International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 8 Issue 08 Series. I || Aug 2019 || PP 69-74

Iron and Steel Slag Utilization: A Comprehensive Analysis

Kabir Malhotra
(Grade 12 Student, Dubai International Academy Emirates Hills, United Arab Emirates)

Abstract :*Steel is the the most important engineering and construction material today. It is used in every aspect of our lives; in cars and construction products, refrigerators and washing machines, cargo ships and surgical scalpels. Although it can be recycled over and over again without loss of property, it has one major drawback: its byproduct, steel slag. Steel slag is produced during the separation of the molten steel from impurities in steel-making furnaces. The slag occurs as a molten liquid melt and is a complex solution of silicates and oxides that solidifies upon cooling. In todays world, steel is a necessity; in 2016 alone, total crude steel production was over 1.6 billion tones. Due to limited modes of practices of utilization, huge amount of steel slag is dumped, engaging important agricultural land and causing grave pollution to the environment. The best management option for this byproduct is by recycling. Physical and chemical characterization of steel slag is a deciding factor of steel slag utilization depending on the properties it can be used as road aggregate, cement and concrete admixture, soil stabilizer, construction materials, etc. This leads to reduction of landfills reserved for its disposal, saving the natural resources and attaining a potential environment. In the paper, I will be reviewing the engineering properties of steel slag and the different ways it can be utilized.*

Keywords:*Steel industry, Steel slag, Iron slag, Blast furnace slag, Cement*

Date of Submission: 05-08-2019 Date of acceptance: 20-08-2019

I. INTRODUCTION

Approximately, 115-180Mt of steel slag is disposed off worldwide every year and in addition to this, previous accumulations have created huge mountains of steel slag. It is estimated that 400 kg of steel slag is produced per ton of steel manufactured. The quantity of slag generated is vast and improper waste disposal creates serious ecological and social problems. Dumping of waste on the open land causes severe environmental impact and associated environmental problems include — lowering of moisture, leaching by water and pollution of nearby water sources, chemical degradation and lack of aesthetics. This report looks into the characteristics of iron/steel slag, slag treatment processes and how it can be utilized in different ways.

II. OVERVIEW OF IRON AND STEEL SLAG

2.1 Iron/steel slag production

Properties of steel slag depends on the type or gray of steel being produced and the furnace used. It is a byproduct of molten iron processing and originates from the gangue in the mineral raw materials such as iron ore, coal, and limestone as well as those in the flux used at steel refining processes to remove Si, P, S, and other impurities. The iron and steel slag that is generated can be broadly categorized into blast furnace and steel making slag.

Blast Furnace Slag:

When iron ore or iron pellets, coke and a flux (limestone/dolomite) are all melted together in a blast furnace, blast furnace slag is formed. Once the metallurgical smelting process is complete, the lime in the flux chemically combined with the aluminates and silicates of the ore and coke ash form a non-metallic product called blast furnace slag. The properties of BFS varies depending on the cooling method used. Air-cooled slag is formed when 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. Granulated slag is formed when the molten slag is cooled rapidly by jets of pressurized water, resulting in a vitreous, granulated slag.

Steel Making Slag:

Steel making 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 highly valued for 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.

2.2 Characteristics of iron/steel slag

The typical compositions of iron/steel slag are shown in figure 1. The exact composition of iron/steel slag varies with the type of furnace used, type of steel grades used and the pre treatment method. Steel and iron slags primary components include limestone (CaO) and silica (SiO2). Blast furnace slag includes alumina (Al2O3), magnesium oxide (MgO), and small quantity of sulfur (S) whereas steelmaking slag contains iron oxide (FeO) and magnesium oxide (MgO).

