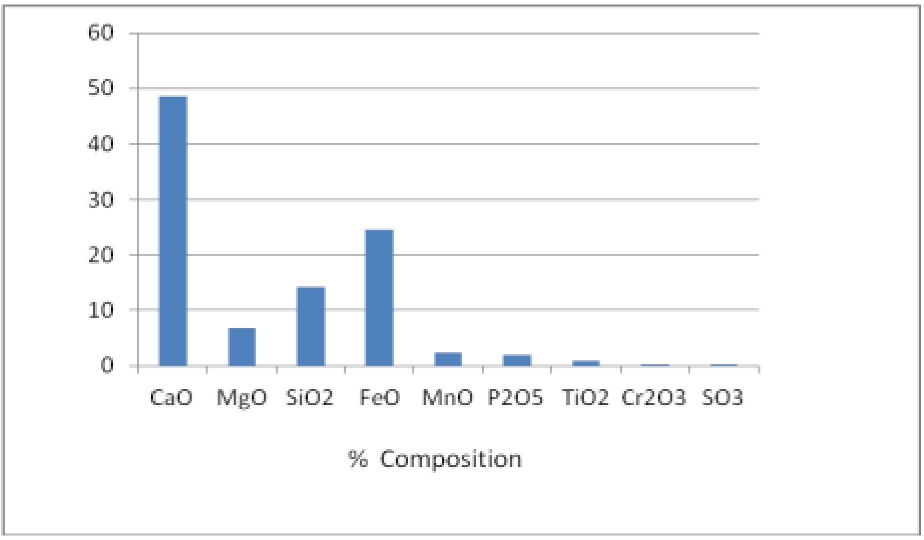

Figure 3: Bar Chart of Composition of Granulated BOF Slag

From the above table and figure it is found that the main chemical constituents of the BOF slag are CaO, FeO, and SiO2. During the conversion of molten iron into steel, a percentage of the iron (Fe) in the hot metal cannot be recovered into the steel produced. This oxidized iron is observed in the chemical composition of the BOF slag. Depending on the efficiency of the furnace, the iron oxide (FeO/Fe2O3) content of BOF slag is 24.59 %; i.e. this is the amount of oxidized iron that cannot be recovered during the conversion of molten iron into steel. The silica (SiO2) content of BOF slag 14.14 %. The MgO content is 6.84 %. The free lime content (CaO – SiO2) is 30.34 %. Large quantities of lime or dolomotic lime are utilized during the process of conversion from iron to steel so that the impurities like silicon, phosphorous, sulphur, etc form a stable bond with CaO and MgO in slag phase.

