Analysis of Induction Furnace Slag of Ferrous Foundry

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Abstract— In process of cast iron and ductile iron production, secondary raw material and industrial wastes are formed. The most abundant waste originating in the process is induction furnace slag. Slags are compounds of oxides of metal & nonmetallic elements which form chemical compounds and solutions with each other and also contain small volume of metals, sulfides of metal and gases. This slag is disposed off the factory floor due to which land contamination takes place which decrease fertility of soil. Induction furnace slag contain about 10-15% metal. Most of industries prefer to ignore this precious metal. The paper presents analysis of induction furnace slag of ferrous foundry at Jadhao Steel Alloys.

Key words: Furnace Slag of Ferrous, Slag Utilization, Electric Induction Furnace

I. Introduction

India is the world's second largest producer of castings and also one of the top 10 in terms of average production per plant. Ferrous foundries generate a large amount of waste. The Indian foundry produces around 6 million ton of castings annually. The slag produced annually is around 1.7 million, it is estimated around 5000 foundries are operating all over India. All foundries produce castings by pouring molten metal into molds, typically consisting of core and molding sands. Once the casting has cooled and hardened, it is separated from the mold and core materials in the shakeout process. The castings are cleaned, inspected, and then shipped for delivery. During the cast iron production large amount of waste is generated which is hazardous to the environment. This waste is store at place near industry in which loading, unloading and transportation cost is involved. To avoid this utilization of waste is very important.

II. Literature review

Andrews et al. [1] discussed that the application of ferrous slag as aggregate, road bed materials, soil fertility conditioner and as clinker materials depend on their chemical and mineralogical characteristics. In order to assess the possibilities of using ferrous slag generated in Ghana, selected slag samples from some foundries have been characterized. A total of six bulk samples were collected from three different foundry shops to determine their chemical and mineralogical composition. The slag samples showed varied chemical and mineralogical characteristics. Differences are as a result of the differences in furnace charge, operation temperatures, grades of refractory furnace lining and melting additives. Calcium oxide (CaO) contents observed in all investigated samples were in combined form (i.e. not free CaO). The low amounts of calcium oxide in the slag samples limit their applications in the area of cement/aggregate production. Even though slag were found to be alkaline, for these slag to effectively neutralize the acidity of soil and improve its fertility, components such as CaO, SiO_2, MgO and FeO in the slag must be improved. However, these slags could be used as road bed materials.

M.H. Joulazadeh and F. Joulazadeh [2] discussed that slag is a non-metallic co-product, produced in the iron (BF) and steelmaking (BOF and EAF) process. Slag has been commonly utilized on a broad scale ever since these processes were first taken into use. Besides economic benefits, environmental requirements will enhance the need for further product development work concerning the properties of slag in the future, in order to observe the principle of sustainable development. Today, one of the important indicators of sustainable steel industry is quantity of slag (production) and its utilization. This paper discuss the utilization of slag in different fields such as cement, heat and sound isolation, filtration, agriculture, tile and glass production and explain some of important researches in last 35 years which done in Esfahan Steel Co. (ESCo) of Iran. From resources and energy saving and CO2 emissions view points; BF slag is an efficient material for cement and isolation industry. Research and long term experience have demonstrated that concrete made with ground granulated slag shows many advantages, such as better workability, resistance to alkali-silica reaction and sulphate attack. Ground granulated BFslag typically replaces 50% of Portland cement in a concrete mix. That replacing Portland cement with slag cement in concrete can save up to 59% of the embodied carbon dioxide emissions and 42% of the embodied energy required to manufacture concrete and its constituent materials. BF slag is a source of alumina and silica in glass and tile manufacturing. Air cooled BF slag is an ideal filter medium in the treatment and subsequent recycling of water and waste water. The agricultural BF slag product is as an economical alternative to agricultural limestone or dolomite, a better source of materials to apply. It is revealed that use of basic slag as a source of lime will be very much effective to increase as well as to sustain the productivity of acid soils. Slag has been shown to be an effective phosphorous removal media at fish hatcheries**.** Slag is beautiful things not waste material.

