

Solid Waste Management in Steel Industry - Challenges and Opportunities

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Abstract—Solid waste management in steel industry is broadly classified in “4 Rs” i.e. reduce, reuse, recycle and restore the materials. Reuse and recycling the entire solid waste generated in the process of steel making is a viable solution in targeting a clean, green and zero waste technology leading to sustainable development of the steel industry. Solid waste management has gained importance in steel industry in view of its uncertainty, volatility and speculation due to world competitive standards, rising input costs, scarcity of raw materials and solid waste generated like in other sectors. The challenges that the steel Industry faces today are the requirement of a sustainable development by meeting the needs of our present generation without compromising the ability of future generations. Technologies are developed not only for gainful utilization of solid wastes in manufacture of conventional products but also for conversion of same in to completely new products.

Keywords—Reuse, recycle, solid waste, sustainable development.

I. INTRODUCTION

STEEL is manufactured from iron ore mostly using blast furnace (BF) and basic oxygen furnace (BOF) and using electric arc furnace (EAF) in case of manufactured from scrap materials. Molten iron is produced in BF in presence of coke and molten steel is produced in BOF in presence of oxygen [2]. Smelting and refining process involves carbon reduction in BF to produce molten iron and decarburization of molten iron to produce molten steel. After BF and BOF process molten steel is controlled to a target composition and temperature for processing into continuous casting machine to produce slabs, billets etc. Finally the castings are rolled to the required dimensions in the rolling mill to get finished steel product [6].

Source of solid wastes generated in steel industries is thus coke oven by product plant, sinter plant, refractory materials plant, blast furnace, basic oxygen furnace, steel melting shop, rolling mill. The types of solid wastes in steel industry are mainly classified as coke and coal dust, BF slag, SMS slag, mill scale, scrap, oil sludge, fly ash, acid sludge, refractory wastes etc [2]. Dumping solid waste in open space and excavated land creates environmental pollution in the form of dusts and leachate apart from huge financial liability. Moreover available land is also scarce now-a-days for dumping the solid waste due to alarming growth in human

population. A major thrust therefore needs to be given on the scope of reuse of these solid wastes. Presently the production of solid wastes per ton of production of steel is 1.2 ton in India compared to 0.55 ton of that practicing in abroad due to inferior quality of raw materials used. Out of total solid wastes generated in the steel plant in our country 63% are dumped which needs to be recycled or reused to target a zero solid waste as being done in many developed countries.

II. STEEL MANUFACTURING

In the conventional integrated steel manufacturing process, the iron from the blast furnace is converted to steel in a basic oxygen furnace (BOF). Blowing oxygen through molten pig iron lowers the carbon content of the alloy and changes it into steel. Steel can also be made in an electric arc furnace (EAF) from scrap steel and, in some cases, from direct reduced iron. In this process steel scrap along with fluxes (e.g., limestone and/or dolomite) are heated to a liquid state by means of an electric current. During the melting process the fluxes combine with non-metallic scrap components and steel incompatible elements to form the liquid slag. As the slag has a lower density than steel, it floats on top of the molten bath of steel. The liquid slag is tapped at temperatures around 1600 °C and allowed to slowly air-cool forming crystalline slag. Refining of the crude steel is done before casting and the various operations are normally carried out in ladles. As a result, Alloying agents are added, dissolved gases in the steel are lowered and impurities are removed or altered chemically to ensure that high-quality steel is produced after casting. The continuous casting operation produces billets, beam blanks, and near-net shape profiles. These semi-finished products are utilized in the rolling mills to produce structural shapes.

A typical flowsheet of materials in Steel making is shown in Fig. 1. The chemical composition of Steel slags from different furnaces is also presented in Table I.

