Effect of Steel Slag on Marshall Properties of Plain and Modified Bituminous Concrete Grade 1 Mix

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***Abstract*— Bituminous Concrete (BC) is often used as a wearing course in flexible pavement. Bituminous concrete layer is laid in three different layer thicknesses viz., 30, 40 and 50mm.Use of industrial waste in bituminous layers is being practiced from many decades and one of such waste is Steel Slag. In India about 10 million tons of steel slag is produced yearly and 70% of this is being used by cement industries. In this study the optimum percentage of steel slag that can partially replace stone dust is determined for VG-30 and CRMB-60 mixes and this is found to be 10%. Then the effect of this optimum steel slag on Marshall Properties is studied.**

Keywords*— BC Grade 1; VG-30; CRMB-60; Steel Slag; Gradation; Marshall Stability.

I. INTRODUCTION

Bituminous concrete is often used as a wearing course in flexible pavement. Bituminous concrete layer is laid in three different layer thicknesses viz., 30, 40 and 50mm. Bituminous concrete is widely used where there is very high traffic movement and high traffic loads. It is a HMA (Hot mix asphalt) mix which is a mix prepared at very high temperature up to 165°C in plain binders and up to 185°C in modified binders. Aggregates behave as structural element and binder as an adhesive in bituminous mixes.

Steel slag is produced amid the generation of steel from liquefied iron from various sorts of systems. The liquefied steel and the wastes are then isolated from the heater. Wastes are then cooled using many techniques which results in steel slag of many types depending on their type of manufacturing process and cooling technique. Steel slag mainly comprises basically of carbon monoxide, manganese, phosphorous and silicon.

According to the Indian Mineral Year Book 2017, currently India produces about 10 million tons of steel slag per annum from its existing steel plants. About 70% of this slag is used in the production of cement by the Indian cement industries. Due to insufficient information of the use of steel slag effectively in various fields, it is being dumped irregularly causing environmental pollutions.

The properties of steel slag allow it to be used effectively in various fields such as in road construction, as ballasts in railway lines, soil stabilization and also embankment material. The use of steel slag in road construction has many advantages such as:

- Steel slag is tougher and durable than our conventional stone aggregates and hence it can be preferred to use as rain ballast which may also prove to be economical.
- Steel slag can prove highly beneficial for stabilization of highly acidic soils.
- Steel slag in flexible pavement results in greater stability which will improve the life of pavement.
- Steel slag gives better skid resistance so that it can be used both in flexible and rigid pavements.
- Steel slag can also be used as base layer aggregates which will result in better stability overall in the pavement.
- Since steel slag is a highly porous material it can be used in rigid pavement and due to the porous nature there will be reduction in sound which is a major issue in rigid pavement.

India is having second largest road network of over 5.5 lakh kms in the world. Due to extreme climatic conditions, growth of traffic and increasing maintenance expenditure on roads in India there is a necessity to develop sustainable technologies and economical road construction. In recent years cost of bitumen in India has raised very rapidly due to hike in the crude oil price. As highway construction involves huge sum of money, appropriate engineering design and use of waste material in construction of highways may save considerable cost. It should be noted that major portion of highway in India is flexible.

CRMB is a blend of selected grades of Bitumen and modifier. The rubber modifier used, balances the required visco-elastic balance of the bitumen binder, which improves the resistance to thermal and low temperature cracking. CRMB has good adhesion to different types of aggregates which therefore reduce cracking, deformation etc.

Advantages of Crumb Rubber Modified Bitumen:

- Cost effective.
- Better adhesion between aggregates and binder.
- Lower susceptibility to temperature variations.
- Higher fatigue life of mixes.
- Better age resistance properties
- Higher resistance to deformation at high pavement temperature.

Since a bituminous mix prepared with Crumb rubber modified bitumen has a higher stiffness modulus, enhanced fatigue life, better resistance to creep and higher indirect tensile strength, it is suitable as a wearing course, a binder course and overlay material on surfaces which are cracked and subjected to heavy traffic. Modified binders are also used for application like Stress Absorbing Membrane (SAM) for sealing of cracks, Stress Absorbing Membrane Interlayer (SAMI) for delaying

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reflection cracking, Porous Asphalt and Stone Matrix Asphalt (SMA).

