IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
Volume 3, Issue 2, March 2023
Impact Factor: 7.301

Use of Steel Slag in the Road Construction

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Abstract: *Roads make a crucial contribution to an economic development and growth and bring important social benefits. They are of vital important in order to make the nation grow and develop. So, by keeping this in mind, Steel Slag Road came in construction, there is no blasting, drilling or any crushing to obtain steel slag as it is material waste coming out of steel industry which is further processed and then converted in the form of aggregates material used for constructions. As per research papers we have referred we found that, the highways and other roads can become more stronger with this steel slag roads than normal conventional roads and they became more economical as steel slag is waste generated from steel industries. So, in this research we have tried to use steel slag as replacement of aggregates by some proportion and by performing tests on it we are aiming that road construction may become more economical and road becomes more durable as compared to conventional road construction.*

Keywords: Road construction, Steel slag, Aggregates, Bitumen, Experimental testing

I. INTRODUCTION

According to Geissler (1996), in 350 BC Aristotle has indicated that during the purification of iron, a by-product is generated like a stone called iron slag. According to National Slag Association iron and steel slags have been used in engineering constructions for more than 150 years. It is utilized as fill material, rail road ballast, subgrade soil stabilization, bounding applications (BFS) in place of Portland cement, and as aggregate in place of natural aggregate. Up to 97% of the total steel slag produced in 1998 was utilized by Germany in various ways for the construction of heavily travelled roadways. According to Godfrey and Nie, enormous quantity of steel slag was used for wall making and road construction during the period of Roman Empire.

Surat has become the first city in India to have a processed steel slag (industrial waste) road built as part of a joint venture project by the Council of Scientific and Industrial Research (CSIR), Central Road Research Institute (CRRI), Union Ministry of Steel, government think-tank NITI Ayog, and ArcelorMittal-Nippon Steel (AM/NS). This was done at Hazira. A kilometer-long section of the six-lane public road can be found in Hazira Industries, which also has the AM/NS facility. Steel slag aggregate was created by turning piles of steel trash into the construction site about a year ago. Early in March, the road's sixth and last lane, which has a three-lane to-and-from carriageway on either side, was finished. Heavy-duty vehicles from global companies operating in the industrial area are increasingly using the road estate on the outskirts of Surat.

1.1 Study Area

Slag is a valuable road material for preparation of macadam material and mineral binders serving as a base for the asphalt concrete mixture, which are widely used in road construction, by using the steel slag in road construction the cost and thickness of road is reduced by 30% as compared to normal roads. By using steel slag (industrial waste) in road construction, this project falls under the waste to wealth and clean India campaign. As an impurity, the molten flux material that makes up the slag is discharged into slag pits for cooling according to a customized procedure before being used to create stable steel slag aggregate with superior material properties in place of natural aggregate, which is typically used in road construction. By-products from the production of iron and steel can be recovered and utilized to make aggregates for asphalt roadways. The by product of making steel is known as steel slag.

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1.2 Objectives

1. To find the optimum quantity of steel slag as a fine aggregate to enhance the strength of mixture by conducting related tests.
2. To utilize steel slag in road construction and reduce waste of steel slag as India is 2nd largest producer of steel.
3. To evaluate the effect of moisture, temperature, and aging on the performance of mixes incorporating steel slag.
4. To assess the performance of dense bituminous mix prepared using a combination of aggregate and steel slag.
5. To compare the performance of a combination of aggregates and steel slag with dense bituminous mix incorporating aggregates.

1.3 Composition 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 lags 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. Both BOF and EAF slags are dicalcium silicate, dicalcium ferrite and wurtzite. Dicalcium silicate 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.

1.4 Properties of Steel Slag

Gradation, specific gravity, stability, durability, corrosivity, and drainage are a few of the crucial characteristics of steel slag that are particularly relevant when using steel slag as an aggregate in granular foundation. As follows, these characteristics are covered:

1. Gradation: Steel slag is easily treated to meet the granular aggregates' graduation standards.
2. Specific Gravity: Steel slag aggregate is predicted to produce a product with a higher density compared to traditional mixes because of the comparatively high specific gravity (3.2–3.6) of steel slag.
3. Stability: Steel slag aggregates have a high California Bearing Ratio (CBR) value of up to 300 percent and a high angle of internal friction (40° to 45°).
4. Steel slag aggregates exhibit good durability and resistance to erosive weathering.
5. Corrosivity: Although leachate from steel slag can surpass a pH value of 11, the pH range of the steel slag aggregate typically lies between 8 and 10.
6. Steel slag aggregates have good drainage properties and are resistant to freezing.

