Research Paper

STUDY OF IRON AND STEEL SLAG AS A PRODUCT WITH RESPECT TO PHYSICAL-CHEMICAL PROPERTIES

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ABSTRACT—

This paper review the generation of slag from an integrated steel plant; focusing on, slag generated in blast furnace during process of iron making and through EAF / BOF during process of steel making .The slag generated from BF and EAF/BOF are having different characteristic. The different type of slag having different chemical and physical properties, this depends on the chemical properties of input raw material charged in process of iron/steel making and this slag used in different process as raw material. Blast Furnace slag production ranges from about 220 to 370 kilograms per metric ton of pig iron produced; although lower grade ores may yield much higher slag fractions. Steel making process in electric arc furnaces generates up to 15 % of slag, which is, based on its properties, classified as non-hazardous waste. Disposal of such material requires large surfaces and it is rather unfavorable in economic terms.

KEY WORDS: Blast furnace, Electric arc furnace, Oxides, Slag.

INTRODUCTION

Slag is the glass-like by-product left over after a desired metal has been separated (i.e, smelted) from its raw ore. Slag is usually a mixture of metal oxides and silicon dioxide. However, slags can contain metal sulfides and elemental metals. While slags are generally used to remove waste in metal smelting, they can also serve other purposes, such as assisting in the temperature control of the smelting, and minimizing any re-oxidation of the final liquid metal product before the molten metal is removed from the furnace and used to make solid metal[19].

Steel making process in electric arc furnaces generates up to 15 % of slag per ton of steel. Major components of steel mill slag include Ca-silicates, Ca-Al-ferrites, and molten oxides of calcium, iron, magnesium, and manganese. The composition of slag varies upon the type of furnace and charge, the desired grade of steel purity and the furnace operation conditions. Materials to be added to the steel melt directly before the end of the reheating process are not fully embedded in the slag structure, so they can be found in the slag as "free" oxides (CaO, MgO). Compared to blast furnace slag, steelmaking slag shows a considerably higher content of iron, manganese, and magnesium along with the lower silicon content i.e. higher CaO/ SiO2 ratio, and, finally, it contains almost no sulphur at all. Steel mill slag has more weight, higher hardness and density; it is less porous and highly resistant to polishing and wear and as such is very suitable for road building [13].

Slag, the by-product of steel and iron producing processes, has been used in civil engineering for more than 100 years. Rapidly water-cooled Blast Furnace Slag, due to its relative high amorphous silica content which has pozzolanic activities*, is to be employed in the production of blended cement. Even there are some research works about the properties of concrete, in which air-cooled and ground granulated BFS is used as aggregate. The inclusions of these studies indicate that there is a great likelihood to use BFS instead of natural aggregate in concrete. Despite BFS, air-cooled Electric Arc Furnace Slag, has no pozzolanic activity. But it has been widely employed as aggregate, mainly in base, sub-base and bituminous pavement for road construction, in which steel slag provides many advantages in comparison with natural aggregates [4]. ASTM C33 gives specifications for the use of blast furnace slag as aggregates in concrete, while there is not such a standard for steel slag [4].

POZZOLANS and POZZOLANIC ACTIVITY:

The pozzolanic reaction is the chemical reaction that occurs in portland cement containing pozzolans.

A pozzolan is an siliceous or siliceous and aluminous material which, in itself, possesses little or no cementitious value but which will, in finely divided form and in the presence of water, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties (ASTM C618).[1]

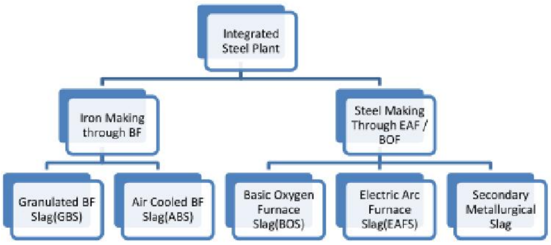
The pozzolanic activity is a measure for the degree of reaction over time or the reaction rate between pozzolan and Ca2+ or Ca(OH)2 in the presence of water[25].