From Table I, it is observed that the steel slag from EAF for the production of carbon steels is very similar to that from BOF. However, the slag from EAF for the production of alloy or stainless steels is quite different. It has a lower FeO content and a very high content of Cr, which leads to classifying the slag as a hazardous waste [15]. It is also evident that the Ladle furnace slag yields maximum amount of Alumina (Al₂O₃) compared to others, which can be reused commercially.

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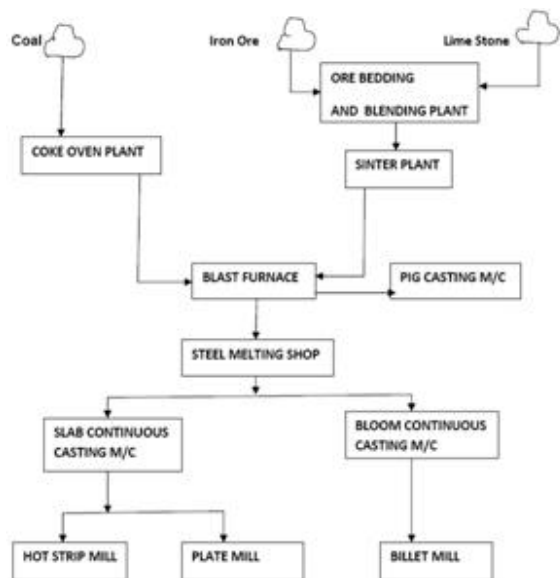


Fig. 1 Flow of materials in steel making

TABLE I
CHEMICAL COMPOSITION OF STEEL SLAGS FROM DIFFERENT FURNACES

Components	B.O.F (%)	E.A.F(For carbon steel)	E.A.F(For alloy stainless steel) (%)	Ladle (%)
SO ₂	8-20	9-20	24-32	2-35
Al ₂ O ₃	1-6	2-9	3-7.5	5-35
FeO	10-35	15-30	1-6	0.1-15
CaO	30-55	35-60	39-45	30-60
MgO	5-15	5-15	8-15	1-10
MnO	2-8	3-8	0.4-2	0-5
TiO ₂	0.4-2	not available	not available	not available
S	0.06-0.15	0.08-0.2	0.1-0.3	0.1-1
P	0.2-2	0.01-0.25	0.01-0.07	0.1-0.4
Cr	0.1-0.5	0.1-1	0.1-20	0-0.5

III. GENERAL MODES OF SOLID WASTES GENERATION

The solid wastes generated in steel industry can be broadly divided into two categories i.e., ferruginous wastes and non ferruginous wastes. The ferruginous wastes, i.e. the iron bearing wastes are generated from steel making viz., mill scale, flue dust, sludges from Gas cleaning plants of Blast Furnaces and Steel Melting Shops, Blast furnace slag and SMS slag. The non ferruginous wastes are lime fines, broken refractory bricks, broken fire clay bricks, acetylene plant sludge etc. A list of solid wastes along with their source of generation is depicted in Table II. The chemical composition of various categories of solid wastes is also presented in Table III.

Blast furnace flue dust and electric earth furnace dust are mixture of oxides and coke fines. It also contains silicon, calcium, magnesium and some undesirable elements like zinc, lead and alkali metals.

Rolling Mill sludge is mainly contaminated with oils and inorganic particles. Dry slag exhibits stable performance, small density, high strength and high temperature endurance, making it suitable as concrete aggregate.

TABLE II

LIST OF SOLID WASTES WITH THEIR SOURCE OF GENERATION	
Sub Processes (Sources of solid waste generation)	Solid wastes
Coke oven and by product plant.	Coke and coal dust, tar sludge, sulphur muck, acid sludge, refractory waste
Lime plant	Lime fines
Sinter Plant	Sludge
RMP	ESP dust, lime fines
BF	Slag flue dust, sludge, refractory waste
SMS	LD slag, GCP sludge, refractory wastes
Rolling mill	Mill scale, scrap, oil sludge