XRD Pattern of BOF Slag

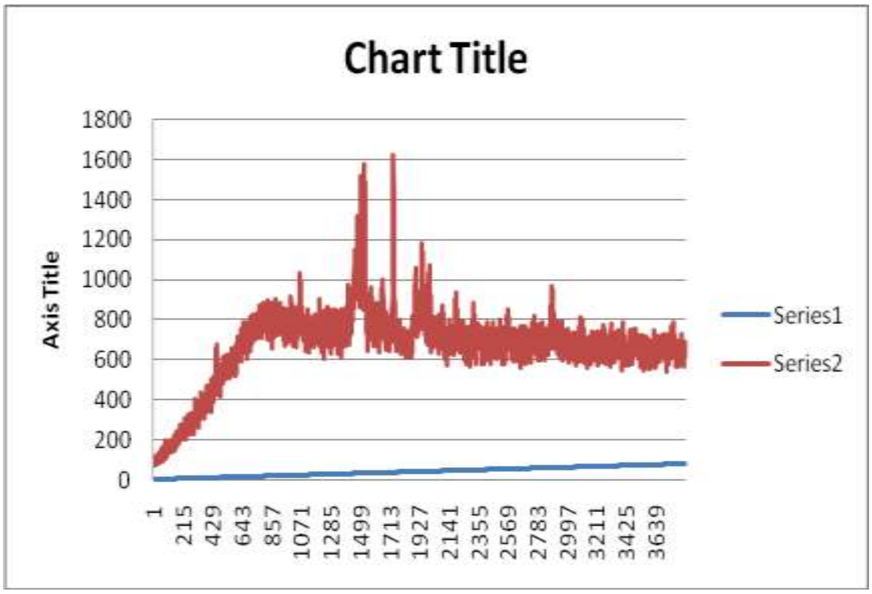

Figure 4: XRD Analysis of BOF Slag

Table 2: Identified XRD Peaks

No.	2-theta(deg)	ESD	d	ESD	Height(cps)	Identification
1	18.1917	0.370661	4.87253	0.096469	62.67	Larnite Ca2SiO4
2	32.1976	0.03445	2.77784	0.00289	240.44	Calcite (manganoan) (Ca, Mn)CO3
3	32.5118	0.039234	2.75171	0.003227	308.15	Merwinite Ca3Mg(SiO4)2
4	33.0439	0.023153	2.70861	0.001844	476.43	Wollastonite CaSiO3
5	33.5185	0.01663	2.67133	0.001287	643.49	Portlandite Ca(OH)2
6	36.1543	0.055975	2.4824	0.003709	166.78	Monticellite CaMgSiO4
7	37.7214	0.016063	2.38279	0.000977	586.28	Srebrodol'skite Ca2Fe2O5
8	40.8397	0.032754	2.20776	0.001694	200.33	Pentahydrite MgSO4·5H2O
9	41.8433	0.035273	2.1571	0.001735	257.35	Lime CaO
10	42.966	0.023776	2.1033	0.001108	261.62	Dolomite CaMg(CO3)2
11	60.7266	0.050197	1.52386	0.001138	188.52	Magnesite MgCO3

The various phases of slag detected under XRD are Larnite Ca2SiO4, Calcite (manganoan) (Ca, Mn)CO3, Merwinite Ca3Mg(SiO4)2, Wollastonite CaSiO3, Portlandite Ca(OH)2, Monticellite CaMgSiO4, Srebrodol'skite Ca2Fe2O5, Pentahydrite MgSO4·5H2O, Lime CaO, Dolomite CaMg(CO3)2 and Magnesite MgCO3. Sinter is produced in pilot scale using the base mix as per table 3. The product sinter properties are given in table 3.

Table 3: Sinter Chemistry Vs SPC of RM

Sintering Material Chemistry								Specific Consumption (kg/ton sinter)		
Sintering Materials	MC (%)	T.Fe %	CaO %	MgO %	SiO2 %	Al2O3 %	P %	Sp. Cons Sinter RM with BOF Slag	Sp. Cons Sinter RM without BOF Slag	Difference (kg/TGS)
IOF	6.01	63.00	0.00	0.00	1.90	1.80	0.090	940	943	3
COKE B	4.04	0.53	0.18	0.07	8.50	5.84	0.030	75	77	2
L/S	1	0.90	53.00	2.82	0.60	0.45	0.020	29	34	5
DOLO	1	0.52	29.53	19.00	4.00	0.73	0.020	84	87	2
BOF Slag	8	17.11	48.00	8.00	12.00	1.50	0.856	10	0	-10
Sand	5	1.00	0.00	0.00	80.00	7.00	0.020	9	10	1
Sinter Chemistry		59.61	5.83	2.21	4.04	2.78	0.096	FeO: 10.42 %, Basicity 1.44, TI 71.20%, AI 6.52%, RDI 29.32%, RI 68.20%		

Results and Discussions: Using 10 kg/ton gross sinter tangible savings in specific consumption of sintering raw materials e.g. 3 kg Iron ore fines, 2 kg coke breeze, 5kg lime stone fines, 2 dolomite fines and 1 kg sand. Due to negligible Al2O3 content in BOF slag, the detrimental effect of alumina is ruled out in blast furnace process.

