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Steel Slag Utilization in Pavements

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Abstract-India, being the world's second largest steel producer also faces the challenges of safe and gainful disposal of 18.5 million tons of steel slag generated annually in India from various integrated steel plants.The biggest a part of generated metallic slag nevertheless ends on frequently non-regulated landfills as commercial waste in adjacent areas. Disposal of metallic slag as landfills results in severe pollutants to the environment. Steel slag is the major waste product of metallic enterprise and the contemporary usage of metallic slag is much less than 30%, a long way in the back of the advanced countries. The sustainable improvement idea calls for a extra green control of waste substances and renovation of environment. Steel slag may be used probably as a sustainable fabric in creation of pavements as India has global's second biggest street community in phrases of period with a complete street period of 4.24 Million Km. Large scale toll road creation in India, emanating from speedy improvement has brought on large depletion of scarce herbal aggregate.Utilisation of Steel slag aggregates as a substitute of natural aggregate in road construction will reduce the unsustainable quarrying and mining of natural aggregates and will also reduce the emission of Greenhouse Gases associated with road construction activities.This paper gives a top level view on the global usage of metallic slag to clear up this trouble and additionally the essential routes and vital troubles for large-scale usage of metallic slag have been proposed.

Keywords –Steel slag, sustainable development, pavements.

I. INTRODUCTION

Sustainability is a primary focus of 21st century engineering, and therefore, the use of sustainable materials has been investigated for their economic, environmental, and social benefits. Preventing the exhaustion of natural resources and enhancing the usage of waste materials has become a significant problem of the modern world. Accordingly, today the emphasis is on the avoidance of waste generation, recycling and reuse of waste, and minimizing the adverse impact of disposal on the environment. Among all the solid/liquid wastes, slag generated at iron making and steel making units are created in the largest quantities. India is the 3rd largest steel producer in the world with total steel production of 95.6 MT per annum [1]. Steel slag is solid waste which is produced from the further refining of iron in a basic oxygen furnace or from the melting of scrap in an electric arc furnace [2]. Approximately 250-300 kg of slag is produced per ton of pig iron and conversion of pig iron into steel yields further 120-150kg of slag per ton of steel. With increasing capacities, disposal of large quantities of slag becomes a big environmental concern and a critical issue for steel makers [3]. The current utilization of steel slag is less than 30%, far behind the developed countries like United States, Japan, France and Germany of which rates of utilization have been close to 100%. And also India has world's second largest road network in terms of length with a total road length of 4.24 Million Km. Large scale highway construction in India, emanating from rapid development has caused massive depletion of scarce natural aggregate[4]. Therefore improving the rate of utilization of steel slag as an substitute for natural aggregate is an imperative way for the steel enterprise to realize sustainable development. In this paper the research progress of steel slag utilization in pavements is overviewed.

II.PRODUCTION OF SLAG

Extraction of 'iron' from ores is a complex process requiring a number of other materials which are added as flux or catalysts. The major fluxing agent, quicklime combines with the impurities in the iron or steel scrap, mainly silica, to form a mineral complex which separates from the purified steel. After being discharged and cooled,steel slag solidifies to form a rock-like material, which can be processed to replace natural rockin the construction industry [5-7].It consists of silicates and oxides. Modern integrated steel plants produce steel through basic oxygen process. Some steel plants use electric arc furnace smelting to their size. In the case of former using oxygen process, lime (CaO) and dolomite (CaO.Mgo) are charged into the converter or furnace as flux. Lowering the launce, injection of higher pressurized oxygen is accomplished. This oxygen combines with the impurities of the charge which are finally separated. The impurities are silicon, manganese, phosphorous, some liquid iron oxides and gases like CO2 and CO. Combined with lime and dolomite, they form steel slag. At the end of the operation liquid steel is poured into a ladle. The remaining slag in the vessel is transferred to a separate slag pot [8]. For industrial use, different grades of steel are required. With varying grades of steel produced, the resulting slag also assume various characteristics and hence strength properties. Grades of steel are classified from high to medium and low depending on their carbon content. Higher grades of steel have higher carbon contents. Low carbon steel is made by use of greater volume of oxygen so that good amount carbon goes into combination with oxygen in producing CO2 which escapes into atmosphere. This also necessitates use of higher amount of lime and dolomite as flux. These varying quantities of slag known as furnace slag or tap slag, raker slag, synthetic or ladle slag and pit or clean out slag. Fig. 1shows BOF and EAF whereas Fig. 2 presents a flow chart for the operations required in steel and slag making.

