Assessing the Utilization of Steel Slag in Asphalt Mixtures of Flexible Pavements

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Abstract:- Production is always accompanied with generation of waste. A waste is not a waste unless we find its potential to utilize it as resource. In India there are many steel plants which are producing several million tons of steel. However, the production of steel is associated with generation of slag, a solid waste. This large quantity of steel slag generated has no significant applications and is dumped haphazardly.On the other hand, industrialization and infrastructure development in large scale has caused depletion of natural resources that has resulted in scarcity of natural construction materials. Hence, it is imperative to find alternatives for conventional construction materials. Many researches have been carried out to use industrial waste for construction activities. Steel slag is one potential industrial mixtures of flexible pavements. The study was conducted by mixing the steel slag with different proportions like 10%, 20%, 30%, 35% and results were analyzed for many scope of application as a substitute for natural aggregates and tested for liberation of potential harmful gases with the addition of steel slag.

Keywords: *Steel Slag, Bitumen , Specific Gravity, Marshall Mix Design, Optimum Binder Content, Thermo Gravimetric Analysis, Indirect Tensile Strength, Tensile Strength Ratio, Stiffness Modulus, Rutting*

I. INTRODUCTION:

India comprises a large number of steel plants and they are producing several million tons of steel. However, the production of steel is always associated with generation of slag, a byproduct obtained either from conversion of iron to steel in a Basic Oxygen Furnace (BOF), or by the melting of scrap to make steel in the Electric Arc Furnace (EAF). The quantity of crude steel production is around 80 million tons per year (Annual report, 2014 – 15 Ministry of Steel, GOI) from different steel industries in India. On average the production of 1 ton of steel results in 200 kg (EAF) to 400 kg (BF/BOF) of Slag i.e., 20 – 40% of the production (Palassanjay*et al*, 2015). Presently, this large quantity of slag generated has no significant applications and dumped on the land available near the plants. These materials are posing disposal problems that are both economically and environmentally expensive.Presently, this large quantity of slag generated has no significant aggregates in road construction works in India if its technical feasibility is proven as per the conventional construction practice in the country waste that can be utilized as an alternative for natural. Road sector is a large consumer of natural aggregates; therefore steel slag can effectively be used as a replacement in large volume.Reuse of steel slag as an alternative can be seen as a way to limit the amount of waste disposed, minimize the consumption of natural resources and also reduces environmental pollution, since it is being dumped as a waste .The objective of this study is to assess the utilization of steel slag in flexible pavements. This research work mainly focuses on using the steel slag as a replacement for natural aggregate in Asphalt mixtures in various proportions as per Indian codepractice and aims to ascertain the maximum amount (%) that can be used as an alternative to natural aggregate in asphalt

1.2 Objective and Scope

The objective of this study is to assess the possibility of utilizing steel slag as a replacement for natural aggregate in asphalt mixtures for the construction of flexible pavements. For this it is aimed to,

i. Investigate the Physical properties of the Steel slag collected.
ii. Replace natural aggregate with the Steel slag. (% by weight)
iii. Prepare test specimens of various proportions of Steel slag.
iv. Study the Volumetric properties of those specimens and its Marshall properties such as stability and flow.
v. Ascertain the Optimum (%) of the steel slag that can replace natural aggregate
vi. Determine the mechanical properties of mix by performance based tests such as Stiffness Modulus and Indirect Tensile Strength tests.
vii. Determine the mix response to Rutting
viii. Study the effect of using steel slag on environment through Thermo Gravimetric Analysis
ix. Compare the results of steel slag Asphalt mixtures with conventional asphalt mixtures.

2.1 Methodology

Based on the review of literature, the methodology was formulated. To achieve the objectives, different proportions of steel slag were added as a replacement for natural aggregate and tested for conventional properties. The detailed methodology is given in Figure 2.1

2.1.1 Bitumen – VG30 Grade

The bitumen used in this study is VG 30 grade which is most commonly used for road construction in India. Conventional bitumen with known characteristics is used in this study and its properties are shown in table 3.1,

2.1.2 Steel Slag

Steel slag is a byproduct obtained from the conversion of steel from Iron in steel melting shops. The Steel slag sample required for this study is collected from Mecheri town Salem, Tamilnadu in required quantities. The physical characteristics of the collected sample were studied and discussed below. The chemical composition of the steel slag is shown in table 3.2.

