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STEEL SLAG AS A SUSTAINABLE ALTERNATIVE AGGREGATE FOR ROAD CONSTRUCTION

[1]Kunwar Divyanshu, [1]Asmin Yadav, [1]Aryam Verma, [2]Abhay Srivastava

[1] B.Tech Student, [2]Assistant Professor,

Civil Engineering Department,

Shri Ramswaroop Memorial College of Engineering & Management, Lucknow, India.

Abstract: Since hundreds of year natural material is used as aggregate in the construction of pavement roads. Various types of roads are constructed using different materials, not only are they required in large quantity but also are unsustainable for long term use. We suggest the use of the steel slag as aggregate in the road construction. The use of the steel slag offers solution to the two big problems the world is currently facing - the growing challenge of efficiently managing the waste which is increasing day by day and the requirement of the large quantity of natural material for pavement construction. Steel slag is a by-product of steel industry which is produced during the separation of the molten steel from impurities in steel-making furnaces. Steel slag can be used to replace the natural aggregate because it has favourable mechanical property including strong bearing and shear strength, good soundness characteristics, and high resistance to abrasion and impact. It is actually recycled as a specialty aggregate for road construction, foundation stabilization and to coat flexible pavement acting as a binding material.

Many researchers have studied the use of the steel slag as an aggregate to design asphalt concrete for road construction. Our test results show that steel slag aggregate surpasses natural aggregate by 27.72% in aggregate abrasion test, 31.41% in aggregate impact value test, 1.94% in aggregate flakiness and elongation test, 3.39% in aggregate soundness test, 6.17% in aggregate stripping value test and 29.81% in aggregate crushing value test. The purpose of this project is mainly to review the properties of steel slag and various uses in road construction which could be of great importance.

Index Terms - Steel slag, aggregate, by-product, stabilization.

I. INTRODUCTION

Steel slag is a complex mixture of silicates and oxides that forms as a molten liquid melt and solidifies after cooling. Due to its advantageous qualities, such as its high strength, durability, and minimal impact on the environment, steel slag, a byproduct of the steelmaking process, has been utilised extensively in a variety of fields. In recent years, there has been an increase in interest in using steel slag as a material for road construction, which is one viable application. The use of steel slag in road construction offers various benefits over conventional materials, including higher skid resistance, less noise pollution, and increased sustainability, in addition to being a sustainable method of getting rid of this industrial waste. We will investigate the viability and possible advantages of employing steel slag as a road construction material in this project and assess its performance in comparison to traditional materials. We will also look into the financial and environmental effects of employing steel slag in road building and make suggestions for how this material should be developed and used in the future.

II. EXPERIMENTAL VALIDATION OF STEEL SLAG

2.1 IMPACT TEST ON STEEL SLAG

The aggregate impact test is performed to measure the resistance to impact of aggregates. Toughness is the property that provides resistance to impact. Aggregates used in roads and pavements are subjected to sudden impact, which can lead to their breakdown and failure. The test is performed in accordance with IS Code 2386: (part 4) 1963. If the result is satisfactory, the aggregates are used in pavement, if not, they are rejected.

CALCULATIONS OF IMPACT TEST:

The aggregate impact value is the ratio of the weight of the fraction passing through 2.36 mm (weight W2) by the total weight of the sample (weight W1 + W2).

Aggregate Impact Value = (W1/ (W1+W2)) * 100

Where, W1 = Weight of the sample passing through a 2.36 mm sieve, W2 = Weight of sample retained on 2.36 mm IS sieves, W3 = W1+W2 (Total Weight of Sample).

