Replacement of Natural Coarse Aggregate by Industrial Steel Slag In Road Construction

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Abstract— Due to growing environmental awareness, as well as stricter regulations on managing industrial waste, the world is increasingly turning to researching properties of industrial waste and finding solutions on using its valuable component parts so that those might be used as secondary raw material in other industrial branches. Although steel slag is yet considered a waste and is categorized in industrial waste catalogues in most countries in the world, it is most definitely not waste, neither by its physical and chemical properties not according to data on its use as valuable material for different purposes. Moreover, since the earliest times of the discovery and development of processes of steel and other metals production, slag as by-product and is used for satisfying diverse human needs, from the production of agricultural and agro-technical agents to production of construction elements. This study demonstrates the possibilities of use of industrial steel slag as natural coarse aggregate in the road construction. Considering the specialty of physical and chemical properties of industrial slag and a series of possibilities for its use in road construction as a replacement of natural coarse aggregates.

Keywords — Steel slag, Natural Aggregate, Industry waste, Recycle, Road construction

I. INTRODUCTION

The need to recycle the materials in society today has become more important as the demands on our natural resources continue to grow. Two of the main components of the infrastructure are steel and concrete and this is why these two industries have seen a steady increase in demand over the last thirty to forty years. Concrete is a very versatile building material that is used in nearly every aspect of the infrastructure of developed countries. Concrete is comprised of fine and coarse aggregates, which account for 60 to 70% of the concrete, and the remaining components are water and the cement, which is the binding material that solidifies and holds the mixture together. With such a large portion of concrete being comprised of aggregates, this has put an increasing demand on the limited supply of natural aggregates. The use of the steel slag as a replacement of the natural aggregates in concrete could be beneficial to the environment in many ways. Some of the environmental impacts that could be seen from using the slag in concrete would be a reduction in the amount of landfill, reducing the CO2 produced by equipment during the mining of natural aggregates, and lowering the cost of shipping if there is a steel plant closer to the concrete plant than the location of the natural aggregates. This research focuses on the use of steel slag as a replacement for natural aggregates in concrete pavement applications.

What Is Steel Slag?

Steel slag is a leftover component from the steel making process and is a material that at one time was considered a waste material that was disposed of in landfills. Today steel slag is no longer considered a waste material and is now considered a byproduct from the steel making process that is used in a variety of different ways. During the production of three tons stainless steel around one ton of steel slag is generated. It has been noticed that per year fifty million tons of steel slag is generated from different steel industries throughout the world. Steel slag is a residual material that generates during the production of stainless steel by different resources either from the melting of scrape to produce steel in electric arc furnace (EAF), or by converting iron to steel in basic oxygen furnace (BOF). Hot liquid metal, scrape and fluxes together with lime and dolomite lime processed in basic oxygen furnace. The impurities like carbon monoxide and silicon, manganese, phosphorous and iron in liquid state combines with lime is and dolomite lime are separated by injecting oxygen with high pressure to form steel slag. Electric arc furnace is a kettle shaped arrangement used to process cold steel scrape instead of hot liquid metal. Some other metals like Ferro, alloys are added to balance the required chemical composition of steel and oxygen is blown to purify the steel. At the end, the floating steel slag is separated from the surface of molten steel.

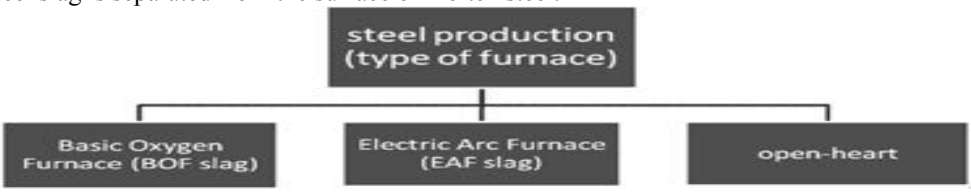

Fig :1 Production of Steel Slag

Chemical constituents of Steel Slag

Generally steel slags consist of CaO, MgO, SiO2 and FeO oxides, which found within the range of about 88% to 90 %. The total concentration of these oxides in liquid slags is in the range of 88%– 92%. Though these oxides fluctuate based on the

material used, type of steel being manufactured and condition of furnace .Use of dolomite instead of lime as a flex, highly influence the chemical composition which provides higher content of MgO. The chemical composition of steel slag is given in Table 1.