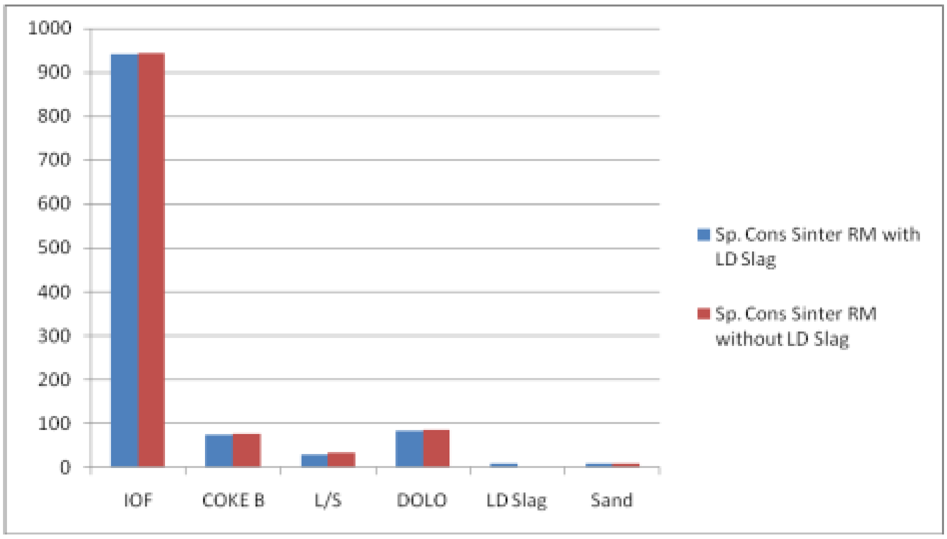

Figure 5: Specific Consumption of Sinter Raw Material

Impact Analysis of SPC of BOF Slag on P % of Sinter and Hot metal

With the help of theoretical modeling of Sinter charge mix (SPC – BOF slag 20, 30 &40) and BF burden, the phosphorous content in product sinter and hot metal is calculated.

Table 5: SPC of BOF slag Vs P % in Sinter and Hot Metal

SPC of BOF Slag per ton of Sinter	P % in the sinter	P % in Hot metal
0	0.083	0.142
10	0.092	0.152
20	0.100	0.162
30	0.109	0.181
40	0.117	0.193
50	0.126	0.206
60	0.134	0.218

From the above, it is evident that with an increase in specific consumption of BOF slag in agglomerates of sinter, not only the P increase in sinter but also in hot metal. The same is also inferred in the figure6.

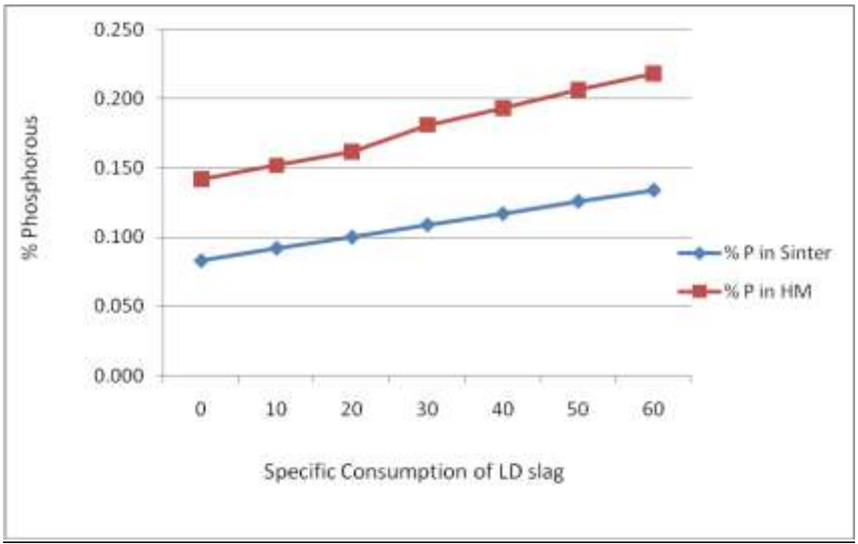

Figure 6: P percentage in sinter Vs P percentage in hot metal

The linear equation to be fitted to the curve for Phosphorous in sinter is

$y = mx + c$

Where y = P % in sinter

x = specific consumption of BOF slag

m = slope of the line for P% in sinter

c = y intercept (for sintering raw material the value is 0.083)

