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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.*

The use of steel slag as a sustainable substitute for conventional building materials in the construction of roads is the subject of this study. The purpose of the study is to find the ideal mix design for maximum performance as well as to assess the viability of employing steel slag as an aggregate in road construction. To assess the performance of the asphalt mixtures containing steel slag and to quantify the physical and mechanical characteristics of the steel slag aggregate, the technique includes laboratory testing. The study's findings indicate that steel slag can be used as a partial replacement for conventional aggregates in road construction with good outcomes in terms of performance and financial gains.

So, in our project we have tried to use steel slag as replacement of aggregates 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.

Study Area: Highway material is a critical aspect of the construction and maintenance of roads and highways. The study area about highway material can be broadly classified into three categories: materials used in the construction of highways, materials used for maintenance and repair of highways, and materials used in the design of highway infrastructure.

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1.1 Objectives

a) To determine the suitability of steel slag as an addictive for flexible pavement construction
b) To conduct a comprehensive laboratory testing program to determine the optimal proportions of steel slag and other materials in road material.
c) To investigate the feasibility of using steel slag as an alternative material in road construction.
d) To assess the performance of dense bituminous mix prepared using a combination of aggregate and steel slag.
e) To analyse the environmental benefits of using steel slag in flexible pavement construction, such as reducing the demand for natural aggregates and promoting sustainable waste management practices

1.2 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.

1.3 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:
a) Gradation: Steel slag is easily treated to meet the granular aggregates' graduation standards.
b) 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.
c) 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°).
d) Steel slag aggregates exhibit good durability and resistance to erosive weathering.
e) 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.
f) Drainage Characteristics: Steel slag aggregates are free draining and are not susceptible to frost.

1.4 Advantages of using Steel Slag:

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

II. LITERATURE REVIEW

"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 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

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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.

"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.

"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.

"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.

"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 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.

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[6] "An Overview on Performance of Steel Slag in Highway Industry" M. A. Aziz et al. This paper provides the study of the steel slag which can be used as a sustainable alternative material that includes two types i.e. Electric Arc Furnace (EAF) and Basic Oxygen Furnace. Steel slag has found to be effective in enhancing the mechanical properties of asphalt and concrete mixtures used in highway construction. The properties of steel slag like chemical, physical, radiochemical, mineralogical, morphological, and textural characteristics are need to recognize hence appraised the suitability and reusing potential of steel slag in asphalt mixture production. In this research paper the author discussed the use of steel slag in different applications including as a replacement for aggregate as a filler material in asphalt and concrete mixture, and as a stabilizer for soft subgrade soils. From this the author found that the use of steel slag in these applications can improve the mechanical properties and durability of the resulting pavement reduce the cost of production and provide environmental benefits. Moreover, they also discussed about the various factors that can influence the performance of steel slag in highway construction and steel slag may be one of the best substitudes of artificial aggregates for road construction which can notonly help to save the friendly environment and but also provides an artificial material with higher resistance. From this they concluded that steel has the potential to be an effective and sustainable material in the construction of highways and the rutting fatigue, skid resistance, creep, and resilient modulus tests the performance of steel slag mixture wearing course is better than that of the conventional wearing course.

[7]"Utilization of Steel Slag as A Replacement for Filler Material In The Asphalt Concrete" Bishow KC et al. The authors reviewed that steel slag has the potential to improve the properties of asphalt concrete mixtures. Steel slag has been found to be effective in improving the stability, durability, and rutting resistance of asphalt concrete mixtures. The major purpose of this study is to explore the effect on Marshall Properties of Asphalt mix with steel slag. The author discussed about the various factor that can influence the performance of asphalt concrete mixtures containing steel slag i.e., size and gradation of steel particles the amount of steel slag used as a filler material, the type of binder used in asphalt concrete mixture and the environmental condition of the application. In this research study, only VG-30 grade Bitumen is considered. By performing Marshall stability test on it, they found out that the optimum steel slag content various depending on the specific application and mixture design. From that they noted the use of steel slag as a filler material in asphalt concrete mixtures can help reduce the cost of production and provide environmental benefits by reducing the amount of waste generated from steel production and conserving natural resources. Moreover, they discussed about the challenges that includes the potential for steel slag to absorb moisture, which can affect the performance and the potential for steel slag to react with the binder, which can affect the long-term durability of the pavement. From this paper concluded that steel slag has the potential to improve the properties of asphalt concrete mixtures and reduce the cost of production while providing environmental benefits.