1.5 Advantages of using Steel Slag

1. This method can prevent the road from any damage caused during the monsoon season.
2. The highways and other roads can become more stronger with this steel slag roads than normal conventional roads.
3. It can also reduce the cost of construction by 30% than conventional road construction.
4. Steel waste produce each year that usually go to landfills can get use now by this method of construction.
5. The use of Steel Slag to construct roads will improve the durability and quality of roads making them safer.
6. The use of Steel Slag on roads will help in reducing the waste and recycling the waste of the Steel industries in India.
7. The carbon footprint in the Steel Slag Roads is lower than usual roads built with other materials.
8. Steel-slag mixture has perfect performance in terms of interconnecting and adhesion.

II. LITERATURE REVIEW

[1] “Steel Slag as A Road Construction Material” (3 January 2015)

Mohd. RosliHainin et al [2015] They researched about the history of steel slag that how it came to known by and were also used in roads during the Roman Empires Era. They stated that over 50 million tons of steel slag is generated across

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the world per year. This paper also reviewed that how steel slag is utilized in road construction around various countries across the world over the years. Also, in this paper they stated all the physical and mechanical properties and the mineralogical compositions present in the steel slag. Various tests are also performed in this paper which came to conclusion that steel slag can be used for future also as it has many advantages with high engineering properties. The purpose of this paper is to review the engineering properties of steel slag and its utilization for road construction in different ways.

[2] "Use of Steel Slag as an Alternative to Aggregate and Filler in Road Pavements" (21 January 2021)
Giulio Dondi et al [2021] They discussed the use of Construction and Demolition Materials (CDM) can be considered as a suitable solution for the construction or the rehabilitation of road pavements as well as their main focus was on using the steel slag. For the road construction they substitute the 30 % steel slag instead of coarse grain aggregates, this paper was also including the experimental plan for cement bound layer using the steel slag and asphalt mixture layer using with the slag. They had analysed both the layers by performing the various test on it. After performing the various test on layer, they obtained the one conclusion for all the mixtures, the stability increases with decreases in the bitumen and vice versa the displacement decreases with same trend. Regarding the cement bound mixture, static mechanical characterizations tests highlights that the result are not far good compare with the asphalts mixture layer. The possibilities of using that material in road infrastructures in order to promote their objectives set by sustainable development goals to promote the circular economy.

[3] "Experimental Study on Steel slag in Construction of Flexible Pavement" (2 April 2018)
Dhavashankaran et al [2018] This paper addresses the various test conducted on the materials use in flexible pavement using the steel slag. Road pavement can be one of the fundamental elements of the transportation system. Significant amounts of bitumen and natural aggregates are used in the construction of asphalt concrete pavements. That paper was giving the experimental result performing on the materials and as per the results obtained from the tests the materials found to be in within the standards range given by IRC. Hence the following features they concluded from this experimentation of steel slag replacement of filler as, the partially replacement of filler by steel slag will increases the strength and also load carrying capacity. Based on the Marshall stability Test results replacing the coarse portion of the aggregate in mixture with the coarse portion of the aggregate leads to a concurrent increase in the Marshall Stability and Flow with an improvement. In this paper they used the BOF (basic oxygen furnace) and the property of BOF is to increase the volume stability due to mixture content present.