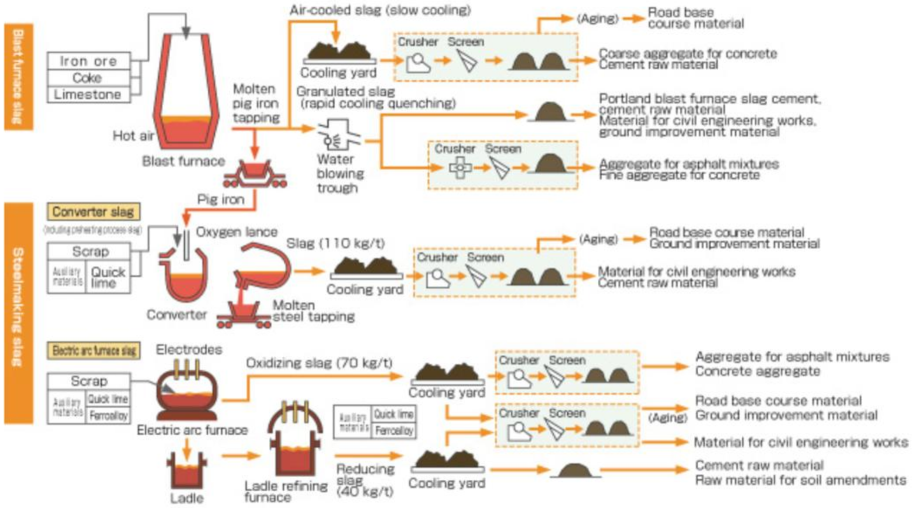
Figure 1. Typical Compositions of iron/steel slag (in %)

Type Component	Blast furnace slag	Converter slag	Electric arc furnace slag	
			Oxidizing slag	Reducing slag
CaO	41.7	45.8	22.8	55.1
SiO_2	33.8	11.0	12.1	18.8
T-Fe	0.4	17.4	29.5	0.3
MgO	7.4	6.5	4.8	7.3
Al_2O_3	13.4	1.9	6.8	16.5
S	0.8	0.06	0.2	0.4
P_2O_5	<0.1	1.7	0.3	0.1
MnO	0.3	5.3	7.9	1.0

III. SLAG TREATMENT PROCESS

The iron/steel slag processing flow is schematically shown in Figure 2. There are 4 major process that steelmaking slag goes through. 1) Cooling and solidifying 2) Crushing and Magnetic separation 3) Crushing and classification for grain size 4) Aging treatment. Furthermore, each process will be explained in detail.

Figure 2. Schematic flow of slag treatment processes



3.1 Cooling and solidifying process

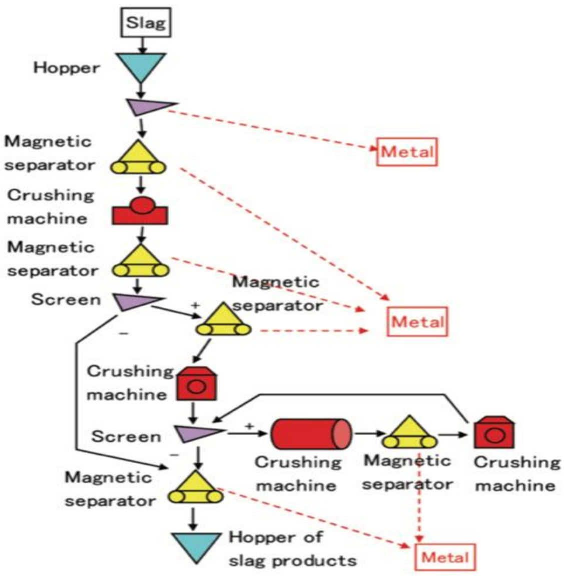
Steelmaking slag is molten (temperature between 1300-1700°C) when formed. Hence, it has to immediately be cooled upon removal from the furnace. Before, this process was performed in a cooling yard by air conditioning and water sprinkling but as this process is time consuming and requires a spacious yard, it is not very efficient. In the recent decades, a number of effective cooling processes have been developed. This includes 1) Air granulation process 2) ISC process 3) Rapid cooling process

- Air granulation process: A high pressure gas is blown onto the molten slag which solidifies and granulates it while it is still being cooled. This process is much quicker and requires a small area relatively.
- ISC process: The molten slag is poured into a steel box in which it solidifies and then subjected to water sprinkling and immersion cooling.
- Rapid cooling process: The molten slag is poured into a special drum in which it is cooled rapidly by sprinkling water over the slag.