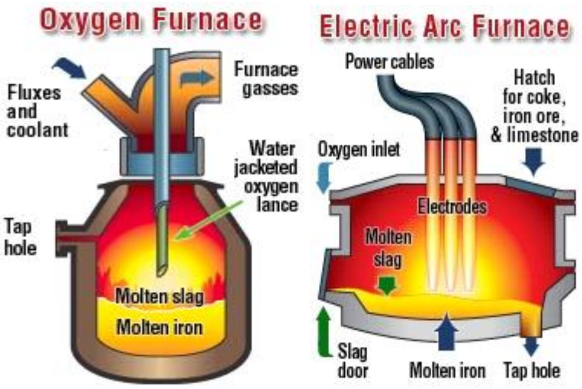


Figure 1. Schematic illustration of Basic Oxygen Furnace and Electric Arc Furnace (NSA accessed, 2008)

The steel slag produced during the primary stage of steel making is known as furnace slag or tap slag which is the major share of the total slag produced in the operation. After the first operation, when molten steel is poured into ladle, additional; flux is charged for further refining. This produces some more slag which is combined with any carryover slag from first operation. It helps the in absorbing of de oxidation products, simultaneously providing heat insulation and protection of ladle refractories. Slag produced on this operation is known as raker and ladle slag.

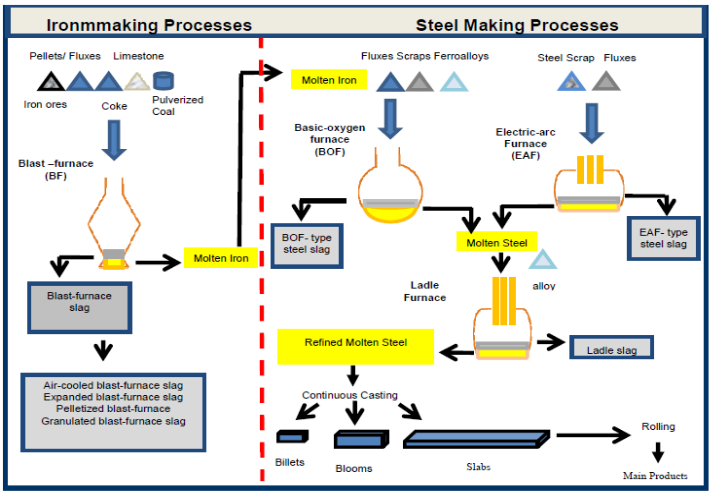
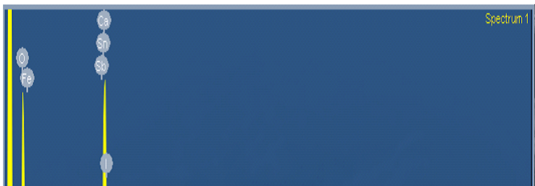


Figure 2. Flow chart of modern integrated steel plant(Source: 9)

III. CHARACTERISTICS OF STEEL SLAG

Steel slag aggregate (SSA) is a byproduct of the production of steel in an electric arc furnace. The high iron oxide content of the aggregate results in an aggregate that is very hard and very dense (SSA is 20-30% heavier than naturally occurring aggregates such as basalt and granite). It also contains a high content of calcium and magnesium oxides, which make it expand when it comes into contact with moisture. It is very angular and porous. Steel Slag is found in the form of big pebbles. It is crystalline in microstructure and non-hydraulic in nature. The microstructure and distribution of steel slag was studied. Microphotographsof the sample are shown in Fig. 3 and Fig. 4. From the figure it can be observed that quartz iron oxide aluminum oxide and various silicates are predominantly present. It is clearly observed that most of the particles are spherical structure with few irregular particles. The surfaces of spherical particles are found to be irregular and round as it is a high calcium steel slag [10].