OBSERVATIONS OF IMPACT TEST:

TEST-1:

W1 = 28gm W2 = 301gm W3 = 329gm

Aggregate Impact Value = (28/329) *100 = 8.51%

TEST-2:

W1 = 26gm W2 = 304gm W3 = 330gm

Aggregate Impact Value = (26/330) *100 = 7.90%

TEST-3:

W1 = 28gm W2 = 308gm W3 = 336gm

Aggregate Impact Value = (28/336) *100 = 8.33%

AVERAGE RESULT OF IMPACT TEST

Aggregate Impact Value = (8.51+7.9+8.33)/3 = **8.246%.**

2.2 ABRASION TEST ON STEEL SLAG

The Los Angeles Test machine is used to determine the hardness of aggregates used in highway pavements construction. The test is done on aggregates that are to be used as surface course and must be hard enough to resist abrasion. The working principle is to produce abrasive action by using standard steel balls mixed with aggregates and rotated in a drum for a specific number of revolutions. This test indicates that materials having more abrasion are relatively less hard and can be easily damaged.

CALCULATIONS OF ABRASION TEST:

The Los Angles Abrasion value is calculated as the difference between the original and final weight of the test sample.

Original weight of the sample (W1).

The weight of the sample retained (W2).

The weight of the sample passing through 1.70 mm sieve (W1-W2).

Abrasion value= (W1-W2)/W1*100

OBSERVATIONS OF ABRASION TEST:

Grade B - (20-12.5mm) - (12.5-10mm)

No. of spheres = 11

Spheres weight = 4584 ± 25gm

Fractional weight - 20-12.5mm = 2500gm, 12.5-10mm = 2500gm

Original weight = 5000gm, After 500 Rotations

Use size 1.70mm IS Sieve

Material retained on IS Sieve 1.70m

	READING	CALCULATION	VALUE
1ST OBSERVATION	4125	5000-4125	875gm
2ND OBSERVATION	4090	5000-4090	910gm
3RD OBSERVATION	4231	5000-4231	769gm

1ST OBSERVATION

LA Value = 875x100 = 17.50% 5000

2ND OBSERVATION

LA Value = 910x100 = 18.20% 5000

3RD OBSERVATION

LA Value = 769x100 = 15.38% 5000

AVERAGE RESULT OF ABRASION TEST:

(17.50+18.20+15.38)/3 = **17.03%**

2.3 STRIPPING VALUE TEST ON STEEL SLAG

The test used to establish how moisture content affects the bituminous film's ability to adhere to the surface particles of the aggregates is known as the "stripping value test on-road aggregate. The "stripping value test on-road aggregate" used to determine how moisture content influences the bituminous film's capacity to stick to the surface particles of the aggregates.

CALCULATIONS OF STRIPPING VALUE TEST:

The outcome is expressed as the percentage covered stone surface that is still present with the designated time with the mean value derived from at least three visually evaluated values rounded to closest whole number.

Stripping value = $\frac{\text{Uncovered area (visually)}}{\text{Total area of aggregate}} \times 100$

OBSERVATIONS OF STRIPPING VALUE TEST:

OBSERVATION NUMBER	**1ST**	**2ND**	**3RD**
TYPE OF AGGREGATE	(20mm-12.5mm)	20mm-12.5mm)	(20mm-12.5mm)
TYPE OF BINDER	Bitumen	Bitumen	Bitumen
% BINDER USED	2 to 5 %	2 to 5 %	2 to 5 %
TOTAL WEIGHT OF AGGREGATE	200gm	200gm	200gm
TOTAL WEIGHT OF BINDER	10gm	10gm	10gm
TEMPERATURE OF WATER BATH (℃)	40℃	40℃	40℃
STRIPPING VALUE (%)	4.8%	4.2%	3.3%

Mean stripping value (%) = (4.8+4.2+3.3)/3 = **4.1%**

2.4 SOUNDNESS TEST ON STEEL SLAG

Soundness test of the aggregate is the test to determine the resistance of an aggregate to the disintegration of aggregate by severe weathering actions and conditions. Such conditions include freezing the thawing, variation in temperature, alternate wetting and drying under normal conditions, and wetting and drying in salt water.

CALCULATIONS OF SOUNDNESS TEST:

Loss of mass (in percent) = (MB-MA) X 100/ MB

Where MB is the mass before to the test. MA is the test-result mass.

The total mass loss of the sample should be determined as the weighted average (by mass) of each aggregate size tested.