Table2: Chemical constituents of Steel Slag

Constituent	*Percentage*	
	Mean	*Range*
Calcium Oxide (CaO)	39	34-43
Silicon Dioxide (SiO_2)	36	27-38
Aluminum Oxide (Al_2O_3)	10	7-12
Magnesium Oxide (MgO)	12	7-15
Sulfur (S)	1.4	1.0-1.9
Manganese Oxide (MnO)	0.44	0.15-0.76
Iron (FeO or Fe_2O_3)	0.5	0.2-1.6
pH	11	10 – 12

Both BOF and EAF slags are dicalciumsilicate, dicalciumferrite and wustite. Dicalciumsilicate provides stability, which prevents disintegration of steel slag. Several studies show that the dissolved lime and MgO does not affect the volume of steel slag, but the excess amount of "spongy free lime" and MgO may cause the volume instability.

II. UTILIZATION OF STEEL SLAG AS A REPLACEMENT OF COARSE AGGREGATE IN ROAD PAVEMENT

Roads are subjected to static and dynamic forces, including the harsh environment like rain, temperature, freezing and thawing. The proposed material should provide adequate physical and mechanical properties to resist and perform well. The physical and mechanical properties are given as: aggregate crushing value, loss angles abrasion, aggregate impact value, soundness, polished stone value, water absorption, surface texture, stripping, specific gravity and flakiness. The physical and mechanical properties of steel slag productively meet the requirements of a high class material. As compare to natural aggregate, it provides an ideal durability, permeability, stability and resistance against abrasion, cracking and permanent deformation. The physical and mechanical properties of steel slag are explained as below. To replace coarse aggregate by the steel slag it very necessary check to the feasibility of steel slag for the construction of road and it can be evaluated by performing various test on slag and comparing it with coarse aggregate and it should also meet to the standard minimum requirement by the codal provision.

Source of steel slag

MIDC Jalna, declared as steel zone in Marathwada region of Maharashtra state. Steel slag was collected from the Kalika steels Pvt. Ltd. Jalna. There are about 43 steel rolling mills and 10 Billet/Ingot mills, producing 60,000 tonnes steel every day. Wasting 20% i.e.12000 tonnes of steel slag. This slag is crushed in crusher; steel is again extracted from the slag, which is held in pores in the slag. About 18% steel slag has been wasted.

Fig.No.2: Steel slag sample collected from Kalika Steels

III. VARIOUS TEST ON NATURAL AGGREGATES AND STEEL SLAG

A. Specific Gravity and water absorption

Steel slag contains sufficient amount of iron oxide, therefore it has greater value of specific gravity as compare to the natural aggregates. Number of researchers has evaluated the specific gravity of other construction materials and that of steel slag fall within the range of 2.6 to 2.8. Steel slag is about 20 % heavier than the lime stone and granite. Here we performed specific gravity and water absorption test on both coarse aggregate and steel slag sample by using IS: 2386-PART-3.

Table:2 Specific gravity and Water absorption of natural coarse aggregate and steel slag

Sr.No.	Description	Natural aggregate	Fine Aggregate
1.	Weight of sample+ vessel+ water (A)	3372gm	3372gm
2.	Weight of vessel and water(B)	2740gm	2748
3.	Weight of saturated surface dry sample(C)	990gm	990gm
4.	Weight of sample after drying it in oven for 24 hrs at 110^0C(AD	982gm	982gm
	Specific Gravity = D/C-(A-B)	**2.74**	**2.68**
	Water Absorption	**0.610%**	**0.503%**

To know the voids in slag, moisture absorption test is carried out as per BIS 2386 Part 3 (1997). Water absorption value of Steel Slag was obtained as similar to natural aggregate. Obtained results are within permissible limit for natural aggregate as well as steel slag aggregate. Hence steel slag shows its feasibility to use as a coarse aggregate on the parameter of specific gravity and water absorption.

B. Impact Test

It is the relative measure of resistance of and steel slag aggregate against the sudden shock or impact. This test imparts the toughness of the aggregates under repetitive loading of the wheels of vehicles running on the roads. Impact test performs on both natural and steel slag aggregate. Weight of empty mould taken for the test is 1.745kg.

Table:3 Impact value of Natural aggregate and steel slag

Sr.no	Description	Natural Aggregate	Steel Slag
1.	Weight of Sample (W1)	0.575kg	0.545kg
2.	Weight sample and including weight of mould	2.320kg	2.290kg
3.	Weight of fraction passing through 2.36mm sieve(W2)	0.06kg	0.095kg
	Impact Value = (W2)/(W1) x100	**10.4%**	**17.43%**

By IS 2386 (Part4)- 1963 Sample passing through 12.5mm and retained on 10mm sieve taken for testing purpose. After the placing of mould filled with sample into the impact testing machine hammer lifted at maximum height and allowed it to fall freely on the aggregates filled in the mould. And similarly 14 numbers of blows are given after which crushed sample sieve through the 2.36mm sieve. Lower the Aggregate impact value (AIV) greater will be the strength of aggregate against the impact loadings. The suitability of coarse aggregate is majorly depending upon this test.

