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Experimental Study on Mechanical Properties of Bituminous Paving Mixes Using Steel Slag

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Abstract: **In flexible pavement construction, the bituminous mixes are most commonly used. It consists of bitumen (used as a binder) and mineral aggregate which are mixed together, laid down in layers. The performance of bituminous mixes is very poor under various situations. Considering this a lot of work has been done on the modification of bitumen. Steel slag is a co-product of the steel industry and can be used potentially as a sustainable construction material in bituminous mix with proper mix design. As natural aggregate sources are becoming depleted due to high demand in road construction and the amount of disposed waste material keeps increasing, researchers are exploring the use of alternative materials which could preserve natural sources and save the environment. This study evaluates the use of Steel Slag as a substitute for fine aggregates in the production of bituminous mix for road construction. Based on Intensive laboratory testing program, the characteristic properties of steel slag were assessed to determine its suitability to be used in bituminous mix. Four different percentages (0, 25, 50, 75, and 100%) of steel slag aggregate were used, and the proposed mix designs for bituminous concrete mix were conducted in accordance with Marshall Mix design. The experiment results revealed that the addition of Steel slag has a significant improvement on the properties of bituminous concrete mix. An Increase in density and stability and a reduction in flow and air voids values were clearly observed in specimens prepared with (0, 25, 50, 75, 100) percentages. It is concluded that the steel slag can be considered reasonable alternative source of fine aggregate at 50 percentages for bituminous concrete mixture production.**

Keywords: **Steel Slag, Bituminous concrete (BC), Marshall Properties and Indirect tensile strength.**

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. Steel slag is a co-product of the steel industry and is, with proper design, a sustainable construction material. The disposal of steel slag in landfills now has to pass strict environmental regulations. Obviously, steel slag should not be used in Portland cement concretes or related mix types such as lean concrete because it will result in rapid destruction of the concrete. Steel Slag has been used in the road laying work as a viable recyclable material due to its mechanical excellence in terms of its strength, skid and abrasion resistance compared to natural aggregate. The Incorporation of steel slag as a partial replacement of fine aggregate in bituminous concrete mix has been evaluated extensively in many parts of the world. Steel-slag is reported to exhibit great potential as a replacement for natural aggregates in road construction. From National Slag Association, Steel-Slag Aggregates have been reported to retain heat considerably longer than natural aggregates. The heat retention characteristics of steel-slag aggregates can be advantageous for bituminous concrete construction, Based on high frictional and abrasion resistance, steel-slag is used widely in industrial roads, intersections, and parking areas where high wear resistance is required. Steel-slag, a dark coloured material, is hard, dense, and abrasion resistant. It contains a significant amount of free iron, giving the material high density and hardness. According to World Steel Association 400 million tonnes of steel slag *is* produced every year around the world. In India total steel slag production is about 25 million tones. In addition, steel-slag is chemically stable and shows excellent binding properties with bitumen, has a low flakiness index, good mechanical properties, and good anti-skid resistance.

1. Scope:

- An experimental work has been proposed to improve the properties of bituminous concrete pavement using steel slag.
- Laboratory studies will be carried out on bituminous concrete mix to evaluate engineering properties using Marshall Stability and Indirect Tensile Strength studies.

2. Objective:

Main objectives of bituminous mix design are to find;

- Optimum bitumen percentage replacement in the BC mixes.
- To compare the High Performance BC mixes with the Conventional BC mixes in term of stability, flow value and indirect tensile strength.

3. Role of Steel slag in Bituminous Pavements:

Steel slag aggregates have properties to retain heat considerably longer than conventional natural aggregates. The heat retention characteristics of steel slag aggregates can be advantageous during variable weathering conditions. It has over 20 % interconnecting voids. These voids absorb noise from the traffic and allow water to drain. In addition, less water on the road means better tyre/road grip and less spray effects improve the driver's visibility. Roads built with porous asphalt using steel slag are quiet, safe and long-lasting.