3.2 Crushing and Magnetic Separation

Steelmaking slag includes 10% to 40 % iron metal which can be separated for different purposes. Iron can be recovered and used as a substitute for scrap iron, iron can be segregated for effective use of slag for applications where iron would act as an impurity. For these reasons the slag is crushed and iron is recovered by magnetic separation. Figure 3 showcases the multiple times magnetic separation process takes place to increase the metal iron recovery ratio.

Figure 3 Schematic flow of crushing, magnetic separation and classification



3.3 Crushing and Classification

To commercialize the slag it is processed to the grain size specified by the customer. Depending on weather the slag is being used for road aggregate, cement and concrete admixture, soil stabilizer, construction materials, etc. the grain size is specified. As depicted in figure 3, a combination of crushers, magnetic separators and screens are used to meet the characteristics needed.

3.4 Aging treatment

There are two main methods of aging treatment 1) Normal aging treating 2) Accelerated aging treatment. In method 1, the hydration process is is allowed to take place using natural rainfall and in method 2, the hydration process is induced to complete quicker. Accelerated aging treatment include “steam aging treatment” which uses high temperature steam, “hot water aging treatment” which immerses the slag in hot water and “high pressure aging treatment” which causes the slag to react with steam under high pressure.

Figure 4 Primary characteristics and applications of iron and steel slag

		Characteristics	Applications
Blast furnace slag	Air-cooled slag	Hydraulic property	Road base course material
		No alkali-aggregate reaction	Coarse aggregate for concrete
		Low Na_2O and K_2O	Cement clinker raw material (replacement for clay)
		Thermal insulation and sound absorption effects when made into a fiber	Raw material for rock wool
		Fertilizer component (CaO, SiO_2)	Calcium silicate fertilizer
	Granulated slag	Strong latent hydraulic property when finely ground	Raw material for Portland blast furnace slag cement
			Blending material for Portland cement
			Concrete admixtures
		Low Na_2O and K_2O	Raw material for cement clinker (replacement for clay)
		Latent hydraulic property	Material for civil engineering works, ground improvement material (Backfill material, earth cover material, embankment material, road subgrade improvement material, sand compaction material, ground drainage layers, etc.)
		Lightweight, large angle of internal friction, large water permeability	
		Does not contain chlorides.	Fine aggregate for concrete
		No alkali-aggregate reaction	
		Fertilizer component (CaO, SiO_2)	Calcium silicate fertilizer
			Soil improvement
Steelmaking slag	Converter slag, electric arc furnace slag	Hard, wear-resistant	Aggregate for asphalt concrete
		Hydraulic property	Base course material

IV. Effective Utilization Of Steel/Iron Slag

4.1 Blast Furnace Slag Cement

Ground granulated blast furnace slag is grounded finely as that of cement and mixed in the proportion as per the requirement. Different percentage of slag is added depending on the different types of production. Figure 4 showcases proportion of slag percentage for different applications.

Figure 5 Proportion of slag percentage for different applications

Application in Type of Construction	Slag Proportion in %
General construction	20-40
Reduction of heat hydration	50-80
Structures exposed to chloride attack	50-81
Structures exposed to sulfate attack	50-82
Marine structures	60-80

There are a number of uses of blast furnace slag cement:
- It can be used in ready mix concrete plants.
- It can be used for structures meant for water retaining such as retaining wall, rivers, ports, tunnels for improvement in impermeability.
- It can be used in mass concreting works such as dams, foundations which require low heat of hydration.
- It can be used in the places susceptible to chloride and sulphate attacks such as sub-structure, bored piles, pre-case piles and marine structures.

Pros:
- It has high resistance to seawater and to chemicals, and can improve durability.
- It has a low chloride ion diffusion coefficient (resists rebar corrosion).
- It can reduce alkali-aggregate reaction.
- Its strength increases over time.
- It produces little elution of hexavalent chrome when used in ground improvement.

Cons:
- Initial Strength is low, due to this it cannot be used in RCC works.
- As the initial setting time is high, this cement is not used for emergency or repair works.

4.2 Road base course use

BF slag and steelmaking slag can be used to make roads that last long under traffic loads. The slag is spread and impacted beneath the pavement to form road base and thus is utilized in this way. Also, steelmaking slag, especially BOF slag, is hard and durable in wear resistance therefore it can also be used as the aggregate for the asphalt pavement mix. BOF slags most important factor as to why it can be effectively used for road base course is the prevention of expansion which has been faced previously cause of hydration expansion of free CaO.