TABLE III

LIST OF SOLID WASTES WITH THEIR CHEMICAL COMPOSITION	
Solid Wastes	Chemical Composition
BF Slag	Fe=46-52%, CaO=22-30%, MgO=4-10%, MnO=2-6% & SiO ₂ =26-31%
SMS Slag	FeO=18-21%, SiO ₂ =16-18%, CaO=47-53%
SMS Sludge	C=2-13%, SiO ₂ = 2.1%, Fe=51.8%, MgO=2%, S=0.21%, CaO=12.8%.
Mill scale	Mixture of iron oxides
Used refractory fire clay brick	CaO, Al ₂ O ₃ , Fe ₂ O ₃ , MgO

IV. REUSE POTENTIAL OF SOLID WASTE

The major solid waste in steel industry i.e. blast furnace slags are used for the manufacture of cement, road base, railroad ballast, light weight concrete block, glass and artificial rock, high performance concrete admixtures. EAF steel making slag can be modified to use in cement making operations [1], [5]. Basic oxygen furnace slag has high fluxing capacity and is being charged in the blast furnace due to easy melt and better utilization of calcium values. Suitable EAF slag generated at SMP can be effectively utilized for filling the low lying areas. Segregated refractories at the source of generation can be used as constituents in manufacture of new bricks/mortars [7], [10]-[12], [19].

Recycled iron and steel scrap is a vital raw material for the production of new steel products requiring much less energy than the production of iron or steel products from iron ore [8]. Blast furnace flue dust and electric arc furnace dust after extracting zinc and other metals can be used as a source of lime and phosphorous in fertilizers. Total scrap generated from rolling mills is either recycled or sold. High capacity Steel Plants can install captive cement plants for the utilization of BF Slag. The SMS Slag with particle size up to 5 mm is being charged into Sinter Plant replacing equal amount of flux. The roads are being repaired by the LD slag having 5-10 mm and 10 - 40 mm particle size. Besides, LD slag with 20-65 mm particle size is being spread in railway track replacing conventional stone ballast. The rejected refractory bricks are used for pavement making. Fly ash can be used in the cement plant for making PPC and for making fly ash bricks for building constructions [8], [9].

V. STATE-OF-THE-ART TECHNIQUES IN SOLID WASTE MANAGEMENT

Improved separation of the constituents in the oily sludge can be obtained using microwave technology and specially

developed oil release agents. Research is presently focused on investigating the partial replacement of clinker with EAF slag for production of slag cement. Molten slag is converted to small round balls, which is later used as a blasting material or in cement admixtures. Vitriified tiles can be prepared with the slags generated from EAF and SMP03 [3]. Recycling of ladle slag as a source for lime is also being carried out. The dry slag products have been widely used in concrete roads, floors and blocks, cement admixture, new fossil cotton products etc. Steel slag has made great progress in the application of composite admixture, dry-mix mortar and so on. The application of steel slag works as a low cost and high allowable bearing pressure. Steel slag as floor materials gives resistance higher than that of ordinary aggregate concrete. Some of the steel slag is recycled to the blast furnace while a major portion is used in road construction (e.g. asphaltic or unbound layer) because of its very high stability, superior skid and high wear resistance [1].

Fly ashes are widely used in project backfilling, road engineering, concrete or mortar projects, bricks and insulating materials. The grinded ash and compound ash have become the essential components of the pump concrete because of its excellent flow ability and low hydration heat.

The technology of making magnesia-carbon brick into renewable raw materials and the recycling technology of quartz sand are the latest technologies in the area of usage of refractory wastes. The converter slag contains substantial amount of lime and iron. This slag is crushed and screened at a separate place. The fines fractions are sent to sinter plant, which is then used in sinter making to replace limestone. The lump fraction is sent to blast furnace and is charged to the furnace as a replacement of limestone. Production of Ground Granulated BF slag (GGBFS) and Air cooled BF slag aggregates for construction industry are the promising avenues for enhancing the BF slag utilization. Oxi-cup is a very good process in which the waste generation can be minimized as low as to zero level. This process is based on self-reducing agglomerates containing iron oxide fines and carbon in the form of brick. These bricks are made up ESP dust, skulls/rubble, iron ore fines, coal fines, processed sags, mill scale sludge, mill scale, flue dust ESP. dust, sponge iron fines, bag filter dust which are charged into a shaft type furnace called Oxi-cup for smelting to deliver sustainable hot metal to EAF/BOF shop [14].