OBSERVATIONS OF SOUNDNESS TEST:

	(19-12.5mm)	**(12.5-9.5mm)**
WEIGHT OF AGGREGATE	672gm	331gm
RETAINED WEIGHT ON 8MM SIEVE	665.9gm	322.7gm
PASSED WEIGHT FROM 8MM SIEVE	672-665.9=6.1gm	331-322.7=8.3gm
ACTUAL LOSS % OR SOUNDNESS VALUE	(6.1/672) *100 = 0.91% %	(8.3/331) *100 = 2.51%

Total Actual loss % or soundness value = 0.91 + 2.51 **= 3.42%**

2.5 FLAKINESS AND ELONGATION INDEX TEST ON STEEL SLAG

This test reveals the proportion of flaky and elongate aggregate in the sample's overall aggregate. Flakiness index is defined as the percentage weight of the aggregate whose thickness is less than 3/5th of their mean dimension. This test is conducted on the aggregate having size larger than 6.3 mm. The weighted percentage of aggregates whose length is more than 1 and 4/5th (1.8 times) of their mean dimension is known as the elongation index of aggregate. Elongation is the measure of the ductility of a material that is determined by a tension test.

CALCULATIONS OF FLAKINESS AND ELONGATION INDEX TEST:

Flakiness index of an aggregate = (W2/W1) *100

The Flakiness index of an aggregate is = (Total weight of aggregate passing flakiness gauge * 100) / Total weight of test sample

Total weight passing flakiness gauge = W2

Total weight of test sample = W1

The flakiness index on an aggregate is = (W2/W1) *100

OBSERVATIONS OF FLAKINESS AND ELONGATION INDEX TEST:

IS Sieve size	IS Sieve size	Sample Wt.	Wt. of Aggregate Passing Gauge	Wt. of Non-Flakiness Aggregate	Wt. of Aggregate Retained on Elongation Gauge
Passed	**Retained**	**(gm)**	**(gm)**	**(gm)**	**(gm)**
63	50	-	-	-	-
50	40	-	-	-	-
40	31.5	-	-	-	-
31.5	25	-	-	-	-
25	20	3250	210	3225	285
20	16	1531	175	1410	175
16	12.5	1040	105	875	170
12.5	10	660	115	410	280
10	6.3	-	-	-	-
		6481	**605**	**5920**	**910**

= (605*100)/6481=**9.33%** = (910*100)/5920= **15.37%**

Total = 24.70%

2.6 CRUSHING VALUE TEST OF STEEL SLAG

In this experiment the pavement material which can fail is by crushing under compressive stress is identified. This test indicates the strength of coarse aggregate which is essential property of the aggregate. It is used to determine the crushing strength of aggregates. Crushing value indicates the strength of the aggregate. Lower crushing value recommended as it indicates a lower crushed fraction under load and would give a longer service life and a more economical performance. The aggregates used to construct pavements and roads must be hardy enough to withstand being crushed by cars and rollers.

CALCULATIONS OF CRUSHING VALUE TEST:

For determining the crushing value, the below mentioned formula is used,

Aggregate crushing value = (W3\W) *100,

Where W1 = Empty weight of cylindrical Measure.

W2 = Weight of Aggregate with Cylindrical Measure.

W3 = Weight of the fraction passing through the 2.36 mm IS sieve

W = W2 –W1 = Weight of Aggregate Sample

OBSERVATIONS OF CRUSHING VALUE TEST:

OBSERVATION-1:

W = 3244gm W3 = 390gm

Crushing Value = (390/3244) *100 = 12.02%

OBSERVATION-2:

W = 3375gm W3 = 383gm

Crushing Value = (383/3375) *100 = 11.35%

OBSERVATION-3:

W = 3298gm W3 = 387gm

Crushing Value = (387/3298) *100 = 11.73%

AVERAGE RESULT OF CRUSHING VALUE TEST:

Average Crushing Value = (12.02+11.35+11.73)/3 = **11.70%**

III. COMPARISON BETWEEN NATURAL AND STEEL SLAG AGGREGATES BASED ON TESTS PERFORMED:

TESTS	NATURAL AGGREGATE	STEEL SLAG AGGREGATE
AGGREGATE ABRASION TEST	23.56%	17.03%
AGGREGATE IMPACT VALUE TEST	12.02%	8.24%
AGGREGATE FLAKINESS AND ELONGATION TEST	25.19%	24.70%
AGGREGATE SOUNDNESS TEST	3.54%	3.42%
AGGREGATE STRIPPING VALUE TEST	4.37%	4.1%
AGGREGATE CRUSHING VALUE TEST	16.67%	11.70%

Steel slag aggregate surpasses natural aggregate by **27.72%** in aggregate abrasion test, **31.41%** in aggregate impact value test, **1.94%** in aggregate flakiness and elongation test, **3.39%** in aggregate soundness test, **6.17%** in aggregate stripping value test and **29.81%** in aggregate crushing value test.

IV. ADVANTAGES OF STEEL SLAG

1. Due to its higher strength and angularity, steel slag could retain more edges and corners after wheel grinding under heavy loading. Therefore, the higher content of steel slag could provide better skid resistance.
2. Containing no organic impurities, clay, shells or other substances that can affect concrete durability. And no expansion due to alkali-aggregate reaction.
3. Discarded steel slag material can be utilized in the production of eco-friendly interlocking concrete paving blocks to help prevent environmental pollution and indiscriminate disposal on the environment.
4. Steel slag has high activity, good stability, and can handle solid slag.
5. The main advantage of steel slag is its cost-effectiveness. Because it's produced as a by-product of metal melting, it's generally much cheaper than traditional aggregates or materials like asphalt or concrete.
6. Steel slag has great compressive strength and can be used as an alternative to gravel or other materials in roadbeds and foundations. Furthermore, its heat resistance makes it useful for applications where temperatures may get hot enough to damage more traditional materials like asphalt.
7. Steel slag also has several environmental advantages over traditional materials. For example, it reduces air pollution because its production doesn't require burning fossil fuels like oil or natural gas that produce harmful emissions when burned. Additionally, because it doesn't require mining to obtain raw materials (like sand and gravel do), there are fewer environmental impacts associated with steel slag production than with traditional construction materials. Finally, steel slag is resistant to erosion so roads built with this material can last longer than roads made with other types of aggregate or asphalt.

V. LIMITATIONS ASSOCIATED WITH STEEL SLAG

1. It is not appropriate for all structural building and road construction applications.
2. However, using steel slag as a construction material for roads is not without its challenges. For instance, heavy metal residues in steel slag may be dangerous for both human and environmental health.
3. Uneven particle size, Subsequent crushing and long processing cycle are few more limitations to this project.

VI. CONCLUSION

It can be inferred from the study and analysis done on the usage of steel slag as road aggregate that it is an effective and sustainable substitute for natural aggregates. Excellent physical and mechanical characteristics of steel slag make it suitable for use as a road aggregate. It features a high degree of angularity and a rough surface roughness, which improves pavement friction and skid resistance. It is also excellent for usage in high traffic locations because to its high stability and shear strength. Utilizing steel slag in road construction paves the way for practical waste utilize and reduces reliance on cyclical regular methods of road construction and implementation in various fields. Greenhouse Gases are also anticipated to decrease during this cycle. The development expenses of such steel slag streets will be 30% less expensive. The challenges with waste disposal linked to the production of steel waste may be lessened by using steel slag as a road aggregate. This promotes sustainable future and environment friendly.

VII. FUTURE SCOPE

The availability of steel slag, the characteristics of steel slag as an aggregate material, the economic viability of employing steel slag, and the environmental effects of its usage are some of the variables that will determine the future scope of a project on steel slag as a road aggregate. The project on using steel slag as a road material has a broad range of possible applications for enhancing the performance and sustainability of road building in future. It involves testing and analysing steel slag's performance, mix design optimization, life cycle analysis, building and maintenance, and economics. The project is being conducted to examine the environmental impact of the material, including its carbon footprint, energy use, and possibilities for waste reduction. It is also being conducted to research the methods used in the building and upkeep of roads utilizing steel slag as an aggregate, including the employment of cutting-edge methods like geosynthetics and pavement recycling.

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