Modified bitumen performs better than conventional bitumen in situations, where the aggregates are prone to stripping. Due to their better creep resistance properties, they can also be used at busy intersections, bridge decks and roundabouts for increased life of the surfacing.

II. MATERIALS USED

A. Aggregates

Aggregates were obtained in four different size fractions and later gradation is carried to get the blend to satisfy the BC Grade 1 as per MoRT&H. Aggregate fractions and their percentages in blend are:

- 20mm size aggregates- 27%
- 12mm size aggregates- 23%
- 6mm size aggregates- 19%
- Stone Dust passing 2.36mm- 31%
- Steel Slag passing 2.36mm sieve.

The aggregates should satisfy the MoRT&H requirements for the Bituminous Concrete.

Table 1 Tests of Aggregates

Sl no	Tests conducted	Test Results	MoRT&H Specifications
1	Aggregate Impact Test	8.45%	Max 24%
2	Crushing Test	18.31%	Max 30%
3	Combined Elongation and Flakiness Test	14.18	Max 35%
4	Water Absorption Test	0.16	Max 2%
5	Los Angeles Abrasion Test	16.94	Max 30%
6	Specific Gravity Test		2.5 to 3.2
a)	20mm passing	2.60	
b)	12mm passing	2.65	
c)	6mm passing	2.70	
d)	Stone dust	2.85	

B. Binders

Two different binders have been used for this study to compare Marshall Properties among them. One is plain binder VG-30 and the other one is Crumb Rubber Modified Bitumen of grade 60 (CRMB-60). The plain binder requirements are as per IS-73:2013 and Modified Binders have to satisfy the standards as per IRC SP-53:2010. The basic test results are indicated in the tables below:

Table 2 Tests on VG-30 Binder

Sl no	Tests	Test Results	IS-73:2013 Requirements
1	Specific Gravity	1.02	0.97-1.02
2	Flash Point, ° C	270	Min 220
3	Penetration Test at 25°C	65	50-90
4	Softening Point Test, °C	49	Min 55
5	Ductility Test	51	Min 40

Table 3 Tests on CRMB-60 Binder

Sl no	Tests	Test Results	IRC SP-53:2010 Specifications
1	Specific Gravity	1.03	
2	Flash Point, ° C	290	220°C
3	Thin Film Oven Test		
a	Penetration Value Before Conducting TFOT	35	30-50
b	Reduction in Penetration Value after Conducting TFOT %	14.28	Max up to 35%
c	Loss in Mass By Heating %	0.075	1
d	Increase in Softening Point, °C, Max	1	6
4	Separation Test		
a	Softening Point Before Test, °C	62	Min 60
b	Softening Point After Test, °C		Difference in softening point, Max 3°C
	Top Portion	61	
	Bottom Portion	60.3	

C. Steel Slag

Prior to its use as a construction aggregate material, steel slag must be crushed and screened to meet the specified aggregate gradation requirements for the particular application. The specific gravity was found to be 3.3 for the steel slag used in this study. The Chemical composition is given in table below.

Table 4 Chemical Composition of Steel Slag

Constituents	Composition (%)
CaO	40-52
SiO_2	10-19
FeO	10-40
MnO	5-8
MgO	5-10
Al_2O_3	1-3
P_2O_5	0.5-1
S	<0.1
Metallic Fe	0.5-10

III. METHODOLOGY

This study is based on the laboratory investigation on the percentage of steel slag that can be used to replace the stone dust partially and to give the comparison between plain and modified binder. The effect of optimized steel slag on the partial properties is determined. The methodology steps are as follows:

- First step in the study is to study the basic properties of materials used and see whether they satisfy the specifications.
- The present study envisages fixing of gradation for the procured aggregates as per the BC Grade-1 as specified in MoRT&H and fixing up the percentages of different fractions.