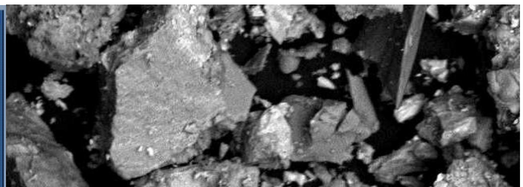


Figure 3.Microscopic pattern of steel slag Figure 4.Microstructure of steel slag

(Source: Evaluation of Strength Characteristics of SSHM by Meena Murmu, pg. 25)

A. *Physical and Mechanical Properties-*

Roads are subjected to static and dynamic forces, including the harsh environment like rain, temperature, freezing and thawing. Steel slag should provide adequate physical and mechanical properties to resist and perform well. The physical and mechanical properties are given as: aggregate impact value, aggregate crushing value, soundness, loss angles abrasion, surface texture, water absorption, specific gravity, stripping, and flakiness. The physical and mechanical properties of steel slag productively meet the requirements of a high class material. Steel slag aggregates (SSA) are highly angular, roughly cubical pieces having flat or elongated shapes. They have many non-interconnected cells which gives a greater surface area than natural aggregates of equal volume; this feature provides an excellent bond with bitumen [11]. As compare to natural aggregate, it provides an ideal durability, permeability, stability and resistance against abrasion, cracking and permanent deformation. Table 2 reports the physical and mechanical properties of aggregates as well as specific test protocol adopted[4].

Table - 1 Physical properties of natural and steel slag aggregates

Properties	Natural aggregates	Steel slag	Specified Limits in MoRTH Specification	Testing Natural Specifications
Bulk specific gravity	2.75	3.06	2.5-3.0	IS 2386 (Part II)
Water absorption (%)	0.70%	0.80%	2% max	IS 2386 (Part III)
Soundness i) Sodium Sulphate ii) Magnesium Sulphate	5.60% 4.80%	4.30% 5.10%	Max.12 % Max 18 %	IS 2386 (Part-V)
Abrasion value (%)	14.23%	12.06%	30 % max	IS 2386 (Part-V)
Aggregate crushing value (%)	19.78	14.67		
Combained Flakiness and Elongation Index (%)	25.20%	8.95%	30% max	IS 2386 (Part I)
Stripping(Retained Coating %)	99.00	99.50	Minimumretained coating 95%	IS 6241

B. Chemical Properties-

The chemical properties of the aggregates vary depending on the furnace, feed stock and slag formers used to produce the steel. The aggregate formed from the slag is comprised of calcium oxide (CaO), silicon oxide (SiO_2), iron oxide (Fe_2O_3), magnesium oxide (MgO), manganese oxide (MnO) and aluminum oxide (Al_2O_3)[12]. The chemical component of steel slag varies with the furnace type, steel grades and penetration method [2]. Table 2 summarizes the chemical composition of BOFS and EAFS [13].The electric arc furnace steel slag has the highest iron oxide content of any of the slags, which accounts for its increased hardness and higher density as compared to the other slags [12]. Use of dolomite instead of lime as a flex, highly influence the chemical composition which provides higher content of MgO [14]

Table - 2Chemical Composition of Steel Slag[13]