Natalia Quijorna et al. [3] discussed that foundry sand and Waelz slag have been used to replace clay in the production of red clay bricks. These are both problematic wastes in Northern Spain that are currently landfilled. A semi-scale industrial trial incorporating 20–40 weight percent additions to bricks has been completed. Trial samples have been compared with control bricks containing no waste additions. The physico-chemical, mechanical and environmental properties have been evaluated. Incorporating Waelz slag and foundry sand in the mix allows the production of more resource efficient, lower cost bricks. Performance benefits included improved extrusion properties during forming, lower water absorption of the sintered brick due to reduced connected porosity, significant reductions in CO_2 and NO_2 emissions during firing and improvements in potential leachability of some pollutants in relation to samples containing only Waelz slag or foundry sand. However, it is necessary to limit the addition of Waelz slag to less than 30 wt.% in order to meet regulatory leaching limits for Mo. Other physico-chemical and mechanical parameters were not significantly affected by the addition of these industrial by-products.

P. A. Bhosale et al. [4] discussed that the study is carried out to evaluate slag heat content and if utilized in recovery to save energy in terms of coke consumption as slag heat content has never been used before to recover the energy contained in it. Special technique to measure specific heat, which is function of temperature is developed and used to verify the standard values and used for theoretical analysis. Paper further reveals the various experimental studies that have been set forth for evaluation of energy conservation and are tested, the results of which (for sample foundry) are for reference. The waste heat potential of sample foundry is 609120 KJ/day, increase in efficiency is 16.06%, increased metal production is 1.602 ton/day, and increase in metal melting rate is 216 Kg/hr. This data is further used to re-estimation of energy conservation. The paperwork concludes that by recovering waste heat, Cupola efficiency can be improved thereby saving heat energy. In SME's, Cupola and induction furnaces are used with duplex operations. Energy losses are due to Cupola operations and are investigated for energy conservation. Various experimental studies have been set forth for evaluation of energy conservation and are tested, the results of which are (for sample foundry) for reference. The waste heat potential is 609120 KJ/day, increase in efficiency is 16.06%, increased metal production is 1.602 ton/day, and increase in metal melting rate is 216 Kg/hr. There is around 238 million ton as estimated slag production in India, which contain slag enthalpy of 1.6 GJ/ton, its heat value of 1.5 TWh/year. Such large amount of slag heat can be recycled and reused in furnace itself, thereby increasing the efficiency of furnace. Total slag produced leads to waste heat recovery of 2070,000 million KJ, $5671x10^6$ KJ per hour, converted into terms of oil; this rate is $5.671x\ x10^6$ kg/hr. So that for energy conservation, the slag heat recovery is essential in Indian foundry sector. Thus there is large potential of energy conservation with slag heat reuse. The energy conserved is energy produced.

D. Baricováa et al. [5] discussed that in process of pig iron and cast iron production secondary raw materials and industrial wastes are formed. The most abundant secondary product originating in these processes are furnace slag. Blast furnace slag and cupola furnace slag originates from melting of gangue parts of metal bearing materials, slag forming additions and coke ash. In general, slags are compounds of oxides of metallic and non-metallic elements, which form chemical compounds and solutions with each other and also contain small volume of metals, sulfides of metals and gases. Chemical, mineralogical and physical properties of slag determinate their utilization in different fields of industry. The paper presents results from the research of the blast furnace and cupola furnace slag utilization in the concrete production. Pilot experiments of the concrete production were performed, by that the blast furnace and cupola furnace slag with a fractions of 0–4mm, 4–8mm, 8–16mm were used as a natural substitute. A cupola furnace slag and combination of the blast furnace and cupola furnace slag were used in the experiments. The analysis results show that such concretes are suitable for less demanding applications. In semi-operational experiments, the possibilities of utilization of blast-furnace and cupola slag in concrete production as a substitution of natural aggregate were examined. For semi-operational experiments, various ratios of this slag were combined. It results from the measured mechanical properties that such concretes do not suit for much stressed road concretes, but they are suitable for common grades of concretes. They are plain concretes with volume mass of 2,000 - 2,400 $kg.m^3$. It is possible to use these concretes for building of base or leveling layers, foundations of structures, core parts of framed structures, etc

G. S. Patange et al. [6] discussed that ferrous foundries generate lots of amount of waste. India is the world's second largest producer of castings and also one of the top 10 in terms of average production per plant, but our share of the global market is below 2 percent. It is estimated around 5000 Foundries are operating all over India. Many Indian foundries have not implemented new environmental conscious technology because they are not aware the source of wastes in their foundry and intensity of wastes. The objective of this paper is to investigate foundry wastes for implementation of cleaner production in foundry particularly for MSEs (Micro and Small enterprise) to sustain the environment for Indian foundries. There is a tremendous scope for these foundries to use the high quality raw material for reduce the solid waste and also use the various devices like Filters, Cyclones, Mechanical Collectors, Scrubbers to enhance the awareness in relation with cleaner production idea. There is a lack of economical information for many recent techniques. There is need of awareness with this regard towards moving for sustainable development.