[4] "Comprehensive Analysis of Steel Slag as Aggregate for Road Construction: Experimental Testing and Environmental Impact Assessment" (28 June 2021)
Marina Díaz-Piloneta et al [2021] They explained the comprehensive analysis of steel slag for the pavement design using the BOF steel slag. But the main issue regarding about the BOF slag is its volume instability in the presence of water. This paper was analyzed the use of untreated BOF slag from a technical and environmental point of view, suggested it as an alternative to natural aggregates in road surface layers and asphalt pavements. A comprehensive analysis of the requirements to be met by raw materials used in asphalt mixes was performed, and a pilot test was carried out with two different mixtures: one mix with limestone as coarse aggregate and another with 15% BOF slag. But the introduction of BOF slag into the asphalt mix as a coarse aggregate, instead of limestone, causes a carbon emissions reduction rate of more than 14%. Laboratory analysis shows that the inclusion of BOF slag in an asphalt mix may enhanced skid resistance, mechanical properties and rutting resistance. Another study shows how mixing limestone with steel slag as a coarse aggregate can provide an asphalt mixture with high resistance to plastic deformation and good resistance to fatigue failure. And for obtaining the good life cycle analysis of the pavement they suggested to replace only 15 % of coarse aggregate with the steel slag.

[5] "Environmental Impacts of Steel Slag Reused in Road Construction: A Crystallographic and Molecular (XANES) Approach" (16 May 2006)
Perrine Chaurand et al [2007] They researched about the environmental hazards of the BOF slag which contains

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calcium silicon, iron but they also contain some toxic elements which are mainly chromium (Cr) and vanadium (V). So, they have performed various tests on the steel slag such as leaching, x-ray diffraction, microscopic technique etc. and the outcomes which had been found during the studies were that the element chromium (Cr) is present in the steel slag but which is very less in amount and is also less mobile and less toxic one and therefore it is considerable. But vanadium(V) in BOF slag is predominantly present, but it reduces with leaching at Ph5 and with natural ageing. At last, this study has shown that vanadium is highly released in BOF steel slag but can be reduced and is safe for use in construction works.

III. PROPOSED METHODOLOGY

3.1 Materials Used

A. Steel Slag

Steel slag, which is a byproduct of the steel-making process, is one of the materials used. The silicates, ferrites, aluminum oxides, magnesium oxides, manganese oxides, and calcined lime employed as flux mix to make the steel slag. This is cooled using air and a water sprinkle in a cooling yard. Basic Oxygen Furnace (BOF) and Electric Arc Furnace (EAF) slag are the two main forms of steel slag produced in India, depending on the type of furnace used to create steel. By mass, steel slag includes 10 to 20 percent metallic iron, which is recovered through magnetic separation. For usage as aggregates, the metal-free slag is crushed and filtered into various sizes.

B. Bitumen

A substance created by distilling crude oil is referred known as bitumen. Bitumen is frequently used in the construction sector, particularly for roads and highways, and is well known for its waterproofing and adhesive characteristics. Through the process of distillation, the heavier bitumen is left behind while the lighter components of crude oil, such as gasoline and diesel, are removed. Crude oil has a byproduct called bitumen. Elements like calcium, iron, sulfur, and oxygen are among the complex hydrocarbons that make up its composition. The type and source of crude oil used to make the substance determines its quality and simplicity of manufacture. It was initially utilized for its built-in waterproofing and adhesive properties, which helped seal ship bottoms and bind building materials together.

C. Aggregates

When combined with a hydraulic cementing medium to create mortar or concrete, aggregates are granular materials like sand, gravel, crushed stone, hydraulic cement concrete, or iron blast-furnace slag. Crushing naturally available rock is a popular method for obtaining aggregates. The parent rock, which might be igneous, sedimentary, or metamorphic, determines the qualities of the aggregate. Testing is used to assess aggregates' appropriateness for different purposes. Evaluation of appropriateness also takes into account the mineralogy, grain size and texture, and petrographic description of rock samples.

3.2 Tests to be conducted

To study the comparative analysis of steel slag, aggregate bituminous mix with conventional bituminous mix, we are going to perform the various test on the natural aggregates and steel slag aggregate, also test on bituminous mix by natural aggregate and bituminous mix by steel slag aggregates. For these tests to be conducted we are going to prepare five samples in which one is conventional sample which is going to be used as reference and other are by adding steel slag with aggregate in proportion of 10%, 20%, 30% and 40%.
Various tests to be conducted in this project are as follows:

A. Tests for Steel Slag Aggregate Mix

1. Aggregate Crushing Value Test

This test measures the relative resistance of an aggregate to crushing under a compressive load that is delivered progressively.