4.3 Road Pavement use

By controlling the lancet hydraulic property of steel slag, it can be effectively used as a pavement material. The key aspects are to adequately control the mixing ratio and the grain size of granulated BF slag and BOF slag such that the BF slag is stimulated by the alkalinity of the BOF slag and undergoes a pozzolanic reaction and, in parallel, Ca ions supplied from the latter react with carbonate ions in the atmosphere and spray water to form calcium carbonate and harden. This slag product is used for a low grade pavement, whereby granulated BF slag and BOF slag are mixed at a prescribed ratio, spread, and then compacted by rollers with optimum water content; the method is capable of securing the strength required for forest and farm roads, parking areas and the like.

4.4 Ground improvement

The ground in the coastal areas often consists of sedimentation of soft and sticky soil. The sand compaction pile (SCP) method, whereby tightly compacted sand piles are formed into the ground, has been a typical measure to improve this type of unstable ground. In the middle of the 1990s, however, in consideration of the limited sources of natural sand and environmental conservation, use of other materials began to be studied, and the development of methods of using BOF slag for port and marine construction has been encouraged. The effects of the slag on water as well as its physical properties were examined, and the studies confirmed that its use would not lead to a significant increase in the pH of seawater due to the elution of alkaline components, and thus BOF slag was considered adequate as a substitute for natural sand. Therefore, it can be effectively be used for ground improvement.

4.5 Steel slag hydrated matrix

The steel slag hydrated matrix has been developed in the recent years aiming at obtaining a substitute for concrete that causes less environmental loads, not requiring natural materials such as gravel and sand. Ground-granulated BF slag is used as the cementation agent of concrete and BOF slag as the aggregate. It can be used in the same manner as concrete by adding an alkali stimulant to accelerate hardening as required, mixing the materials with water, and pouring into molds to form substitutes for unreinforced concrete blocks, or crushing into random lumps of artificial stone or the like. Since the main binder is the ground-granulated BF slag, as a side effect of the reduction of specific surface area due to lump forming, the dissolution of alkaline components in seawater is limited and the rise in pH is suppressed.

4.6 Improvement technology of dredged soil

More than 20 million cubic meters of dirt and sand are dredged annually from sea bottoms along the coast of Japan; they are mostly used for landfill, or otherwise damped to the sea. In view of the dwindling space for damping and environmental problems, however, the need for their recycling is increasing rapidly. Conversely, decreasing the use of land sand, gravel, and stone for civil engineering work is required. Thus, slag can be used for reforming dredged soft dirt into CaO-improved soil and recycling it as a substitute for natural sand gravel and stone. The process comprises mixing dredged soil and BOF slag, which is prepared through composition control and classification by grain size. The mixture hardens and its strength increases as the silica and alumina in the dredged soil and the free CaO in the slag undergo hydrolysis to form hydrates of calcium silicate and calcium aluminate. The product is expected to be suitable for the work involved in restoring marine environment such as refilling of sea bottom depressions, forming seaweed beds and mounds, etc. The characteristics of the product are as follows: (i) it suppresses the rise of pH, (ii) prevents the formation of phosphorus and sulfur compounds, and (iii) has adequate strength for structural use.

V. Conclusion

In conclusion, it clearly indicates that there is plenty of opportunity for utilization of integrated iron and steel slag. Most of the researchers have explored and focused steel slag potential as natural aggregate replacements for concrete and road construction along with cement manufacturing. It is economical to use the steel slag, as the costs of steel slag are just about 50% of that of conventional aggregates. It was identified from the past researches that the steel slag is heavier than conventional aggregate, having improved friction asphalt mixtures, providing high stability (less rutting) and high angle of internal friction. Thus steel slag, instead of being disposed-off on valuable land, is suggested for use as a low-cost construction material inquality construction.

References

[1]. Awoyera et al. (2015) Influence of Electric Arc Furnace (EAF) Slag Aggregate Sizes on the Workability andDurability of Concrete, International Journal of Engineering and Technology (IJET), Vol 7 No 3 Jun-Jul 2016

[2]. Ahmed Ebrahim Abu El-MaatyBehiry (2013) Evaluation of Steel slag and crushed limestone mixtures as subbase material in flexible pavement, Ain shams Engineering Journal (2013) 4, 43-53.