Sr.No.	Type of Oxide	BOFS Oxide%	EAFS Oxide%
1	Calcium - CaO	45-60	30-50
2	Silica - SiO_2	10-15	11-20
3	Aluminium - Al_2O_3	1-5	10-18
4	Iron Oxide- Fe_2O_3	3-9	5-6
5	Ferrous Oxide- FeO	7-20	8-22
6	Magnesium - MgO	3-13	8-13
7	Manganese - MnO	2-6	5-10
8	Phosphorous - P_2O_5	1-4	2-5

C. Affinity of Steel Slag with Binder

The aggregate should have affinity with binder to provide an adequate adhesion to the mix design. This property of aggregate having affinity with binders is known as “hydrophobic” and the aggregates which are not having such a property called “hydrophilic”. Steel slags are hydrophobic (strong affinity with binder), basic or alkaline in nature having pH value of around 12. Whereas the bitumen binder normally acidic, having a naturel chemical affinity with steel slags and the pH value of bitumen binder is less than 7. This property of steel slag provides a good adhesion and helps to resist against the stripping. A simple test is conducted by putting the sample into boiling water and the degree of stripping is evaluated [3].

D. Thermal Properties

It has been noticed that steel slag, has a potential to retain the heat as longer than natural aggregate [15]. The heat retention property of steel slag aggregate is an advantage. It helps to prepare hot mix asphalt concrete to coat the aggregates properly specially repairing of pavements surface in cold weather [16].

IV. UTILIZATION IN PAVEMENTS

The physical properties of steel slag aggregate make it a suitable material for road construction where it can be used from the foundation layers to the asphalt surface course[17]. Steel slag, due to its high strength and durability, can be processed to aggregates of high quality comparable with those of natural aggregates. The high bulk density, the high level of strength and abrasion as well as the rough texture qualify steel slag as a road construction material. Also based on high level of strength, high binder adhesion as well as high frictional and abrasion resistance, steel slag can be used as an aggregate not only in surface layers of the pavement but also in unbound bases and subbases, especially in asphaltic surfacelayers [18].

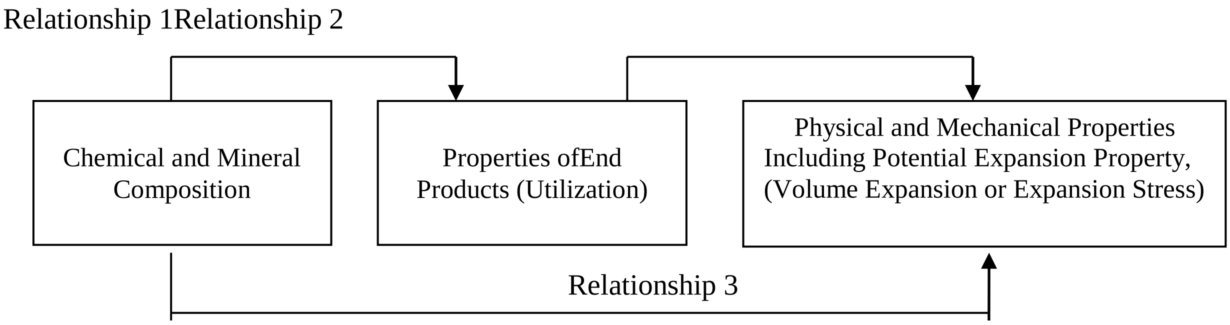


Figure 3. Relationships for Slag Utilization in Highway Construction (Source:19)

To effectively use a slag, it is necessary to know how its chemistry and mineral composition affect any potential negative properties (volume expansion of steel slag for instance) (Relationship 1), and how the negative properties can affect the performanceof the end products (uses) (Relationship 2). Relationship 3 is dependent on Relationships 1 and 2. Relationship 1 determines the necessary treatment modificationof the properties of the specific slag and related quality control. Relationship 2 isessential to enable the slag, with known or modified properties, to be put into use in civilor highway construction. Once Relationship 2 is known quantitatively and

demonstrated, the use becomes viable. Once Relationship 1 is known, suitable Relationship 2 treatment methods, if necessary, can be chosen and then Relationship 3for optimal end uses established [19].