HISTORICAL BACK GROUND OF SLAG

Iron and steel slags have a long history of being utilized as industrial by-products. The material itself is as old as the production of iron by humans (sometime after 2000 B.C.), although the large number of applications is a recent development. The earliest reports on the use of slag refer to the Greek physician Aristotle who stated that slag can be used as medicine (e.g. for curing wounds) as early as 350 B.C. During the following centuries, slag has been used for different purposes including cast cannon balls in Germany (1589), wharf buildings in England (1652) and roads made from slag were first built in England in 1813. The latent hydraulic activity of ground granulated blast furnace slag i.e., its cementitious properties when in contact with water, was discovered by Emil Langen in 1862 and started a new era for using slag. However, the applications were quite sporadic. It was not until the early twentieth century, when the use of slag became usual and large quantities of slag began to be used for number of purposes[23].

By the year 1880, blocks cast of Slag were in general use for street paving in both Europe and the United States. A major city under the American Flag with a long history of Slag-paved streets is San Juan, Puerto Rico. Perhaps the earliest appearance of Slag in American history came with the Pilgrims. Since Slag was commonly used as ship ballast in that era, it seems likely that the Mayflower itself carried a load of this useful material [22].

TYPES OF SLAG



The slag generated during iron making from BF and Steel making from BOF/EAF are classified as BF Slag and Steel slag:

MANUFACTURING/GENERATION PROCESS

A. Blast furnace

Blast furnace slag is recovered by melting separation from blast furnaces that produce molten pig iron. It consists of non-ferrous components contained in the iron ore together with limestone as an auxiliary materials and ash from coke. Approximately 290 kg of slag is generated for each ton of pig iron. When it is ejected from a blast furnace, the slag is molten at a temperature of approximately 1,500℃. Depending on the cooling method used, it is classified either as air-cooled slag or granulated slag [17].

Air-cooled slag

The molten slag flows into a cooling yard, where it is cooled slowly by natural cooling and by spraying with water. This results in a crystalline, rock-like air-cooled slag [17].

Granulated slag

The molten slag is cooled rapidly by jets of pressurized water, resulting in a vitreous, granulated slag [17].

B. Steelmaking slag

This slag is a byproduct from steelmaking processes in which the components of pig iron and steel-scrap are modified in order to produce steel that is so highly valued for excellent toughness and workability.

Steelmaking slag consists of converter slag that is generated by converter and electric arc furnace slag that is generated during the electric arc furnace steelmaking process that uses steel-scrap as the raw material [17].

Converter slag

In the same way as air-cooled blast furnace slag, converter slag is cooled slowly by natural cooling and water spray in a cooling yard. It is then processed and used for various iron and steel slag (converter) applications. Approximately 110 kg of slag is generated for each ton of converter steel [17].

Electric arc furnace slag

Electric arc furnace slag is generated when iron scrap is melted and refined. It consists of oxidizing slag that is generated during oxidation refining, and reducing slag that is generated during reduction refining [17].

PROPERTIES OF SLAG

Blast furnace slag is chemically and mineralogically as consistent as naturally occurring aggregates, comprising primarily the silicates and aluminosilicates of calcium and magnesium together with other compounds of sulfur, iron, manganese and other trace elements. In terms of its mineralogy, BFS is usually melilite (solid solution series of gehlenite, **2CaO**.Al2O3.SiO2, and akermanite, 2CaO.MgO.2SiO2) with a small amount of calcium sulphide (oldhamite) <1%. Sometimes merwinite (3CaO.MgO.2SiO2) is also present and more rarely dicalcium silicate 2CaO.SiO2 [20].

EAF steel slag is a strong, dense, none porous aggregate that is cubical in shape, has good resistance to polishing and has an excellent affinity to bitumen. This makes it an ideal aggregate for asphalt surface course materials and road surface treatments as it produces materials that are resistant to deformation (rutting), safe and durable [21].