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2. Impact Value Test

The aggregate crushing value gives a comparative measurement of an aggregate's resistance to crushing under a compressive stress that is gradually applied.

3. Abrasion Value

The Los Angeles abrasion test measures the toughness and abrasion resistance of aggregates, including their resistance to crushing, degradation, and disintegration.

4. Flakiness Index

Flakiness index of aggregate is done to determine the particles shape of the aggregate specimen and each particle shape being preferred under specific condition.

5. Elongation Index

The proportion of particles in an aggregate whose largest dimension (length) exceeds one and four-fifth times (1.8 times or 9/5 times) its mean dimension is known as the elongation index.

B. Tests for Bitumen:

1. Penetration Test

Penetration is a measurement of hardness or consistency of bituminous material. It is the vertical distance traversed or penetrated by the point of a standard needle in to bituminous material under specific condition of load, time, and temperature. This distance is measured in one tenth of a millimeter. This test is used for evaluating consistency of bituminous materials.

2. Viscosity Test

Viscosity of a fluid is the property by virtue of which it offers resistance to flow. The viscosity test of bitumen measures the viscosity. This property shoes how easily bitumen flows. The higher the viscosity of the bitumen, the harder it is to flow. Consequently, it behaves more like semi-solid matter. Bitumen viscosity is determined by viscometers.

C. Test for the Steel Slag Bituminous Mix Specimen

1. Marshall Stability Test

In normal test programs for paving operations, the Marshall stability test is often utilized. Maximum load carried by a compacted specimen at a standard test temperature of 6000 C is used to define the mix's stability. The deformation in units of 0.25 mm between the specimen's no-load and maximum load during the stability test is used to estimate the flow. The goal of this test is to determine the ideal binder content given the kind of aggregate mix and traffic volume.

IV. DESIRED OUTCOMES

Outcomes that we expect from our research are as follows:

1. **To create the sustainable development modal:** Using the steel slag in flexible pavement it utilizes the industrial waste from steel industry so that it reduces the metallurgical pollution hence it creates the sustainable development modal in front of MORTH.
2. **Providing less rutting deformation:** The addition higher rutting resistance occurred because of the higher creep stiffness of the mixtures with steel slag aggregate.
3. **Making easy to maintenance:** The flexible pavement easy to maintenance because after constructing the flexible pavement do not take much more time for strengthening the layer and hence traffic density do not jam for large duration time.
4. **Giving eco-friendly results:** Instead of keeping the stock pile in the dumped area nearby it can be used in road construction pavement so that it reduces the pollution. hence it creates eco-friendly example in front government of India.

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5. **Good resistance to fatigue failure:** Limestone with steel slag as a fine aggregate can provide an asphalt mixture with high resistance to plastic deformation and good resistance to fatigue failure.
6. **Less quantity of materials required:** As compared to conventional flexible pavement it required large amount of material. The thickness of the road is also 30% lesser than normal ones while the durability is much longer due to utilization of steel slag.
7. **More economical for major district road as well as village road:** According to Indian road congress (IRC) guidelines for construction of a heavy traffic road that can take the load of 1000 to 1200 trucks per day. Hence, we can conclude the give more durability for ODR and Village Road.

V. DISCUSSION AND CONCLUSION

The basic aim of this research is to utilize the waste generated from steel industries i.e., steel slag in road construction so that it can reduces the construction cost and make road construction more economical. Also, it has several other advantages such as it is ecofriendly, durable etc. So, in this report we are going to conduct various tests on steel slag aggregate bituminous mixture and on natural aggregate bituminous mixture to study comparative analysis between conventional road construction method and road construction by using steel slag.

This report focuses on the design of the roads with the use of steel slags. As India has a very high scale production of steel and hence the waste coming out from these steel industries in a form of steel slag can be used in the design of the roads. By doing so, this will reduce the impact waste being generated by industries and also the roads will be able to sustain more incoming road of traffic and also yield a better life of the roads. Along with all the benefits of using steel slag in the road construction; another major factor is that this will also cut on the cost of the building the road with conventional resources by a sufficient margin. Hence with all the above construction using steel slag in the road will always be beneficial for the road user.

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