Fig: 2.1 Steel Slags

2.1.3 Analysis of physical properties of natural aggregate and steel slag

To ensure that the collected sample meets the required specification to be used as a replacement for the natural aggregate, a series of laboratory tests were carried out as specified by the Ministry of Road Transport & Highways (MoRTH) specificationV revision and it has been detailed in Table 3.3. the details of the tests carried out are detailed below

Table II. Characteristics of VG30 Bitumen

S. No	Characteristics	Requirement as per IS 73-2013	VG 30 used
1	Penetration @ 25° C, in mm	45 (minimum)	47
2	Softening point (R&B) °C	47 (minimum)	51
3	Kinematic Viscosity @ 135° C, cSt	350	380
4	Absolute Viscosity @ 60° C, Poises	2400-3600	2890
5	Solubility in Trichloroethylene, %	99(minimum)	100
6	Flash point °C, COC	220 (minimum)	250 +
7	**Test on residue from TFOT**		
a	Viscosity ratio at 60° C	4.0 (maximum)	2.9
b	Ductility @ 25°C, cm	40 (minimum)	70

Source: HRS, Chennai.

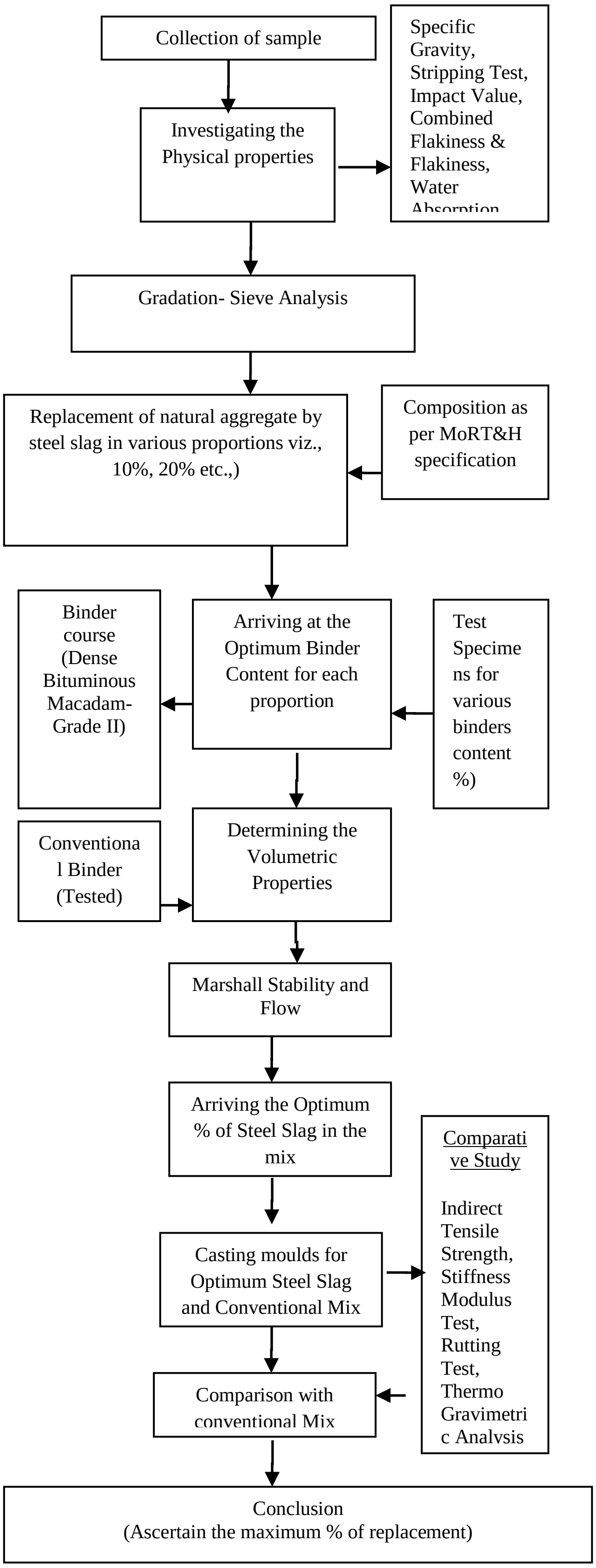


Fig: 2.2Methodology Flow Chart

Table II(b) Chemical Composition of Steel Slag

S. No	Constituent	Composition (%)
1	CaO	40-52
2	SiO2	10-19
3	FeO	10-40
4	MnO	5-8
5	MgO	5-10
6	Al2O3	1-3
7	P_2O_5	0.5-1
8	S	<0.5
9	Metallic Fe	0.5-1.0

Source: Palas sanjay et al.