This study aims to investigate the feasibility of utilizing steel slag aggregates in bituminous concrete mixtures. The use of steel slag as the fine portion of aggregates can enhance Marshall Stability, Tensile Strength, resistance to moisture damage and resistance to the permanent deformation of bituminous concrete mixtures. For the present study, the steel slag has been taken from the karaikal steel plant.

II. METHODOLOGY

This chapter deals with the project work flow methodology of our project.

1. Steps Involved in the Present Work:

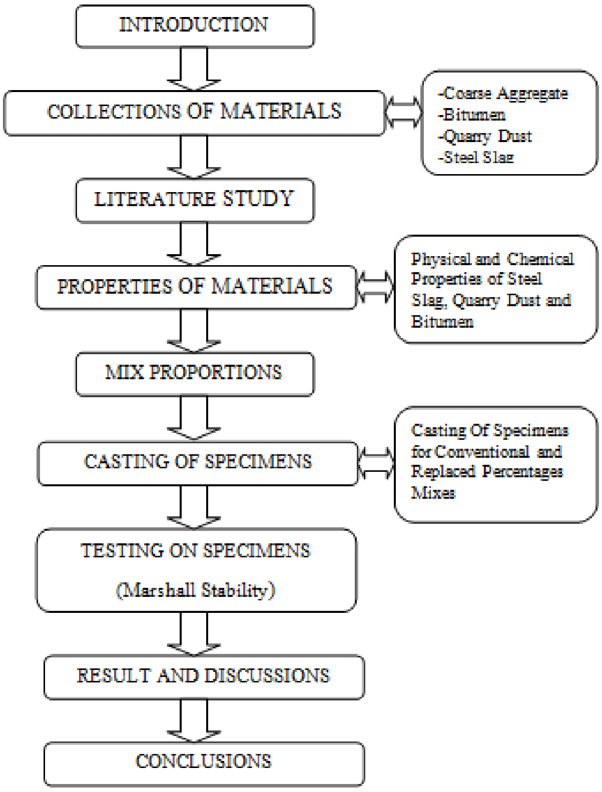

Fig 1: Work Methodology

2. Aggregates:

As per the code of Indian Roads Congress (IRC 29-1988). The material for the bituminous concrete mixes are selected

The basic materials used are as follows:

- Aggregates of size 19mm, 13.2mm, 6.7mm.
- Quarry dust of size lesser than 4.75mm
- Steel Slag of size lesser than 4.75mm
- Bituminous Binder of grade VG-30

3. Micro Structural Analysis of Steel Slag:

SEM Analysis

SEM is an effective tool for visually examining the particles that are too small to be seen under an optical microscope. The SEM works by aiming an electron beam at the surface of the specimen.

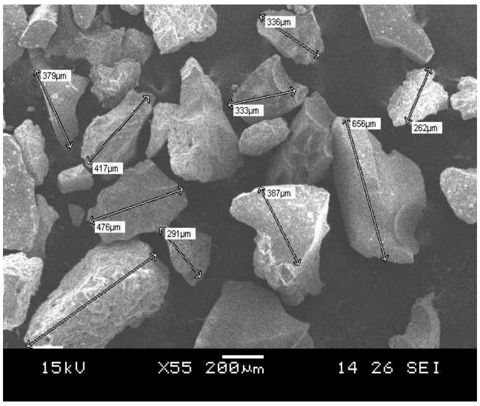

Fig 2: SEM Analysis Of steel slag

SEM Micrographs showing the shape and surface texture of Steel Slag particles respectively. The SEM studies showed that the sand and silt-size steel slag particles had sub-rounded to angular shapes. Distinct asperities and edges were visible in angular, bulky particles. Most of the sand and silt-size particles examined under the SEM had rough surface textures.

XRD Analysis:

In the next step X-Ray Diffraction (XRD) analysis is performed to determine the silica phase of the samples. The samples are scanned by an X-Ray diffract-meter which is shown in Figure.