From the obtained result it is clear that natural aggregate shows lower loss than that of the steel slag but it is within maximum allowable impact value given by IS standards for the road construction. Hence steel slag aggregate possesses better toughness against the sudden shocks or impact by hammer.

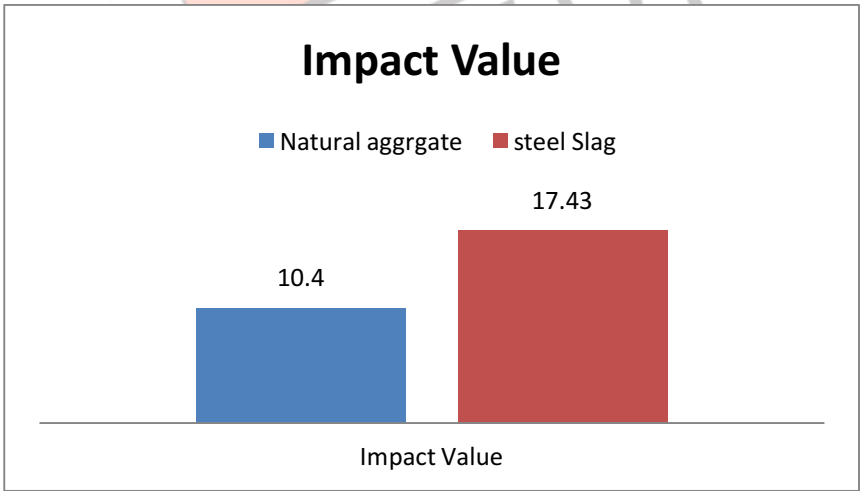

Chart No.1 Impact value of natural and steel slag aggregate

C. Crushing Test

It is the relative measure of resistance of an aggregate against the gradually applied compressive loading. This test deals with strength of aggregates against the gradual increase of load. Weight of empty mould for crushing strength is 10.69kg.

Table No. 4: Crushing value of Natural aggregate and steel slag

Sr.no	Description	Natural Aggregate	Steel Slag
1.	Weight of Sample (W1)	3.49 kg	3.40kg

2.	Weight sample and including weight of mould	14.18kg	14.09kg
3.	Weight of fraction passing through 2.36mm sieve(W2)	0.585kg	0.625kg
	Crushing Value = (W2)/(W1) x100	**16.76%**	**18.38%**

As per IS standards sample passing through 12.5mm and retained on 10mm IS sieve is taken for the test. After filling the mould completely, it is to be placed into compression testing machine and gradual compressive load is applied at a constant rate. After the finishing of test crushed fraction passed through the 2.36mm IS sieve.

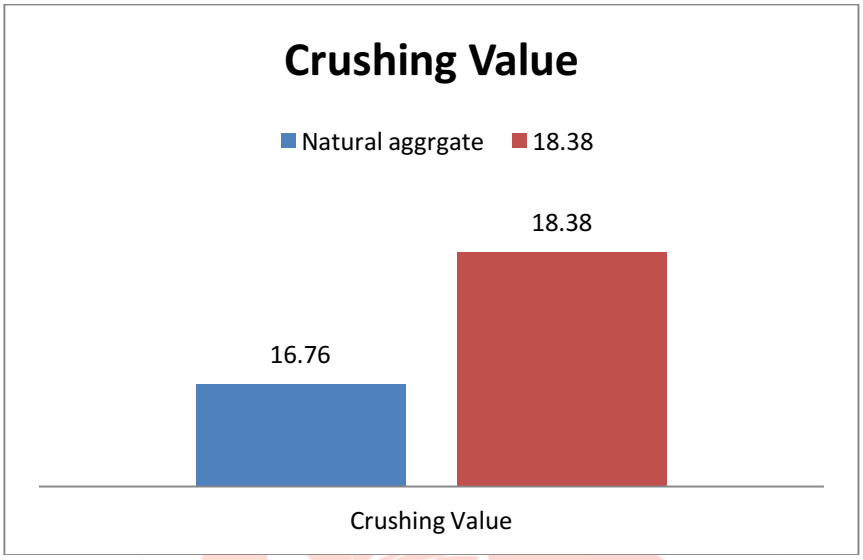

Chart No.2: Crushing value of natural and steel slag aggregate

Above table and chart no.2 it is shows that the steel slag aggregate performs very good against gradual compression load that it is slight lesser than that of natural aggregate taken for the test. Steel slag satisfies the minimum permissible value of crushing strength for wearing surface such as roads and runways.