Table II(c) Physical properties of Coarse aggregates for DBM as per MoRTH specification V revision

S.No	Property	Test	Specification
1	Gradation	Sieve Analysis	-
2	Specific Gravity	Pycnometer	IS 2386 (Part III)
3	Shape of Particles	Combined Flakiness and Elongation Index	IS 2386 (Part I)
4	Strength	Aggregate Impact value	IS 2386 (Part IV)
5	Water absorption	Water absorption	IS 2386 (Part III)
6	Stripping	Coating and Stripping of Bitumen Aggregate mix	IS - 6241

3.0 Results and Discussion:

3.1 Physical Properties of SS and NA

3.1.1 Sieve Analysis

Gradation of Steel slag was carried out with a series of IS sieves ranging between 37.5 mm and 75 micron. The results are given below in table 3.1. From the test carried out to analyze the size of the Steel slag, result obtained is 26.5 mm a, which can be used as a substitute for natural aggregates.

Table 3.1 Gradation of steel slag – Sieve Analysis

S.No.	Sieve size in mm	Steel Slag (Total Weight taken = 5140 g)		
		Wt. Rt. In gram	Wt. Pas. In gram	% Passed
1	37.5	0	5140	100.00
2	26.5	424.5	4715.5	91.74
3	19	1343	3372.5	65.61
4	13.2	1958	1414.5	27.52
5	4.75	1282	132.5	2.58
6	2.36	78	54.5	1.06
7	0.3	24.5	30	0.58
8	0.075	19.5	10.5	0.20
Total		5129.5		

3.1.2 Specific Gravity Test ((IS 2386 (Part III) – 1963)

The specific gravity of natural aggregate and steel slag were determined as follows,

Weight of the Jar, W1 = 692.27g

Weight of jar and Aggregate (Slag), W2 = 1612.14 g

Weight of Jar, Aggregate and water, W3 = 2141.82 g

Weight of jar and water, W4 = 1563.04 g

The specific gravity of the steel slag (sample) is calculated by,

$$\text{Specific Gravity} = \frac{W2 - W1}{(W4-W1) - (W3 - W2)} = \mathbf{2.697}$$

Similarly, the specific gravity of natural aggregate is found to be 2.70.

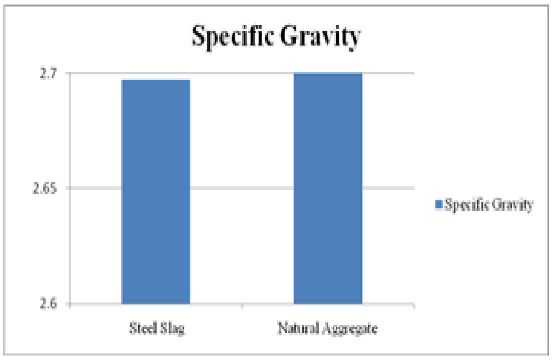


Fig 3.1Specific gravity of Steel slag and Natural Aggregate

It was inferred that the specific gravity values for steel slag and natural aggregates was similar.

3.1.3 Aggregate Impact Test (IS:2386 (part –IV)-1963)

The Impact value of the natural aggregate and steel slag were determined as follows,

Impact value of steel slag,

Total weight of the dry sample (W1) – 366.0 gm

Weight of the portion passing through 2.36 mm Seive (W2)– 89.0 gm

Aggregate Impact Value (%) = (W2 / W1) x 100

= (89.0 / 366.0) x 100

= 24.32 %

Similarly, the impact value of natural aggregate was found to be 21%, as shown in fig 4.3.

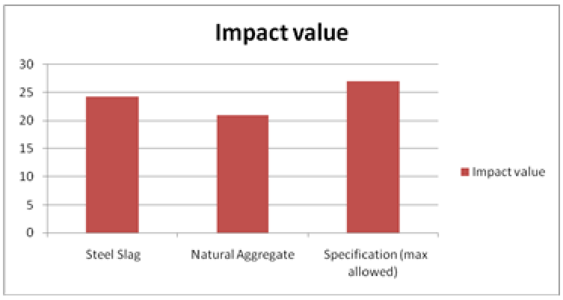


Figure 3.2Aggregate Impact Value

The impact values of both steel slag and natural aggregate are well within the permissible limit specified by MoRTH which is 27%. The specifications given by MoRTH.

3.1.4 Water Absorption Test IS2386 – Part III

The water absorption for steel slag and natural aggregate observed are given in Table 4.2

Table III (a)Water absorption of NA and SS

S.No	Description	Steel slag	Natural aggregate
1	Wt. of saturated surface dried sample (A) in g	2706.8	2761.90
2	Wt. of oven dried sample (B) in g	2680	2740
3	Water absorption $= \frac{A-B}{B} \times 100$	1%	0.8%

MoRTH specifies a maximum water absorption of 2%. The results obtained here for steel slag is well within the limit.