VI. APPROACH TO A SUSTAINABLE AND BEST MANAGEMENT PRACTICES

Compared to the developed countries, slag generation rates at developing countries' Steel Plants are comparatively higher mainly due to inherent adverse quality of raw materials like high ash in coal, high alumina and silica in iron ore etc. Efforts should be made to reduce coke ash percentage by judicious blending of different indigenous and imported coals and increased use of washed low alumina Iron Ore in Sinter Plant and in Blast Furnaces, so as to reduce the metallurgical slags from the process units [4]. Coke rate can also be reduced by introducing Coal Dust Injection (CDI) and Coal Tar

Injection (CTI) system in BF which in turn reduces BF slag. Furnace operating parameters need to be optimized and improved for reducing the coke rate ensuring 100% screened iron ore and sinter. High top pressure and oxygen enrichment in BF is to be introduced for minimizing the slag waste in BF. Ore beneficiation plant also needs to be installed for reducing the gangue content in the raw materials. The spillages on roads during transportation, is the main problem with recycling of sludge. Installation of in-house slag granulation facilities in Blast furnaces may solve the problem of slag solidification and facilitate 100% slag granulation [13], [16]-[18].

There is an opportunity for reducing wastes by optimizing charging practices, reducing furnace heat time, and optimizing operating cycles through the operation of EAF. Formation of scales can be avoided by controlling proper atmosphere and soaking time in the reheat and annealing furnace. Excess slag volume and iron losses in the blast furnace, BOF and EAF can be avoided by proper control of limes, silicon and sulphur. Slag processors should be developed in the vicinity to handle a variety of materials such as steel slag, ladle slag, pit slag, and used refractory material to recover steel metallics. Cast house slag granulation plant may be installed in all furnaces ensuring 100% granulation for full utilization of the granulated slag in cement plant. Magnesia-Carbon spent refractories can be used as slag conditioner in electric arc furnace steel making or as a patching material for the eroded portion of BOF lining (charge pad). Although most steel slag can be used up as asphalt concrete aggregates in many countries, in Indian scenario the best use of steel slag should be considered for use as a cementing component from technical, economical, and environmental aspects.

VII. CONCLUSION

With growing shortages of energy and materials and to keep up with Environmental Legislation and Regulations and The Economies of Disposal in the present scenario, solid waste should be treated as one of the potential resources in the steel industry. Most economic management practices in steel industry of developing countries for minimizing the generation of solid wastes and maximizing the recycle of collected wastes can be opted in the following ways:

- A waste audit should be done to define sources, quantities and types of solid wastes generated from different sub-processes including hazardous wastes.
- Reasons of generating these solid wastes to be found out
- An advanced technology with economical feasibility options for minimizing wastage of resources to be evaluated.
- Should strive to make improvements in yield losses.
- To treat the waste as raw material of related industry on the base of avoiding secondary pollution.
- To build up series of integrated utilization programs, from the industry system technologies and products systems.
- To develop technology focused competitive products based on deep processing of wastes and by-products.

A zero waste approach should be considered viewing solid wastes as potential raw materials to be conserved or reused

instead of wasted. The extent of solid waste reduction, reuse, recycling and restoration to make a zero waste generation is really a challenge to the steel industry today.

ACKNOWLEDGMENTS

The authors would like to acknowledge their sincere thanks to Miss. Arpita Dasgupta, PhD (Scholar), IIT (Mumbai) for her dedicated assistance in carrying out the present research work.