XRD report summarizes all of the mineral phases that were identified in the Steel Slag samples. The mineral phases identified in the Steel Slag samples were determined as major or minor phases depending on the intensity of the peaks, which is an indication of the quantity of the minerals present in the samples. The most abundant mineral phase present in steel slag is Silicon oxide 15.6% (SiO_2), iron 20% (fe_2O_3) and calcium oxide 41% (CaO)

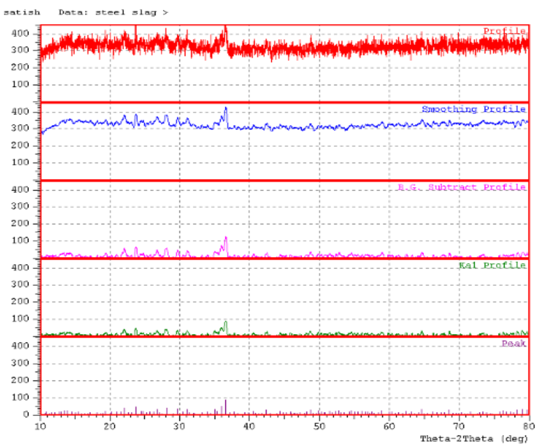

Fig 3: XRD Analysis Of steel slag

Table: 1: Chemical Properties of Steel Slag

Chemical properties	
% of Sio_2	15.6
% CaO	41
% fe_2O_3	20
Appearance	Black

4. Properties of Material:

The physical properties of the Steel Slag, Quarry dust, coarse aggregate and bitumen are tested as per the standard codes; the specified properties of the materials are as follows.

Properties of Quarry Dust and Steel Slag

Table 2: Properties of Steel Slag and Quarry Dust

S. No	PROPERTIES	STEEL SLAG	QUARRY DUST	STANDARD VALUE
1	Specific gravity	2.8	2.73	2.2-2.85
2	Fineness modulus	3.8	3.95	2.2-3.2
3	Gradation(Zone)	Zone-I	Zone-II	I – IV

Coarse Aggregate:

Table 3: Properties of Coarse Aggregate

S. No	PROPERTIES	REFERENCES	OBSERVED VALUES	STANDARD VALUES
1	Specific gravity	IS:2386-1963 Part-2	2.69	2.6-2.9
2	Water absorption	IS:2386-1963 Part-3	1.08%	Max 2%
3	Crushing value	IS:2386-1963 Part-4	18.15%	Max 30%
4	Impact value	IS:2386-1963 Part-4	18.81%	Max 20%
5	Abrasion test	IS:2386-1963 Part-4	11.05%	Max 40%

Bitumen:

Table 4: Properties of Bitumen

S. No	NAME OF TEST	REFERENCES	EXPERIMENAL VALUE	STANDARD VALUE
1	Penetration	IS:1203-1978	61	60-70mm
2	Ductility	IS:1208-1978	41	38 to 45cm
3	Softening point	IS:1206-1978	49^oC	40^oC to 59^oC
4	Specific gravity	IS:1202-1978	1.35	Min 0.99

III. TESTING DETAILS

1. Marshall Stability Test:

As per ASTM D1559 (Marshall Mix Design Method) Marshall Stability testing setups was used. Tests were performed to determine the Marshall stability, flow value, optimum bitumen content and amount of bitumen required for mix types containing different percentage of filler

Table 5: Compactions of Specimens

Type of traffic	No. of blows
Low traffic	35
Medium traffic	50
Heavy traffic	75

Fig 4: Marshal Test Apparatus

Table 6: Replacement Percentage

% of Replacement	**Steel slag (%)**	**Q.Dust (%)**
0	0	100
25	25	75
50	50	50
75	75	25
100	100	0

The partial replacement percentages were taken based on the study of literatures on use of Foundry sand as filler material replacement in the asphalt paving mixes.

2. Batching Of Materials:

The combinations of materials were taken from following percentage of 1200grams.

19mm-12%

13.2mm -20%

6.7mm-23%

Dust-45% (Dust and Steel Slag)

Bitumen -5%, 5.5%, 6% and 6.5%

Testing of Sample: Marshall Test is a simple and low cost standard laboratory test adopted all over the world for design and evaluation of bituminous mixtures.

Before

after testing

Fig 5: Tested Samples

3. Design Parameters:

As per ASTM D7263, the following parameters are studied and they are calculated from the obtained values.