3.1.5 Stripping value of the Aggregate (IS:6241)

The stripping value observed for steel slag is 98% and natural aggregate is 99%. The minimum retained coating specified by MoRTH is 95%.

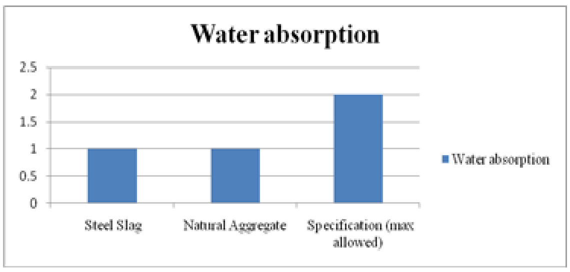


Fig 3.3: Water Absorption

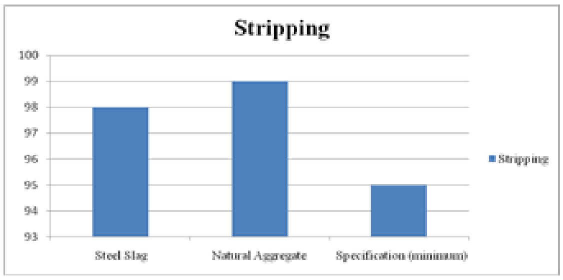


Figure 3.4 Stripping value of NA and SS

The physical properties of the steel slag and natural aggregate found are summarized in the following table 3.3

Table 3.3 Physical Properties of SS and NA

S.No	Property	Test	Specification	Steel Slag	Natural Aggregate
1	Gradation	Sieve Analysis	-	26.5 mm downgraded	-
2	Specific Gravity	Pycnometer	-	2.697	2.7
3	Strength	Aggregate Impact value	Max 27 %	24.2 %	21%
4	Water absorption	Water absorption	Max 2%	1%	0.8%
5	Stripping	Coating and Stripping of Bitumen Aggregate mix	Min retained Coating 95%	98%	99%

3.2 Mix Design – Marshall Method

The Asphalt mix adopted in this study is Dense Bituminous Macadam (Binder course of flexible pavement) grade II. Marshall moulds were prepared for conventional Asphalt mix and Steel slag mix in various proportions of steel slag starting from 10% replacement of natural aggregate. The aggregate gradation adopted is given in table 3.4 and shown in fig.4.9

Table 3.4 Combined Gradation ofAggregate

Sieve size (mm)	Cumulative percent by weight of total aggregate passing	
	Specified grading (MoRTH)	Adopted grading
37.5	100	100
26.5	90-100	100
19	71-95	82.33
13.2	56-80	73.60
4.75	38-54	43.67
2.36	28-42	33.09
0.3	7-21	14.90
0.075	2-8	4.60

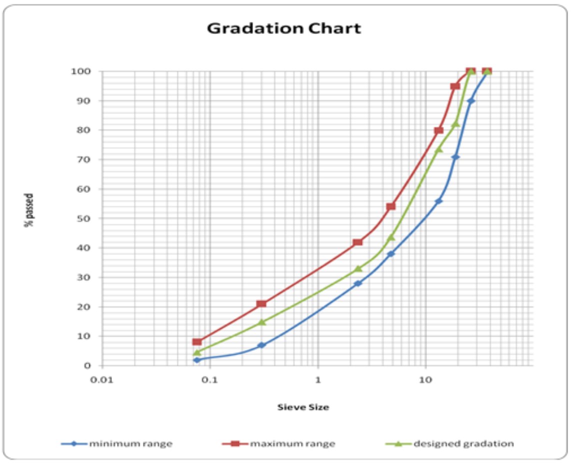


Fig 3.5: Gradation Chart

3.2.1 Volumetric Properties of the mix

The following volumetric properties of the extracted samples were analyzed to ascertain the Marshall stability and flow for the samples for determining the Optimum binder content for the proportion of DBM mix.

Theoretical specific gravity of the mix, G_t(g/cc)

= 100/([100-Pb] /Gse) + (Pb / Gb)

Where, Weight of binder mix Pb = %by Specific Gravity of Bitumen G_b = 1.038 Specific Gravity of Aggregate G_{se} = 2.760 Substituting values, Theoretical Specific Gravity G_{mm} = 2.59 g/cc

Bulk specific gravity of mix, G_m

Density measured from mix 2 Where, Weight of mix in air =1245.80 Weight of mix in water (Buoyancy wt)= 735.10g Saturated surface dry weight (SSD) = 1249.70g Density of the mix given by = Wt in air/ (SSD wt – Wt in water) Bulk specific gravity of mix , G_m = 2.421 g/cc