James E. Vondracek RMT Inc.[7],discussed that the foundry industry is a major recycler of waste materials (scrap metal). Unfortunately, the recycling of these materials can result in the generation of hazardous wastes. This article focuses on two potentially hazardous waste types in the ferrous foundry industry - calcium carbide desulfurization slag (potentially reactive) and melt emission control residuals (potentially EP toxic). An overview is given on how foundries have evaluated different waste management options. The ultimate goal is to minimize the amount and degree of hazardous wastes generated while reducing the cost of managing these wastes. In the production of ductile iron, it is often necessary to add a desulfurizing agent in the melt because the input (charge) materials contain excessive amounts of sulfur. One desulfurization agent commonly used is solid calcium carbide (CaC2). Based on investigations by Talballa et al. (1976), calcium carbide is thought to decompose to calcium and graphite. The calcium then reacts with sulfur to form calcium sulfide (Cas). The calcium carbide desulfurization slag Ps generally removed from the molten iron in the ladle and placed into a hopper. For adequate sulfur removal, calcium carbide must be added in slight excess. Therefore, the slag contains both Cas and CaC2.

III. Methodology

A. *Electric Induction Furnace:*

In Jadhao steels & alloys electric induction furnace is used for cast iron/ductile iron production.

The electric induction furnace is a type of melting furnace that uses electric currents to melt metal. Induction furnaces are ideal for melting and alloying a wide variety of metals with minimum melt losses, however, little refining of the metal is possible. An electric induction furnace requires an electric coil to produce the charge. This heating coil is eventually replaced. The crucible in which the metal is placed is made of stronger materials that can resist the required heat, and the electric coil itself cooled by a water system so that it does not overheat or melt. The induction furnace can range in size, from a small furnace used for very precise alloys only about a kilogram in weight to a much larger furnaces made to mass produce clean metal for many different applications. The advantage of the induction furnace is a clean, energy-efficient and well-controllable melting process compared to most other means of metal melting. Foundries use this type of furnace and now also more iron foundries are replacing cupolas with induction furnaces to melt cast iron, as the former emit lots of dust and other pollutants.

– Capacity : 500kg
– Power : 250kw
– Voltage : 1600-1700v

Fig. 1: Induction Furnace

B. *Slag:*

Slag: During the operation of electric induction melting furnaces, non-metallic are produced from the various sources such as scrap, dirt of runner & riser etc. Depending on the specific process being used and the type of iron or steel being melted the composition of slag will vary. The composition of furnace & ladle slags is often very complex. The slag that form in electrical furnace melting are the results of complex reactions between silica, iron oxide from steel scrap, other oxidation by products from melting, and reactions with refractory linings. The resulting slag will consists of complex liquid phase. Slag contains Al_2O_3, MgO, SiO_2, Fe_2O_3, CaO & MnO.

No. of heat	Weight of CI (kg)	Slag produced (kg)
1	650	12.5
12 per day	7800	144.6
312 per month	16900	3133
3744 per year	202800	37596

Table 1: Production of Slag

Fig. 2: Slag

IV. Objectives

(1) To Study existing system of slag utilization at Jadhao Steel & Alloys.
(2) Collect industrial data for slag utilization in steel industries.
(3) To separate metal from slag of induction furnace to increase the productivity.
(4) Analysis of metal contain in slag to decrease cost require for raw material.
(5) Estimate cost of metal to overcome losses.
(6) Use of remaining slag in red clay brick industry.

V. Conclusion

It is been observed that the production of induction furnace slag is 37.5 ton/year. Such a large amount of induction furnace slag is considered as waste. Slag contain small amount of metal and there is no arrangement for beneficial reuse, disposal, treatment and handling. Today, the protection of Earth’s resource endowments and ecosystems adds to the incentive for recovering metals after use. Inefficient use of metals increases reliance on primary source. This slag can be crushed in crusher and by using plate type magnetic separator metal can be separated. Metal contain in slag can be reuse in furnace itself so that cost of raw material decreases and remaining slag can be used in red clay bricks manufacturing. So, there is tremendous scope for these foundries to use method of extracting metal from induction furnace slag which can be recycled and reuse in industry for various purpose. Thus, Total utilization of waste is the beginning of journey towards green revolution.

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