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- Preparation of standard Marshall samples for VG-30 and CRMB-60 binder with and without steel slag as partial stone dust replacement.
- Steel Slag has been introduced in the mix in the increments of 5% up to 20%.
- To carry out Marshall Stability Test as per *ASTM D6927 -06* standard test procedure.
- Using these test results graphs are plotted with bitumen content on X axis and (1)Marshall stability,(2)flow value, (3)density,(4)air voids in total mix (Vv),(5) Voids in Mineral Aggregates (VMA) and (6) Voids Filled with Bitumen (VFB) on Y axis.
- Optimum binder content is obtained considering (1) maximum Marshall Stability, (2) mid-range of recommended flow value, (3) maximum density.
- The steel slag replacement percentage which gives maximum stability in both VG-30 and CRMB-60 mix the optimum steel slag percentage:

A. *Marshall Stability Test*

- Approximately 1200gm of aggregates and filler is heated to required temperature. Temperature required in different stages are shown below:

Table 5 Temperature at Different Stages of the Mix

Stages of Mix Preparation	VG 30	CRMB 60
Aggregate Temperature	150-170	165-185
Bitumen Temperature	150-165	165-185
Mix Temperature	150-165	150-170
Laying Temperature	110(min)	130-160
Compacting temperature	90(min)	115-155

- Bitumen is heated to a temperature of 120-165°C, to a pouring consistency.
- The heated aggregates and bitumen are thoroughly mixed at a temperature of 160°C for VG-30 mix and at 180°C for CRMB-60 mix.
- The mix is placed in a preheated mould and compacted by a rammer with 75 blows on either side at temperature of 115°C to 155°C.
- Vary the bitumen content in the next trial by +0.5% and repeat the above procedure.
- Next for the steel slag partial replacement, weight of steel slag required is calculated and it is added to the stone dust. Finally stone dust with steel slag must be gradation blending percentage obtained; in this case it is 31%.
- These specimens are cooled in room temperature for 24 hours and later maintained at 60°C for about 40mins before testing the specimens in the stability testing machine.
- Stability and flow values are obtained from testing in stability testing machine.
- Determine the optimum binder content for the mix design by taking average value of the following three bitumen contents found form the graphs obtained in the previous step.
    - Binder content corresponding to maximum stability
    - Binder content corresponding to maximum bulk specific gravity (G_m)
    - Binder content corresponding to the median of designed flow that is 3mm.

B. *Marshall Stability Test Results*

The consolidated Marshall Stability test results are indicated in the following table which gives maximum Marshall Stability and corresponding flow, air voids and VFB at maximum stability. Optimum Binder Content is the bitumen content for each percentage of steel slag replacement.

Table 6 Marshall Data for VG-30 BC Mix

Steel Slag (%)	Maximum Stability (kN)	Flow (mm)	Air Voids (%)	Voids Filled with Bitumen (%)	Optimum Binder Content (%)
0	16.8	3.16	4.52	73.91	5.43
5	19.46	2.84	4.84	72.52	5.67
10	23.68	2.84	4.72	73.10	5.62
15	17.52	3.45	4.34	76.31	5.71
20	14.51	3.68	3.98	77.93	5.82

Table 6 Marshall Data for CRMB-60 BC Mix

Steel Slag (%)	Maximum Stability (kN)	Flow (mm)	Air Voids (%)	Voids Filled with Bitumen (%)	Optimum Binder Content (%)
0	23.15	3.03	5.53	69.62	5.57
5	24.26	2.82	5.42	70.11	5.65
10	27.31	2.73	5.68	69.12	5.63
15	20.89	3.51	4.93	73.81	5.82
20	18.54	3.56	5.39	71.99	5.86

C. *Effect of Optimised Steel Slag on Marshall Properties*

To know the effect of steel slag on Marshall Properties, Marshall graphs are plotted for 0% steel slag data and 10% steel slag replacement data for both VG-30 and CRMB-60. The graphs clearly show that steel slag mix has higher Marshall Stability, Bulk Density and Air Voids. Steel Slag mix has lower Flow and Voids Filled with Bitumen. This behavior is due the dense and porous characteristics of the steel slag.