Air Voids Percent ,V_a

= Gmm–Gmb /Gmm * 100

Where, Maximum Theoritical Specific Gravity= 2.59 Kg/cc Bulk Specific Gravity =2.421 Kg/CCSubstituting values, Theoretical Specific Gravity G_{mm} = 2.59 g/cc Air voids percent Va **= 6.53 %**

Voids in Mineral Aggregate , VMA

= (100 – (Gmb (100-P_b)– Gse) * 100

Where, Bulk Specific Gravity = 2.421 Kg/CCPb = % by Weight of binder in MixGse = Specific Gravity of the aggregateSubstituting values Voids in mineral aggregateVMA = 15.51 %

Voids filled with bitumen, VFB

= (VMA -V_a/ VMA) * 100

Where, Voids in Mineral Aggregate VMA = 15.51% Air Voids V_a = 6.53% Substituting values, Voids filled with Bitumen VFB = 57.92 %

Table 3.5 Volumetric Properties obtained for Conventional DBM

% by Wt. of Binder Content	Bulk Specific Gravity, Gmb, g/cc	Theoritical Specific Gravity, Gmb, g/cc	Air Voids, Va, %	Voids in Mineral Aggregate, VMA, %	Voids Filled with Bitumen, VFB, %
4 %	2.425	2.59	6.53	15.51	57.92
4.5 %	2.457	2.58	4.61	14.81	68.84
5%	2.485	2.56	2.85	14.25	80.02
5.5%	2.461	2.54	3.12	15.48	79.86

3.2.2 Optimum Binder Content

A Graph is plotted for Binder Content (% by Wt. of the aggregate) Versus % Air voids as shown in fig.4.16 . The binder content corresponding to 4 % air voids is considered as Optimum Binder Content. From plot, OBC obtained for Conventional DBM Mix is 4.62 %by wt. of the aggregate

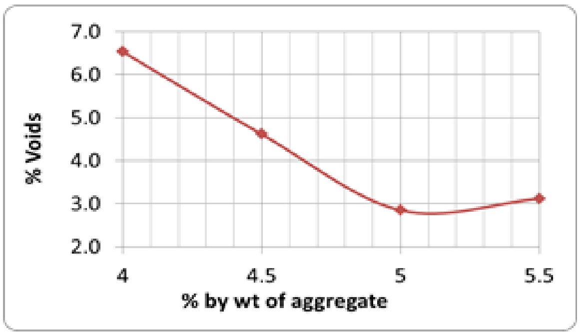


Fig 3.6: OBC obtained for Convention DBM mix

3.2.3Marshall stability and Flow for Conventional DBM Mix

The Marshall Stability and flow values observed for conventional DBM mix prepared with optimum binder content are 1566 Kg and 3.14 mm respectively. The Marshall stability test is shown in fig.4.17. MoRTH specifies the following requirements for DBM mix as shown in table 3.6

Table 3.6Volumetric Properties obtained for Conventional DBM Mix

Sieve size (mm)	Cumulative percent by weight of total aggregate passing				
	Specified grading (MoRTH)	10%SS	20%SS	30%SS	35%SS
37.5	100	100	100	100	100
26.5	90-100	98.45	97.73	97.07	96.66
19	71-95	77.63	77.11	78.04	76.62
13.2	56-80	67.32	63.99	62.61	58.98
4.75	38-54	41.46	47.72	39.97	35.58
2.36	28-42	33.45	32.65	31.84	28.20
0.3	7-21	17.27	16.85	16.43	14.54
0.075	2-8	5.02	4.91	4.79	4.24

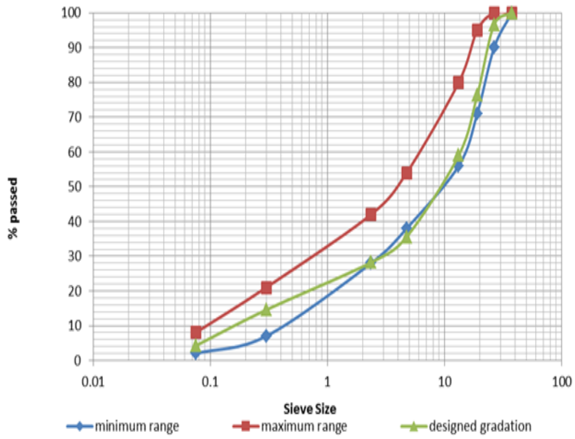


Fig 3.7: Gradation Chart for 35% SS Mix

The Optimum Binder Content and Stability values obtained for various proportions of Steel slag are shown in fig.3.8 and 3.9