- Bulk specific gravity of aggregate
- Bulk specific gravity of compacted mixture
- Maximum specific gravities of mixtures
- Air voids in compacted mixture
- Voids in mineral aggregate
- Voids filled with asphalt
- Indirect tensile strength (ITS)

IV. RESULT AND DISCUSSIONS

This chapter deals with the results obtained from the Marshall Stability test, and the calculations are tabulated below.

1. Conventional Mix:

This table results shows the without replacement of the waste foundry sand in the mix, the obtained and calculated values as follows.

Table 8: 0%Replacement Results

BC %	Wt in air (g)	Wt in Water (g)	Stability (kg)	Flow value (mm)	VMA (%)	AV %	VFB (%)	Strength (N/mm^2)
5	1256	741	1332	2.84	4.76	3.97	16.74	1.32
5.5	1268	746	1634	3.7	5.21	3.84	26.37	1.62
6	1272	750	1855	3.5	5.66	3.03	46.49	1.79
6.5	1273	754	1561	4.4	6.10	1.89	69.08	1.54

2. High Performance Bituminous Concrete With 25% Steel Slag:

Table 9: 25%Replacement Results

BC %	Wt in air (g)	Wt in Water (g)	Stability (kg)	Flow value (mm)	VMA (%)	AV (%)	VFB (%)	Strength (N/mm^2)
5	1264	754	1418	2.96	4.76	4.6	21.79	1.40
5.5	1271	763	1640	3.61	5.21	3.2	38.28	1.62
6	1271	765	1711	4.12	5.66	2.3	59.32	1.69
6.5	1274	762	1458	4.03	6.10	2.6	55.80	1.44

3. High Performance Bituminous Concrete With 50% Steel Slag:

Table 10: 50%Replacement Results

BC %	Wt in air (g)	Wt in Water (g)	Stability (kg)	Flow (mm)	VMA %	AV %	VFB %	Strength (N/mm^2)
5	1252	752	1458	2.62	4.7	3.8	20.0	1.44
5.5	1260	765	1752	3.60	5.2	1.6	68.0	1.73
6	1266	767	1620	4.0	5.6	1.4	74.3	1.60
6.5	1279	773	1245	4.5	6.1	1.2	78.9	1.23

4. High Performance Bituminous Concrete With 75% Steel Slag:

Table 11: 75%Replacement Results

BC %	Wt in air (g)	Wt in Water (g)	Stability (kg)	Flow mm	VMA %	AV (%)	VFB %	Strength (N/mm^2)
5	1259	756	1316	3.7	4.7	3.9	16.5	1.3
5.5	1268	763	1509	4.2	5.2	3.1	39.9	1.4
6	1273	762	1580	4.5	5.6	3.3	40.5	1.5
6.5	1273	764	1235	4.4	6.1	2.4	59.7	1.2

5. High Performance Bituminous Concrete With 100% Steel Slag:

Table 12: 100%Replacement Results

BC %	Wt in air (g)	Wt in Water (g)	Stability (kg)	Flow mm	VMA (%)	AV %	VFB %	Strength (N/mm^2)
5	1279	766	850	1.6	4.7	4.4	5.9	0.84
5.5	1282	764	962	1.8	5.2	4.6	10.8	0.95
6	1283	760	891	2.8	5.6	4.9	12.2	0.88
6.5	1285	759	698	2.5	6.1	4.8	20.6	0.69

Comparing the replacement of Steel Slag from the 0 to100%, stability increases up to 50%, and decreases gradually for 75 and 100% in the 5.5% bitumen content

Table 13: Percentage of Increases

BC %	Stability(Kg)		% of Increases	Indirect Tensile Strength(N/mm^2)		% of Increases
	Conventional	50%		Conventional	50%	
5	1332	1458	8.6	1.32	1.44	8.3
5.5	1634	1752	6.7	1.62	1.73	6.4
6	1855	1620	0	1.79	1.60	0
6.5	1561	1245	0	1.54	1.23	0

This graph shows the representations of the Stability value and bitumen content of 5.5% for the various replacements of the Steel Slag.