A. Rigid Pavement-

The furnace and welding slags have been utilized in the work by using it in the building materials as addition to concrete. WS and FS concretes showed better performance towards compressive strength. The compressive strength on seventh day of concrete cubes increases from 10% to 15% replacement of sand by WS than the reference materials. Similarly 10% of FS shows an optimum strength of 21.1 N/mm2. The optimum compressive strength of slag concretes has been found to be 41 N/mm2 for 5% WS and 39.7 N/mm2 for 10% FS. The results show that 5% of WS and 10% FS replacement with sand is very effective for practical purpose.[20]Use of slag as an aggregate for high-strength and refractory concrete. Investigation of feasibility of the refractory concrete production using EAFS as aggregates was carried and the results showed that when slag was heated up to a temperature of 1000 °C prior to its use for refractory concrete, the final products exhibited mechanical properties which are comparable to concrete with conventional refractory aggregate, e.g. bauxite[21]. It is also found that the compressive strength of concrete using steel slag as fine aggregates was 1.1 to 1.3 times of common concrete [22]. The research results showed that steel slag concrete exhibited similar fire resistance to the river aggregate mixture up to 400^0, and much improved fire resistance at high-temperature ranges [23].

B. Flexible Pavement-

Based on high level of strength, high binder adhesion as well as high frictional and abrasion resistance, steel slag can be used as an aggregate not only in surface layers of the pavement but also in unbound bases and subbases, especially in asphaltic surface layers [18]. Through the cooperation with major construction companies and their experience in the use of slag combined with mixture studies the conclusions drawn are -mixtures with EAF slag coarse aggregates require smaller percentage of bituminous binder per weight of aggregates -mixtures with EAF slag aggregates and limestone sand can be regarded as the optimum solution by ensuring compliance to the specifications while reducing the percentage of binder and thus being cost effective.[24]The results of the examined geometric, physical, and mechanical and durability properties indicate that thetested EAF slag satisfy the characteristics necessary for their use in asphalt mixtures. The good volume Stability (2.9%) of EAF slag in relation to natural aggregates used in asphalt mixtures on highways and othertop-class traffic load roads showed that examined slag has equally good properties, and can be used in theproduction of asphalt mixtures on test field[25].

C. Geocell-Reinforced Pavement

Based on the findings from various investigators the conclusion canbe made that the provision of geocell reinforcement in the overlying sand layer improves the loadcarrying capacity and reduces the surface heaving of the foundation bed substantially. From the results obtained through limited tests carried out by various investigators it appears that for same quantity of geogrid material, geocellreinforcement system yields better performance improvement than planarreinforcement system [26-28]. Stabilityanalysis of experimental model embankments with respectivemeasured surcharge capacities revealed that this approach is reasonablygood in capturing the effects of the dimensions of a geocelllayer and the secant modulus of the geocell material and inestimating the collapse loads. [29]. The geocell placed in a circular shape had a higher stiffness andbearing capacity of the reinforced base than that placed in anelliptical shape. And the performance of geocell-reinforced bases depended on theelastic modulus of the geocell. The geocell with a higher elasticmodulus had a higher stiffness and bearing capacity of thereinforced base. Type III and Type IV geocells made of the novelpolymeric alloy were found to have significantly higher stiffnessand ultimate bearing capacity than Type I geocell made of HDPE [30].

IV.CONCLUSION

In India the rate of utilization is still very low as compared to the developed countries. Large-scale utilization of steel slag is the only solution to the environmental problems arisen by dumping of steel slag on large valuable land. For steel slag large-scale utilization in India, the author believes that there are two important routs: one is to produce concrete using the steel slag; the second is utilizing slag in construction of pavements. In order to fully realize significant environmental and practical benefits which the use of slag can offer, there is an obvious need to direct more research into this area.

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