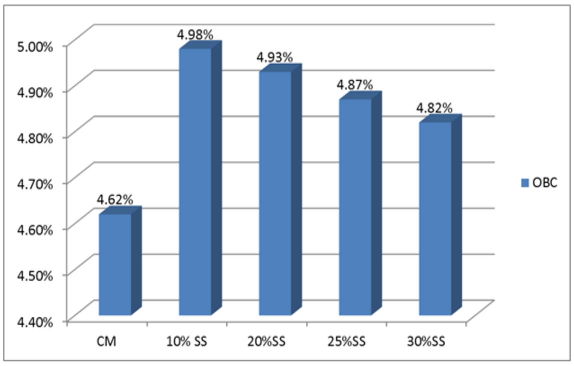


Fig 3.8: Optimum Binder Content for various SS Asphalt mix

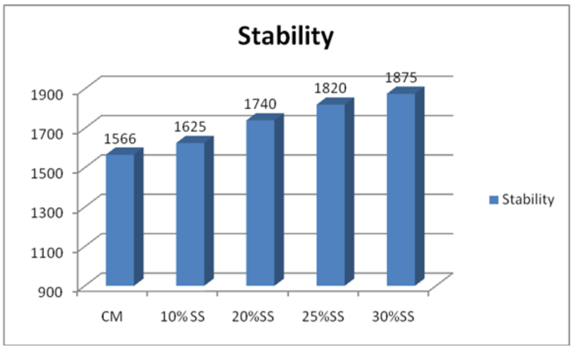


Fig 3.9: Marshall Stability for various SS Asphalt mix

To determine the strength and durability properties of conventional and steel slag asphalt mix, separate test specimens were prepared for conventional mix with achieved OBC and steel slag Asphaltmix with 30% steel slag proportion and OBC. The following performance tests such as Indirect Tensile Strength, Stiffness Modulus and Rutting tests were carried out in laboratory and comparison of the results obtained were made.

3.2.4Indirect Tensile Strength Test (ITS) / Tensile Strength Ratio (TSR)

To evaluate the moisture susceptibility and tensile strength of Steel Slag Asphalt mixture ITS and TSR were carried out as shown in the fig. 4.24 and 4.25. The results obtained are given in the table 4.9.

Table 3.7ITS and TSR values for 30% SS steel slag Asphalt mix

Parameters	Tensile Strength of Conditioned samples in Kpa	Tensile Strength of Dry samples in Kpa	TSR	Specification Limit as per MORTH V revision
30 % SS mixed DBM	1450.22	1666.92	92%	80%

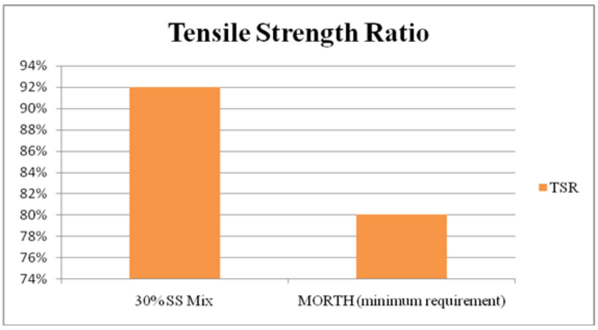


Fig 3.8: Chart showing TSR of 30% SS Asphalt

3.2.5 Stiffness Modulus Test

To analyze the pavement response to traffic loading Stiffness modulus test was carried out using a Universal Testing Machine, as shown in fig 3.9 and the results obtained for convention Asphalt mix and 30% SS Asphalt mix are given in the table 4.10

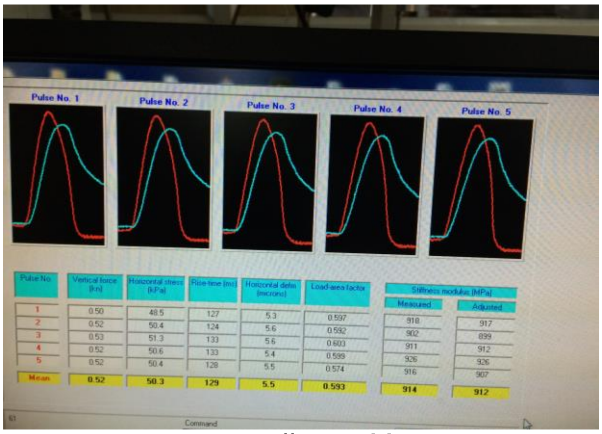


Fig 3.9 Stiffness Modulus

Table 3.8Stiffness Modulus Test Results

SAMPLE	Temperature	Conventional mix	30 % SS mixed DBM
0 degree	25^0C	2800	2950
90 degree	25^0C	2750	2825
0 degree	40^0C	1500	1750
90 degree	40^0C	1500	1800