[8] "Utilization of Steel Slag as Aggregates For Stone Mastic Asphalt (SMA) Mixtures" Shaopeng Wu et al. This research paper explores the feasibility of using steel slag, a byproduct of steel production, as aggregates in stone mastic asphalt (SMA) mixtures. Steel slag is commonly deposited in slag storing yards, causing environmental issues. 11 The study aims to evaluate the properties of asphalt mixtures with steel slag aggregates compared to those with traditional basalt aggregates. The paper begins by discussing the current low utilization of steel slag in China and the increasing demand for construction aggregates. Previous research on recycling and utilizing steel slag in various fields is also mentioned. The paper highlights the need for exploring steel slag as an aggregate in asphalt mixtures, as few studies have been conducted in this area. Finally, the paper concludes that steel slag can be a viable alternative to basalt as aggregates in SMA mixtures. The use of steel slag aggregates improves high temperature properties and resistance to low temperature cracking. In-service SMA pavements with steel slag showed excellent performance in terms of roughness and British Pendulum Number (BPN) coefficient of the surface.

[9] "Use of Steel Slag in Construction of Flexible Pavement" Sandip S. Patil et al. This study investigates the feasibility of using steel slag waste as a construction material in road pavements. Steel slag is a waste material generated during steel manufacturing and its disposal causes environmental and health hazards. The study collected a typical steel slag sample from M/s Jindal Steel Industry Pt. Ltd Sinnar MIDC, India and mechanically stabilized it with locally available soil in the range of 5-25% to improve its geotechnical engineering properties. The geotechnical characteristics of the steel slag, locally available soil, and their mixtures were investigated to determine their suitability in different layers of road pavement. The results showed that the steel slag could be used in the construction of embankment, subgrade, and

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subbase layers of flexible pavement. Technical specifications were developed for utilizing steel slag in road construction. The study recommends the use of steel slag as a construction material to address the problem of waste disposal and depletion of natural resources like soil and aggregates.

[10] "Skidding Characteristics of Pavement Surface Incorporating Steel Slag Aggregates" A.F Stocks et al. This paper reported the assessment of the skid resistance of asphalt surface incorporating steel slag, with reference to polished stone value (PSV) and in situ measurement of skidding resistance. They analysed previous work on measurement PSV of steel slag. the skidding resistance of road surface is measured using the sideways force coefficient routine investigation machine (SCRIM) which provide data for highway authorities facilitate their maintenance management procedure for various category of road like village road, other district road etc. this paper also mentioned the skidding resistance performance of steel slag and natural aggregate. As per the survey they conclude that steel slag road surface has at least good long term skidding resistance properties as compare to natural aggregates road surface under the same traffic density.

III. PROPOSED METHODOLOGY

3.1 Materials Used:

1. 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.

2. 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.

3. 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.

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:

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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.

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.

3.Softening Point:

The softening point of bitumen or bitumen is the temperature at which the substance attains a particular degree of softening. As per I.S. 334-1982 it is the temp. in 0°c at which a standard ball passes through a sample of bitumen in a mould & falls through a height of 2.5cm when heated under water or glycerine of specified condition of test. The binder should have sufficient fluidity before its application in load uses. The determination of softening point helps to know the temperature up to which a bituminous binder should be heated for various road use applications.