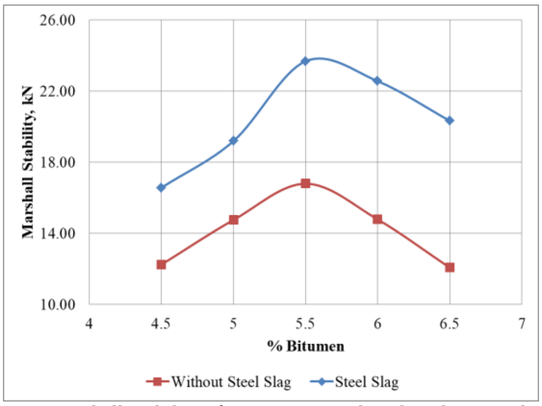

Figure 1 Marshall Stability of VG-30 Mix with and Without Steel Slag

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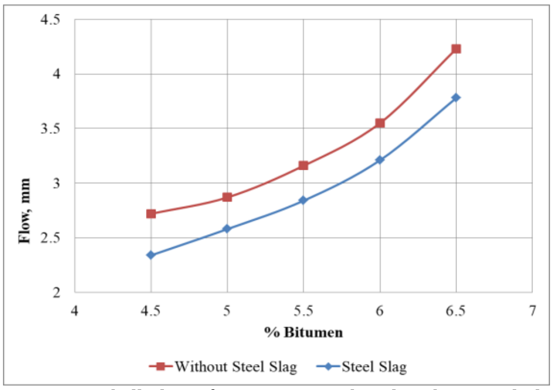