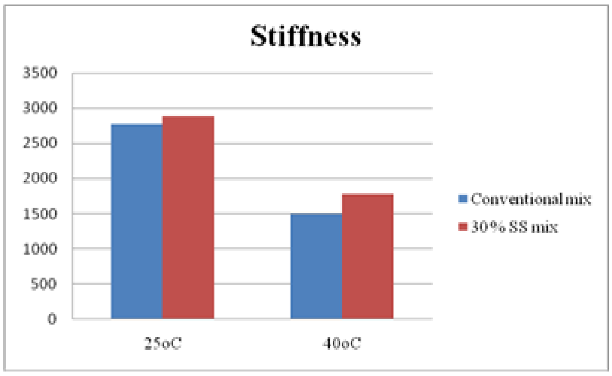


Fig 3.10 Stiffness Modulusfor results

From the above test, it was inferred that SSA mixture has performed better than conventional DBM mix.

3.2.6Rutting Test

Immersion wheel tracking test was carried out to assess the Asphalt mix response to traffic loadings. Pavement distress due to rutting was ascertained for both the mixes and the results are detailed in Table 3.9 and Fig 3.12 shows the deformed sample.

Table 3.9 Rutting Test Results

CYCLES 26 cycles / min.	Rutting depth measured at different cycles in mm	
	Conventional mix	30 % SS MIXED DBM
5 hours – 7800 cycles	16	12

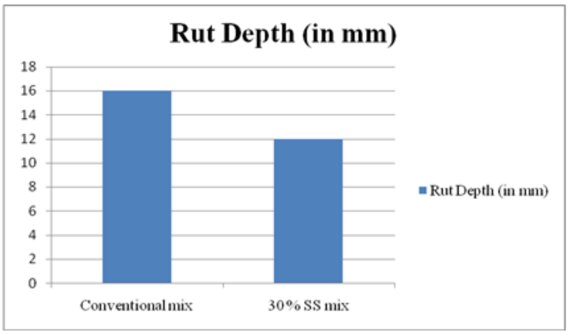


Fig3.12: Rut Depth Measurements

From the above test, it was inferred that SSA mixture has performed better than conventional DBM mix.

3.2.7 Thermo Gravimetric Analysis

To assess the thermal stability of the steel slag and to check the presence of any potential harmful gases Thermo Gravimetric Analysis (TGA) was carried out using Thermo Gravimetric Analyzer. Change in mass of steel slag was detected from the TGA as shown in fig. 4.32 and Table 3.10. Here, the weight loss detected was 2.73% at 200ºC.

Table 3.10 – Weight loss in steel slag with increase in Temperature

Temperature °C	Weight loss %
0	100
10	100
20	100
30	100
40	99.98
50	99.65
60	99.39
70	99.15
80	98.94
90	98.77
100	98.6
110	98.43
120	98.29
130	98.14
140	98
150	97.84
160	97.74
170	97.62
180	97.51
190	97.39
200	97.27
210	97.18

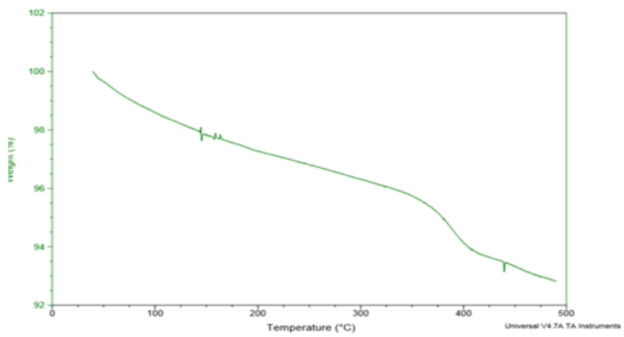
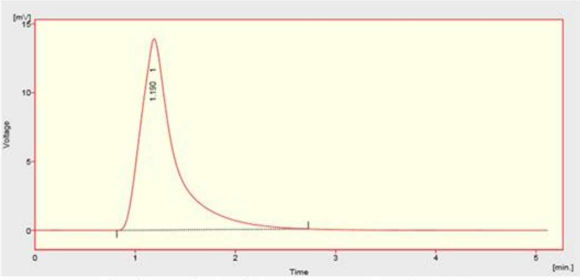


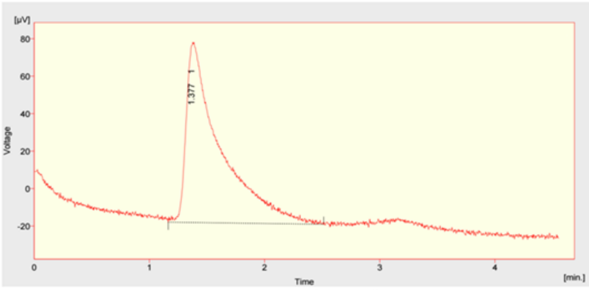
Fig 3.13:Weight loss in Steel slag – TGA Graph