[3]. Biradar, K. B., kumar, A. U. And Satyanarayana, P.V.V. (2014) Influence of Steel Slag and Fly Ash onStrength Properties of Clayey Soil: A Comparative Study, International Journal of Engineering Trends and

[4]. Technology (IJETT) Volume 14 Number 2 Aug 2014Brindha, D., Baskaran,T, and Nagan,S. (2010) Assessment of Corrosion and Durability Characteristics ofCopper Slag Admixed Concrete, International Journal Of Civil And Structural Engineering, Vol. 1, no.2, pp.192-211.

[5]. Bhagwan, J. and Guru Vittal, U. K.(2014) Use of Marginal Materials for Rural Road Construction - Some Recent Initiatives, Proceedings of Indian Geotechnical Conference IGC-2014 December 18-20, 2014, Kakinada, India.

[6]. Buddhdev, B. G. and Varia, H. R. (2014) Feasibility Study on Application of Blast Furnace Slag in Pavement Concrete, International Journal of Innovative Research in Science, Engineering and Technology, Vol. 3, Issue 3, March 2014

[7]. Bharath, V. S. and Rao, P. R. M. (2015) Study on the Fibre Reinforced Concrete Using Steel Slag as the Coarse Aggregate Replacement, International Journal For Technological Research In Engineering Volume 2, Issue 7, March-2015

[8]. Humaria, M. S. Y. (2014) Impact of Iron and Steel Slag on Crop Cultivation: A Review. Curr World Environ 2014;9(1). Available from: http://www.cwejournal.org/?p=5746,http://dx.doi.org/10.12944/CWE.9.1.31

[9]. CPCB, http://www.cpcb.nic.in/newitems/24.pdf, 31, March 2016

[10]. Chaubey, S. and Ali Jawaid, S. M. (2016) Soil stabilization using steel slag, Global Journal for Research Analysis, Volume-5, Issue-1, January -2016

[11]. Chaudhary, P. N. and Pal, J. (2002) An Overview of Treatment of Steel- Making Slag for Recovery of Lime and Phosphorus Values, http://eprints.nmlindia.org/4220/1/186- 190- PN_chaudhury.PDF - accessed on 22 June 2016

[12]. Chand, S., Paul, B., Kumar, M. (2015) An Overview of Use of Linz-Donawitz (LD) Steel Slag in Agriculture. Curr World Environ 2015;10(3). Doi : http://dx.doi.org/10.12944/CWE.10.3.29

[13]. Chand, S., Paul, B. and Kumar, M. (2016) Sustainable Approaches for LD Slag Waste Management in Steel Industries: A Review, Metallurgist, Vol. 60, Nos. 1 - 2, May, 2016, DOI 10.1007/s11015-016-0261-3

[14]. Das et al. (2007) An overview of utilization of slag and sludge from steel industries, Resources, Conservation and Recycling 50 (2007) 40 – 57, doi:10.1016/j.resconrec.2006.05.008

[15]. Devi, V.S. and Gnanavel, B. K. (2014) Properties of concrete manufactured using steel slag, 12th Global Congress on Manufacturing and Management, GCMM 2014, Procedia Engineering 97 (2014) 95 – 104, doi: 10.1016/j.proeng.2014.12.229

[16]. Dhoble, YogeshNathuji and Ahmed, Sirajuddin, Use of Steel Slag as Engineering Material and Its Limitations (June 18, 2012). CAN2012 Tenth AES-ATEMA International Conference AES- ATEMA' 2012 Tenth International Conference on Advances and

Trends in Engineering Materials and their Applications (Montreal, Canada: June 18 – 22, 2012). Available atSSRN: http://ssrn.com/abstract=2157198

[17]. Deccan Herald (2016) http://www.deccanherald.com/content/418164/now-pwd-use-slag-building.html accessed on 17 May 2019

Kabir Malhotra" Iron and Steel Slag Utilization" International Journal of Engineering Science Invention (IJESI), Vol. 08, No. 08, 2019, PP 69-74