Figure 2 Marshall Flow of VG-30 Mix with and Without Steel Slag

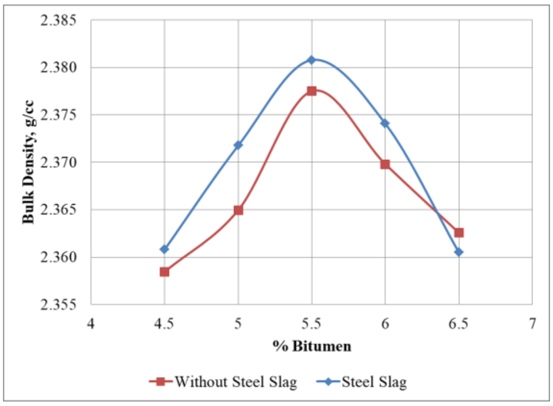

Figure 3 Bulk Density of VG-30 Mix with and Without Steel Slag

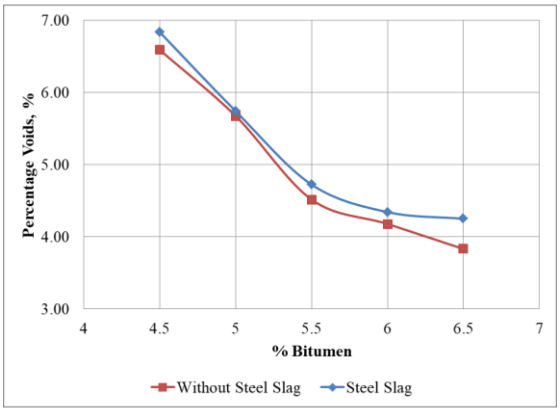

Figure 4 Air Voids in VG-30 Mix with and Without Steel Slag

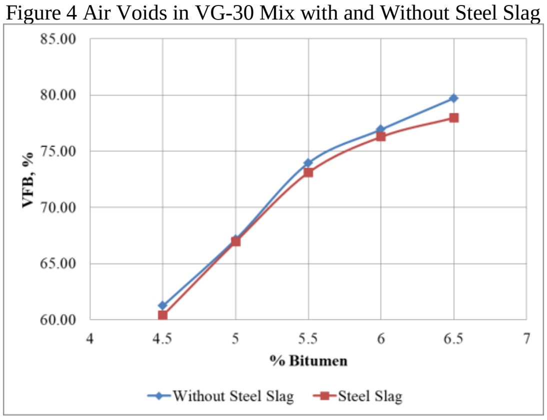

Figure 5 VFB in VG-30 Mix with and Without Steel Slag

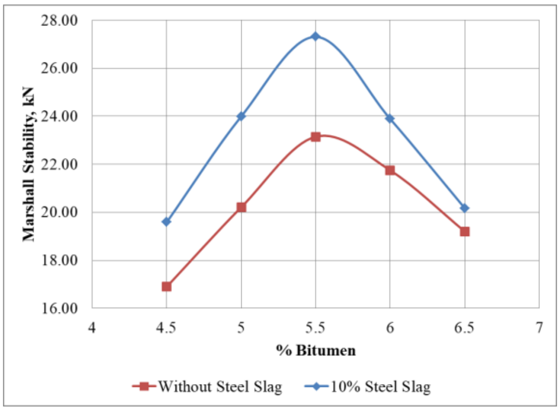

Figure 6 Marshall Stability of CRMB-60 Mix with and Without Steel Slag

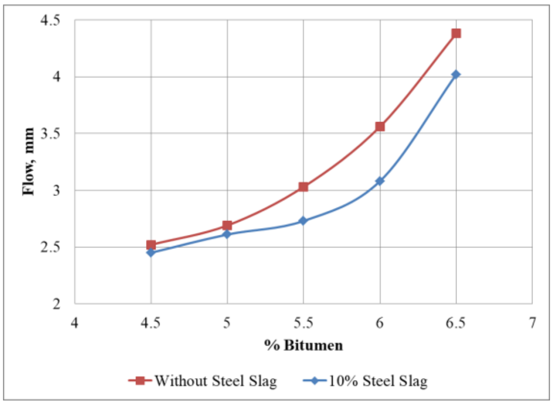

Figure 7 Marshall Flow of CRMB-60 Mix with and Without Steel Slag

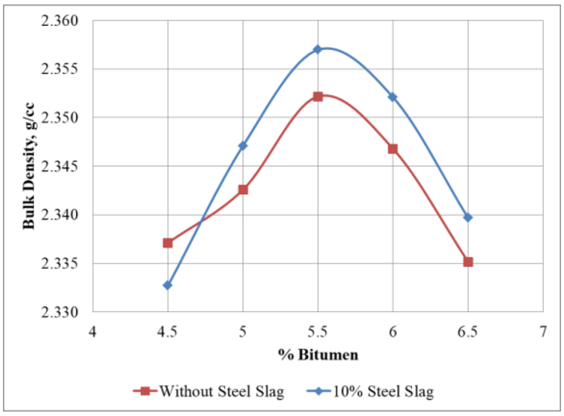

Figure 8 Bulk Density of CRMB-60 Mix with and Without Steel Slag

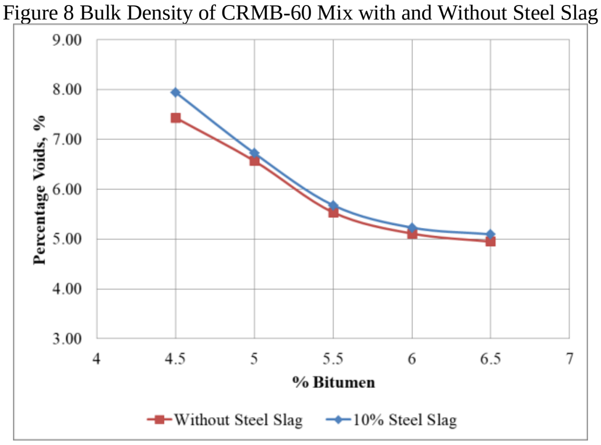

Figure 9 Air Voids in CRMB-60 Mix with and Without Steel Slag

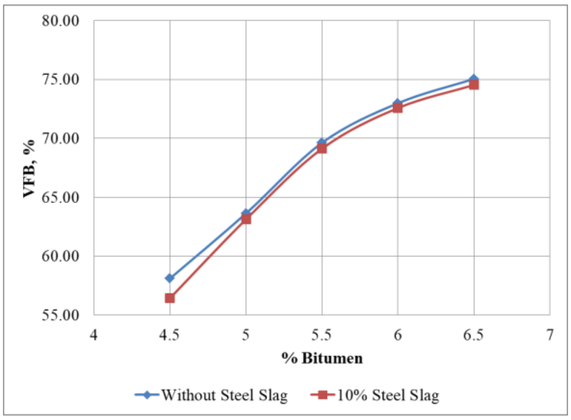

Figure 10 VFB in CRMB-60 Mix with and Without Steel Slag

IV. CONCLUSIONS

Based on the laboratory investigation from Marshall Stability Test results following conclusions are drawn.

- The optimum percentage of steel slag that can substitute stone dust partially is found to be 10% in both VG-30 and CRMB-60 mixes.
- The Marshall Stability is increasing with steel slag addition in the mix and is higher for CRMB-60 BC mix than VG-30 BC mix.
- However with introduction of steel slag optimum binder content is observed to be increasing in both plain and modified BC mix, this is due to characteristic porous nature of steel slag.
- The Flow has decreased with introduction of optimum steel slag in both plain and modified mix. This is due to hard and dense characteristics of steel slag.
- With the introduction of optimum steel slag percentage there is increase in percentage voids and decrease in voids filled with bitumen; this is also due to characteristic porous nature of the steel slag.
- CRMB-60 binder performs better than VG-30 binder with satisfying the Marshall Parameters.

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