The gas liberated from Steel Slag in Thermo GravimetryAnalyser (TGA) was collected from the exhaust of the TG analyzer and was analyzed using Gas Chromatography (GC) technique.The Chromatogram of the standard Hydrogen and of the Hydrogen present in the sample analysed is shown in Fig 3.14 and 3.15. The concentration of various components present in the sample are tabulated in Table 3.11



	Reten. Time [min]	Area [mV.s]	Height [mV]	Area [%]	Height [%]	W05 [min]
1	1.190	323.554	13.888	100.0	100.0	0.31
	Total	323.554	13.888	100.0	100.0	

Fig 3.14: Chromatogram of standard Hydrogen



	Reten. Time [min]	Area [mV.s]	Height [mV]	Area [%]	Height [%]	W05 [min]
1	1.377	1.971	0.096	100.0	100.0	0.24
	Total	1.971	0.096	100.0	100.0	

Fig 3.15: Chromatogram of Hydrogen liberated from Steel Slag in TGA

Table 3.11 – Composition of Gas from Steel Slag

S. No.	Components	Symbol	Concentration
1	Hydrogen (%)	H_2	0.609
2	Methane (%)	CH_4	- NIL -
3	Carbon dioxide (%)	CO_2	- NIL -

Source- MCRC, Taramani

From the above test , it was observed that the weight loss was very minimal till 200 ºC and steel slag was thermally stable. However, the maximum temperature maintained for Asphalt mixture is 160ºC as per the conventional practice. The gas liberated during the above test contained no potentially harmful gases.

4.1 Summary

The purpose of this study was to assess the usage of steel slag in asphalt mixtures of flexible pavements. To check the feasibility of usage of steel slag along with natural aggregate, the physical properties of steel slag were analyzed based on the methods specified in IS standards. The natural aggregates were partially replaced by steel slag starting from the range of 10% by weight of steel slag, satisfying the gradation procedure specified by the MoRTH. Gradually, the percentage of replacement was increased every 10%. Marshall Method of mix design was adopted in this study. Marshall Moulds were prepared in required numbers for both conventional and Steel slag Asphalt mixes and their volumetric properties were studied to ascertain the optimum binder content.
Strength and durability tests specified by MoRTH were carried out for the maximum proportion of Steel slag mixed Asphalt mixture to study their mechanical properties. The results were compared with that of the conventional Asphalt mix. To assess the thermal stability and the effect on environment Thermo gravimetric Analysis was carried out.

IV. Conclusion

The following conclusions have been drawn from this research work and are as follows,

i. From the physical properties analyzed, it was found that steel slag can replace the natural aggregates, as their properties are similar and meet the requirements of an aggregate to be used in asphalt mixtures in flexible pavement construction.
ii. The proportion of steel slag in Marshall mix has been restricted to 30% since the proportions beyond, failed to satisfy Gradation Graph.
iii. The Optimum Binder Content for 30% SSA mix is found to be 4.82 % by weight of aggregate which satisfy the code specification and the Marshall stability and flow values for the same were also found to be satisfactory which is even higher than the conventional asphalt mix.
iv. Performance tests such as Indirect Tensile Strength test and Tensile Strength Ratio, Stiffness Modulus test, Rutting test on SSA mix have shown good results which indicate that the modified mix is durable and Strong.
v. The weight loss of steel slag was very less (2.73% at 200ºC) during TGA . Hence steel slag proves to be thermally stable.
vi. Thermo Gravimetric Analyzer – Gas Chromatography results show that the concentration of Methane and Carbon dioxide were nil in the gas which was liberated from Steel Slag. It was inferred that, both these Green House Gases (GHGs) were not emitted from Steel Slag in TGA.

However, H_2 concentration in the gas from SS was found to be 0.609%. Hence, it is established that there is no environmental impact from the gases liberated from SS at higher temperature.

Hence, steel slag proves to be a potential industrial waste that can be used in Asphalt mixture of flexible pavements with no harm to the environment.

4.3 Future Scope of Study

In the collected steel slag, 4.75 mm sized Aggregate was found to be less in quantity and so the maximum proportion was restricted to maximum of 30% by weight of aggregate. Steel slag may be crushed and used which will result in usage of steel slag as a replacement in maximum proportion in Asphalt mixtures. This study was carried out in laboratory. Field researches may also be pursued in future. Though steel slag is not a hazardous industrial waste, leaching characteristics of steel slag mixed asphalt mixtures must be assessed.

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