D. Abrasion Test

It is the relative measure of resistance of an aggregate against wearing and tearing action. This test is conducted to know the wearing of aggregates especially for road construction. This test gives the strength of aggregate under the repetitive loadings or collision of aggregates.

Table:5: Abrasion value of Natural aggregate and steel slag

Sr.no	Description	Natural Aggregate	Steel Slag
1.	Weight of dry Sample taken (W1)	5.00 kg	5.00kg
2.	Weight of fraction retained on 1.70mm IS sieve	4.32kg	4.09kg
3.	Weight of fraction passing through 1.70 mm sieve(W2)	0.680kg	0.91kg
	Abrasion Value = (W2)/(W1) x100	**13.6%**	**18.2%**

Los Angeles abrasion test conducted on both natural aggregates and steel slag aggregates. According to grading table we chosen sample of grading "G" (size 25mm passed and retained on 20mm IS sieve) under which 5000gm for each and corresponding 12 number of abrasive charge (spheres) were added in los Angeles revolving drum and provided 500 revolution for both natural aggregate and steel slag aggregate at the rate of 20 to 30 revolution per minute.

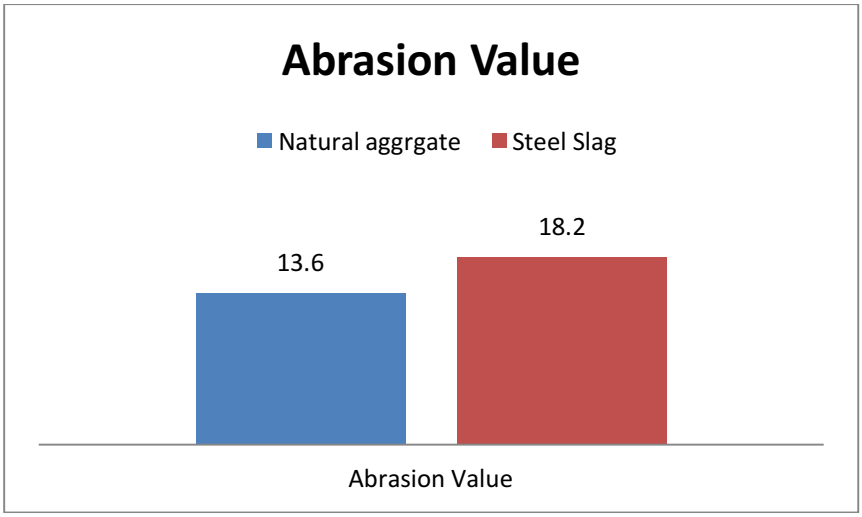

Chart No.3: Abrasion value of natural and steel slag aggregate

As per IS 2386 (part 4)-1963, The maximum abrasion value of coarse aggregates to be used for road construction is 45% and from above graph it is clear that obtained abrasion value of coarse aggregate is 18.2% which symbolizes that steel slag aggregates also satisfies the criteria of minimum required strength of coarse aggregate against wearing action.

IV. CONCLUSION

Based on various physical tests performed on the natural aggregates and steel slag aggregates following conclusions can be made:

1. Specific gravity of steel slag aggregate is found to be 2.68 which is under permissible limit as natural aggregate sample give specific gravity 2.74.
2. Water absorption by the steel slag is 0.503% whereas natural aggregate shows 0.610% water absorption.
3. Impact value obtained for steel slag aggregate is 17.43% which is more than the impact value of natural coarse aggregate which is 10.4% but we can use steel slag aggregate as natural aggregate because aggregate impact value for road construction must be below 45% for wearing surface.
4. Aggregate crushing value is obtained in case of steel slag and natural aggregate is 18.38% and 16.76% respectively. Both aggregates satisfy the permissible value of crushing value for road construction.
5. Loss of natural aggregate and steel slag aggregate on abrasion is 13.6% and 18.2% respectively which symbolises that steel slag can be utilised as coarse aggregate in road construction. Though the steel slag is not performing better than the natural aggregate but it fulfils and far ahead of the minimum required strength of coarse aggregates for safe and long life results for the road construction.
6. As per IS standards impact value, crushing value and abrasion value shall not exceed 45% for wearing surfaces (Roads, runways etc) and 50% for non-wearing surface(building, roof slab) so as per the obtained result steel slag aggregates fulfils the minimum required value of all tests.
7. Application of slag as an alternative to standard materials like stone aggregate in road pavement is possible.
8. Due to the use of steel slag as replacement of natural aggregates, land filling will decrease.
9. Construction cost will reduce as slag is a by product and widely available without spending any capital.
10. Slag is one of the best material which not only saves the natural resource but also gives the minimum required strength and service life to the road pavements.

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