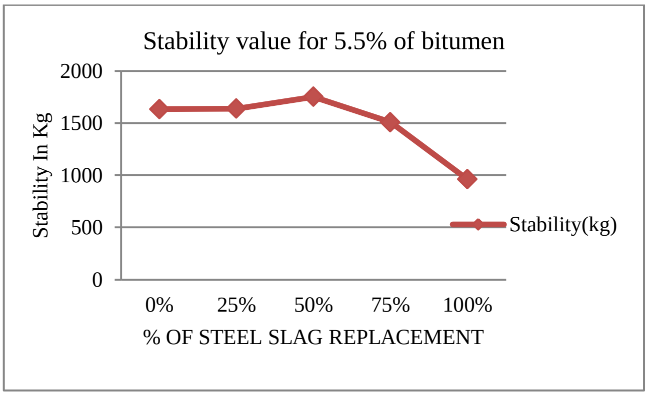

Fig 11: % of Steel Slag Vs Stability for 5.5% BC

This graph shows the representations of the Air voids and % of Steel Slag Replacement.

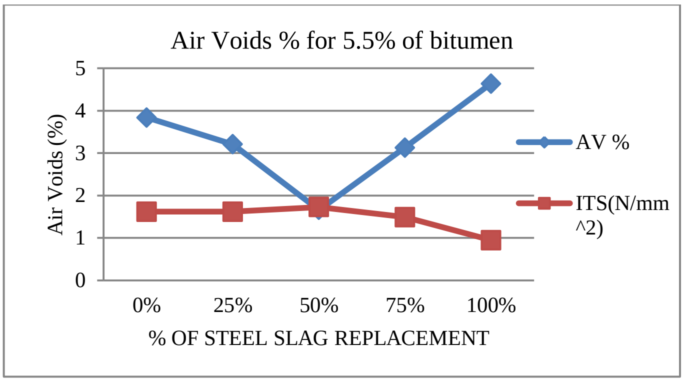

Fig 12: % of Steel Slag Vs Air voids 5.5% BC

Cost Comparison:

Table14: conventional cost

Material	Quantity	Rate/m^3	Total
Coarse Aggregate	0.75Cu.mt	2400	1800
Fine Aggregate (Quarry Dust)	0.65Cu.mt	1600	1040
Bitumen	50.3Kg	47/Kg	2364
Total			5204

Table 15: Cost of WFS material

Material	Quantity	Rate/m^3	Total
Coarse Aggregate	0.75Cu.mt	2400	1800
Fine Agg.(Slag)	0.65Cu.mt	-	-
bitumen	50.3Kg	47/Kg	2364
Total			4164

This estimated material and cost for the Bituminous Concrete for the 40mm thick. Therefore saving in cost per10 m^2 is Rs.1040 by using Steel Slag replacement for fine aggregates in bituminous mix. Hence saving in cost for 1 m^2 is Rs.104

V. CONCLUSION

Steel slag, which is waste material derived from the steel industry, is a promising candidate for use as fine aggregate in BC mix. Overall Steel slag as fine aggregate replacement shows the potential for excellent performance when used in a proper BC mix design.

The conclusions drawn from this study are as follows:

- The mix design study shows that the addition of steel slag as fine aggregate reduces the demand for bituminous content in the mix.
- The addition of steel slag might be a good economical approach to a sustainable outcome. Also the use of steel slag could also be beneficial in light of environmental concerns.
- In terms of optimum bitumen content, the steel-slag mixture has a higher value than the conventional mixture. This is due to the higher degree of porosity possessed by steel-slag aggregates.
- The physical properties indicate, the addition of steel slag increases studded tire wear resistance, thermal cracking resistance, and rutting resistance.
- In terms of rutting, the mixture prepared with steel-slag has greater cohesive strength compared to the conventional mixture. Thus, bituminous concrete wearing using steel-slag has a higher load resistance than the conventional mixture.
- However, SSA has little effect on top-down fatigue cracking resistance and moisture susceptibility of the sample mixes. Based on laboratory test results, SSA appears to be especially beneficial for the NH and SH.

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