COMPARISON OF PROPERTIES

Table1: Typical compositional ranges of iron slag, steel slag and Portland cement

	Constituent	Blast furnace slag [11]	Blast furnace slag [20]	Steel Slag[11]	Steel Slag [7]	Steel Slag [8]	Steel Slag [9]	Portland cement [24]
		wt. %						
Calcium	CaO	35 - 42	41	35 - 45	42	30.8	33.2	60-67
Silica	SiO2	33 - 38	35	11-17	17.2	18.2	10.08	17-15
Aluminium	Al2O3	10 - 15	14	1-6	7.1	9.8	1.66	3-8
Magnesium	MgO	7 - 12	7	2-9	7.2	8.5	13.09	0.5 - 4.0
Iron	FeO	≤ 1,0	--	16 - 26	17.7	29.7	29.64	0.5-6.0
Manganese	MnO	≤ 1,0	--	2-6	4.3	0.6	6.18	--
Phosphorous	P2O5	-	--	1-2	<1	0.67	--	--
Sulphur	Stotal	1 - 1,5	0.80	≤ 0,2	<1	0.05	--	2.0-3.5
Chromium	Cr2O3	≤ 0,1	--	0,5 - 2	< 1	--	--	---

The brief idea from above table can be laid down as :

- We can see that BF slag mainly constitute of same silicates and aluminates and where as chemistry differs with Portland cement.
- Approx. CaO in BF Slag is 50 % of CaO in Portland cement.
- So, BF slag is an option to use as raw material for cement industries as low cost substitute.
- On the other hand, in EAF slag we find Iron Oxide content is much higher as compared with Portland cement. Some literature reported that, if iron could be lowered by one or the other method/s, can be use in cement making and more suitable than BF slag because of high basicity.

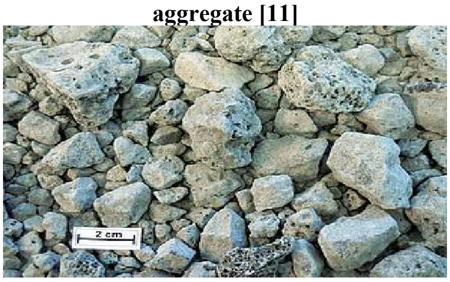
Table2: Some properties of iron and steel slag aggregates compared to natural rocks [11]:

Property	Blast furnace slag	Steel slag	Basalt	Greywacke
bulk density (g/cm^3)	2,4	3,6	3,0	2,7
compressive strength (N/mm^2)	100	200	300	200
impact value (%)	27	17	17	20
resistance to polishing (PSV)	50	57	50	56
water absorption (%)	2	1	<0.5	<0.5
resistance to freeze/thaw (%)	<0.5	<0.5	<0.5	<0.5

MAJOR USES OF BLAST FURNACE SLAG [20]

- Air cooled Blast furnace slag primarily provides quality controlled aggregates for use in construction. It can be used in most applications that would otherwise require the use of natural aggregates.
- The principal applications include aggregates for use in asphalts and surface dressings in accordance with BS EN 13043 and aggregates for use in unbound mixtures, BS EN 13242, covering sub-bases, cappings and fills.
- The hard, stable, vesicular nature of air-cooled blastfurnace slag provides an excellent medium for percolating filter beds in sewage treatment works where its high surface area maximises biological activity.
- The hydraulic self-cementing nature of granulated BFS makes it ideal as a pavior bedding material and also as a slow cementing binder in Slag Bound Materials (SBM) which are increasingly being used as alternative road bases and for surfacing pedestrianised areas.
- BFS also acts as a source of lime, silica and alumina in mineral wool production for thermal insulation.

Picture1: Air-cooled blast furnace slag (ABS), coarse aggregate [11]



Picture2: Granulated blast furnace slag (GBS)

Picture 3: Electric arc furnace slag in hot condition

Picture4: Electric arc furnace slag (EAFS)

MAJOR USES OF STEELMAKING SLAG [6]

- Aggregate in bituminous mixes such as: pavement surfaces, bases, surface treatments, seal coats. slurry coats and cold patch
- Concrete aggregate and as an ingredient in cement
- Anti-skid aggregate (snow and ice control aggregate)
- Surfacing of stabilized shoulders, banks and other select material Bank stabilization (erosion control aggregate) Gabions and riprap.
- Aggregate base courses and sub-bases
- Unpaved driveways, surface roads and walkways Railroad ballast
- Neutralization of mine drainage and industrial discharge
- Agricultural uses, such as soil remineralization and conditioning, pH supplement/liming agent. Fertilizer.
- Landfill daily cover material
- Landscape aggregate
- Trench aggregate/drain fields
- Sand blast grit
- Roofing granules.
- Bulk filler (e.g., paints, plastics, adhesives)
- Mineral wool (home and appliance insulation) Fill

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