4.DuctilityTest:

The ‘Ductility Test’ gives a measure of adhesive property of Bitumen and its ability to stretch. In a flexible pavement design, it is necessary that binder should form a thin ductile film around the aggregates so that the physical interlocking of the aggregates is improved. Binder material having insufficient ductility gets cracked when subjected to repeated traffic loads and it provides pervious pavement surface. Ductility of a bituminous material is measured by the distance in centimetres to which it will elongate.

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IV. RESULT AND DISCUSSION

4.1 Aggregate Crushing Value:

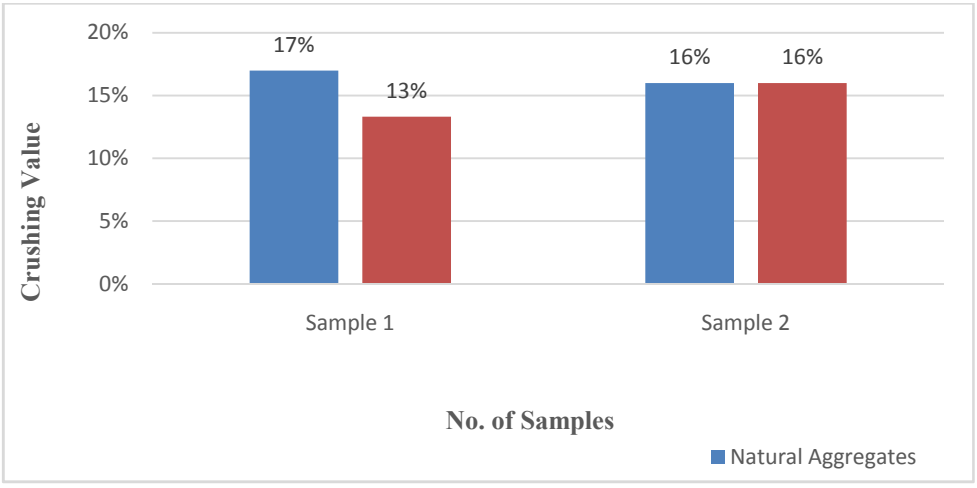

Fig 4.1Aggregate Crushing Value

Impact Value Test

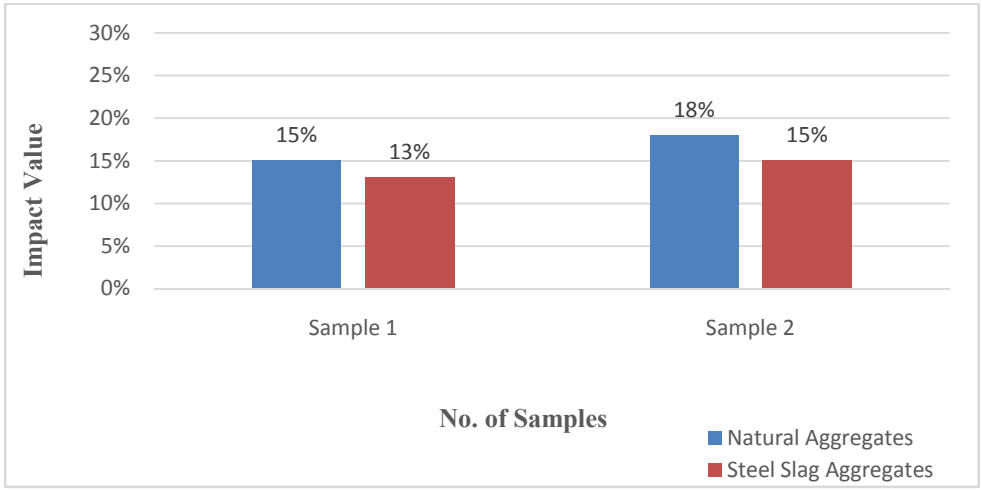

Fig. 4.2Aggregate Impact Value

Deval Abrasion Test:

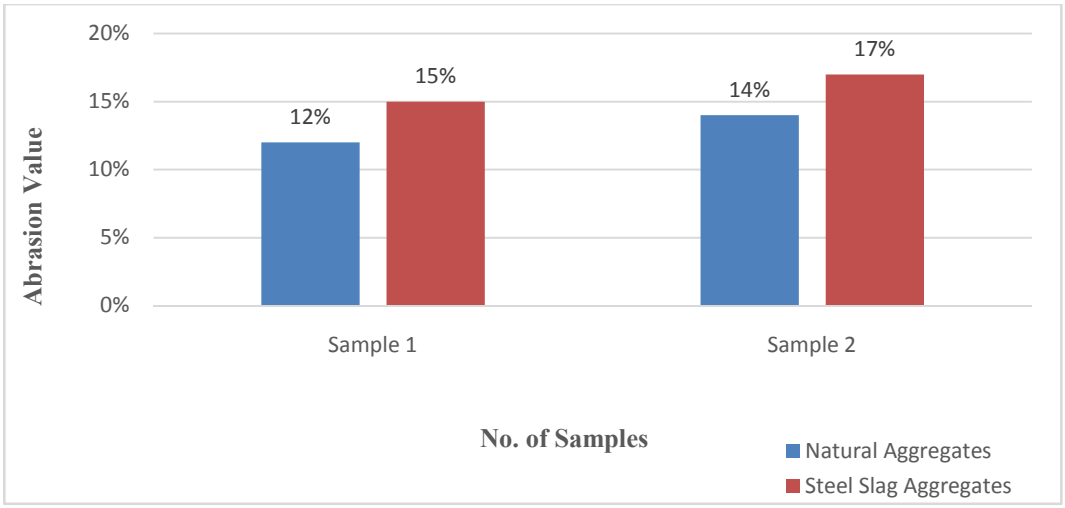

Fig.4.3 Deval Abrasion Test

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Flakiness Index:

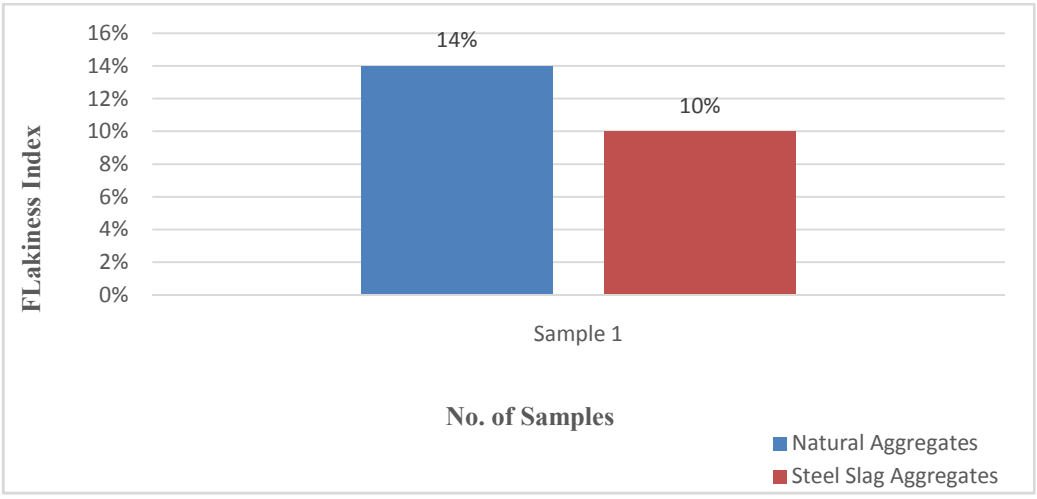

Fig.4.4 Flakiness Index

Elongation Index:

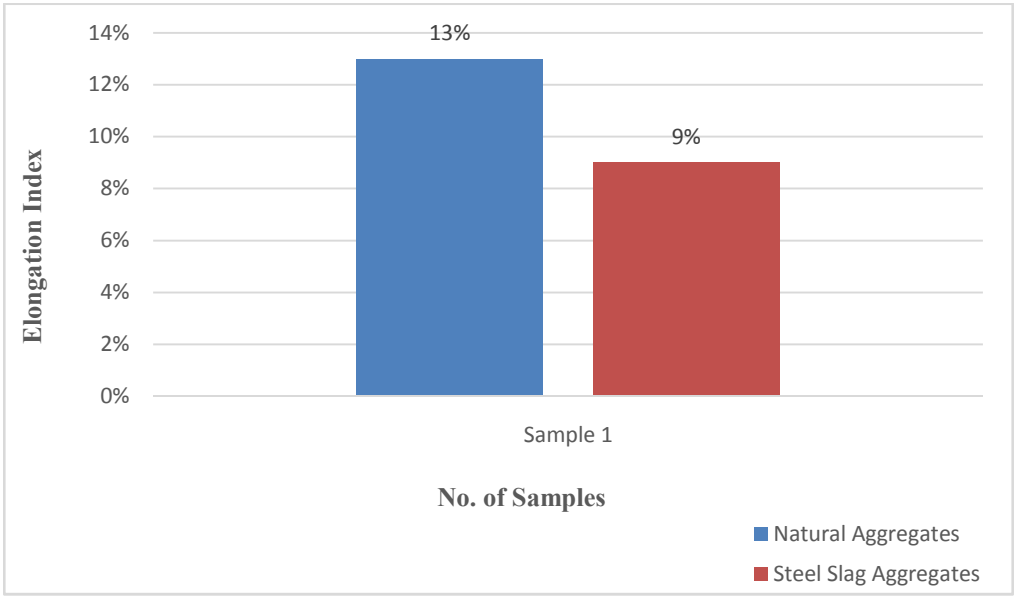

Fig.4.5 Flakiness Index

Average of Results:

Table 4.1 Aggregate Testing Results

Testing	Conventional aggregates	Steel slag aggregate	Permissible limit
Aggregate Crushing Value	16.7%	15.09 %	<30%
Aggregate Impact Value	16.5%	14.55%	-
Deval Abrasion Value	12.66%	16.69%	<25%
Flakiness Index	14.75%	10.45%	<25%
Elongation Index	13.57%	9.745%	<25%

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Results of tests on Bitumen:

Table 5.2 Bitumen Testing Results

Testing	Unit	Test Results
Penetration Value	29^0C	69
Viscosity Test	Sec	38.01
Softening Point	0_C	66.5
Ductility Test	25^0C	27.4

V. CONCLUSION

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 the roads will be able to sustain more incoming road of traffic and yield a better life of the roads.

As per the testing which we have done in our project we can conclude that, the results we obtained from the testing steel slag aggregates are much similar that of conventional aggregates so if we replaced natural aggregate with steel slag aggregates then it will not affect the durability and strength of road construction. Also, with addition to this it will help to reduce the steel slag waste which is going to landfill and causing soil erosion.

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.

VI. FUTURE SCOPE

The future scope of using steel slag in road construction appears promising. Here are some potential aspects to consider:

- The possibility of the use of steel slag in geotechnical engineering applications, such as for soil stabilization.
- Another area of research is the use of steel slag in the production of lightweight aggregate for use in concrete for rigid pavement of road construction.
- Steel slag can be used as a substitute for traditional aggregates in asphalt mixes, improving the durability and performance of the finished product.
- The research could be done on the use of steel slag in the construction of embankments and retaining walls.
- Another potential future development is the use of steel slag in the production of building materials such as bricks, blocks, and tiles. Steel slag can be used as a substitute for traditional raw materials, reducing the environmental impact of these products.
- Steel slag can be used as a base material or as a filler material for road construction, providing a stable and long-lasting foundation for the road surface.

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