REFERENCES

- [1] Chaurand Perrine, Rose Jerome, Briois Val'erie, Olivi Luca, Hazemann Jean-Louis, Proux Olivier, Domas Jérémie and Bottero Jean-Yves (2006), "Environmental impacts of steel slag reused in road construction: A crystallographic and molecular (XANES) approach", *Journal of Hazardous Materials*, pp.1-6.
- [2] Chkravarty T. K. and Panigrahi S. K. (1996), "Strategies for solid waste management in SAIL steel plants", *Proceedings: NS-EWM*, pp. 52-62.
- [3] Das. S. K., Kumar Sanay and Ramachandrarao P. (2000), "Exploitation of iron ore tailing for the development of ceramic tiles", *Waste management*, 20, pp. 725-729.
- [4] Frosch Robert A. and Gallopoulos Nicholas E (1989), "Strategies for Manufacturing", *Scientific American*, 261, pp.144-152.
- [5] Geiseler J. (1996), "Use of steel works slag in Europe", *Waste management*, Vol 16, pp 59-63.
- [6] International Seminar on Waste Management in Iron and Steel Industry jointly organized by SAIL and IIPE, 9-10 May' 2008, pp 1-192.
- [7] Kumar Sanjay, Kumar Rakesh and Bandopadhyay Amitava (2006), "Innovative methodologies for the utilisation of wastes from metallurgical and allied industries", *Conservation and recycling*, 48, pp. 301-314.
- [8] Makkonen Hannu Tapani, Heino Jyrki, Laitila Leena, Hiltunen Aimo, Poylio Esko and Harkki Jouko (2002), "Optimisation of steel plant recycling in Finland: dusts, scales and sludge", *Conservation and recycling*, 35, pp.77-84.
- [9] Metin E, Erozturk A and Neyim C. (2003) "Solid waste management practices and review of recovery and recycling operations in Turkey", *Waste management*, 23, pp.425-432.
- [10] Pappu Asokan, Saxena Mohini and Asolekar Shyam R (2007), "Solid wastes generation in India and their recycling potential in building material, *Building and Environment*", 42, pp.2311-2320.
- [11] Papayianni I and Anastasiou E, "Utilization of electric arc furnace steel slags in concrete products", pp.1-18
- [12] Perrinea Chaurand, Jeromea Rose, Jean-Yvesa Bottero and Jérémieb Domas, "Environmental impact of BOF steel slag reused in road construction: a crystallographic approach", pp.1-80.
- [13] Pires Ana, Martinho Graça and Chang Ni-Bin (2011), "Solid waste management in European countries: A review of systems analysis techniques", *Journal of Environment management*, 92, pp.1033-1050
- [14] Ramakrishna Konduru R. and Viraraghavan, (1997), "Use of slag for dye removal", *Waste Management*, Vol. 17, pp. 483-488.
- [15] Shi Caijun, (2004), "Steel Slag—Its Production, Processing, Characteristics, and Cementitious Properties", *Journal of materials in civil engineering*, ASCE, 16, pp.230-236.
- [16] Trend in Solid Waste Management: Issues, Challenges and Opportunities, International Consultative Meeting on Expanding Waste Management Services in Developing Countries, 18-19 March 2010 Tokyo, Japan, pp. 1-22.
- [17] Viswanathan P. V and Gangdharan T. K. (1996), "Environmental and waste management in iron and steel industry, *Proceedings: NS-EWM*, pp. 199-207.
- [18] Waste management in China: Issues and Recommendations (2005) Urban development working papers, East Asia Infrastructure department World Bank, Working paper no. 9, pp. 1-156.
- [19] Xuequan Wu, Hong Zhu, Xinkai Hou and Husen Li (1999), "Study on steel slag and fly ash composite Portland cement", *Cement and concrete research*, 29, pp. 1103-1106.

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