The same liner equation also applicable for P % in hot metal, where c value is 0.142

The cycle of Concentration:

Use of 10 kg/ton BOF slag in sinter, maximum seven cycles sinter can accommodate the BOF slag at the P % in hot metal at the desired level. This model is based on the existing level of Phosphorous load in other raw materials.

Table 5: COC of P in Sinter, Hot metal, and BOF slag

COC	P % IN Sinter	P% Hot metal	P % of BOF slag
1	0.1035	0.172	0.878
2	0.1046	0.175	1.003
3	0.1048	0.176	1.020
4	0.1060	0.177	1.026
5	0.1070	0.178	1.030
6	0.1080	0.180	1.039
7	0.1090	0.204	1.057

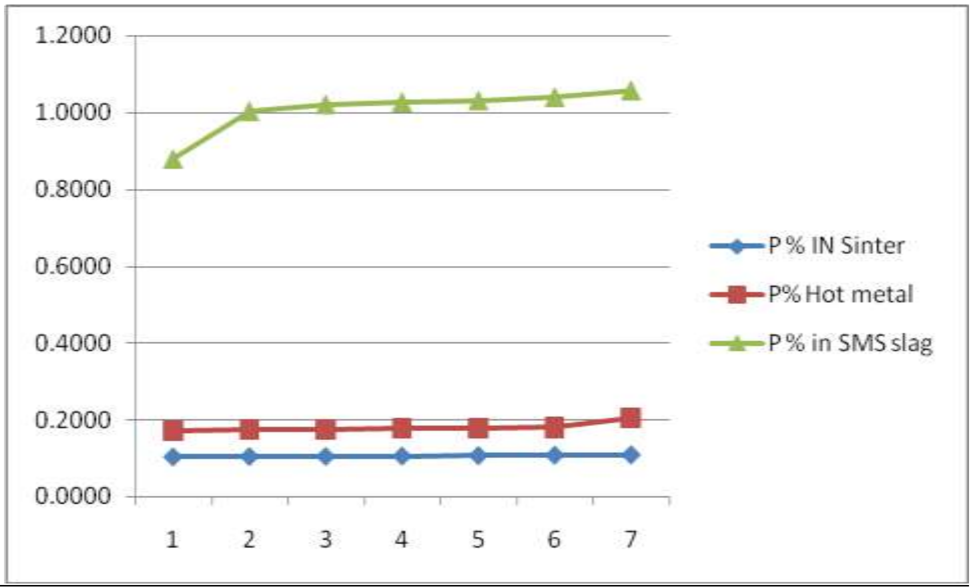

Figure 7: COC of P in Sinter, Hot metal, and BOF slag

CONCLUSION

Origination of the slag during the steel production is inevitable and cannot be prevented. Use of BOF slag as an additive to the blast furnace charge is restricted due to its high P2O5 content. However, due to its high metallic value (FeO %) and lime content (CaO), it is possible to use in iron ore sintering to replace lime and recover iron. Due to negligible Al2O3 content in BOF slag, the detrimental effect of alumina is ruled out in blast furnace process. The present study indicates upto 10 % utilization in sintering is accommodated without affecting sinter and hot metal chemistry in batch type. Batch type use is possible for seven cycle of concentration and higher cycle use is detrimental due to rise in phosphorous content in hot metal. Approximately 10 % of generated BOF slag is utilized and some tangible benefit in term of flux & iron ore is noticed. On the contrary due to high Mohr' Scale of Hardness of Lumpy BOF slag (6 – Orthoclase and 7-Quartz) the BOF slag may be utilized as aggregates.

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