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A Study of Marshall Properties of Bituminous Concrete by using Marshall Hammer at 75 Blows

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ABSTRACT

In the areas where there are heavy movement of vehicles and also where the temperature of the pavement are really high the mix design done by the normal Marshall method is not appropriate so a new method of mix design has to be considered. The normal assumption done in the Marshall method is that the density achieved during the test represents the actual density on the field after the pavement is allowed to the traffic movement. The severity caused by the movement of the traffic will be underestimated in this case. The importance of maintaining the sufficient air voids in the Bituminous concrete during mix design is to have a minimum of 3% of Air voids at the refusal density. The design procedure for this has to ensure that the mix should be designed as to maintain the minimum Air void level (3%) at the stage of refusal density and determine the optimum bitumen content of bituminous concrete grading (BC-1) Mix prepared using Bitumen (VG-30) and by Marshall hammer and study behavior of BC mix at the refusal density with mix air voids under the conditions of secondary compaction and assess the Marshall Properties of BC-1 Mix prepared using Bitumen at optimum bitumen content by varying number of compaction blows and compare the Marshall properties of the specimen casted using Marshall Hammer and the standard Marshall rammer at 75 Blows compaction effort.

Keywords : Bituminous Concrete (BC), Marshall Mix, Marshall Compactor.

INTRODUCTION

The important highways in India are built by Dense Bituminous Macadam (DBM) or Bituminous Concrete (BC). As there is an increasing demand in highway construction, scientists and researchers are constantly trying to improve the performance of bitumen pavement. Asphalt concretes are widely used in pavements. Bitumen is the naturally occurring byproduct of crude oil. Due to increase in vehicles in recent years the road surfaces have been exposed to high traffic resulting in deformation of pavements due to excessive stress. Permanent deformation happens when pavement does not have sufficient stability, improper compaction and insufficient Pavement strength. The performance of pavement is determined by the properties of bitumen. Bitumen is a Visco elastic material with suitable mechanical and rheological properties for water proofing and protective covering for roofs and roads, because of its good adhesion properties of aggregates. In India Marshall Method is adopted for designing bituminous mixes where specimens are prepared using Marshall Hammer. Compaction effort generated by Marshall Hammer does not simulate the field compaction effect which leads to aggregate degradation. The secondary compaction of the pavements has been neglected during the design of the mixes for the pavement. Secondary compaction is caused soon after the pavement is laid and the vehicles are allowed to move on them. Compaction plays a vital role in performance of a bituminous mixes. The drawback of Marshall Procedure is the number of blows given to compact the specimen is fixed.

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The conventional compaction effort by Marshall Method which is 75 blows is not adequate to examine the field condition in laboratory; hence the compaction energy in the laboratory has to be increased to the maximum called as the 'refusal density' of the pavements.

Asphalt paving mixes designed by the Marshall method have been failing prematurely on our roads. One of the reasons for such failures is inadequate initial compaction. Densities achieved under 75 blows Marshall Compaction in the laboratory do not simulate the field densities of the mix after it has undergone secondary compaction due to traffic. When the air voids in the mix decrease to below 3 per cent during such densification and as the viscosity of asphalt in the mix decreases sharply in summer the mix permanently deforms ass a rut under the wheel loads. Three factors contribute to good performance of an asphalt mix carrying heavy axle loads in hot climates. They are adequate initial compaction so that secondary compaction under traffic is minimized, sufficient asphalt content for durability of the mix and enough air voids in the mix for its stability. All the three factors are influenced by the aggregate grading. Dense grading give rise to low VMAs and open grading to high VMAs.

LABORATORY EXPERIMENTS

1.1 Aggregate Test

Aggregate used in this study is crusher aggregate from Chikhli Quarry. The sizes of aggregate used are 20 mm, 10mm, 6mm and Stone Dust (SD) as per recommendation of MORT&H Section 509 for nominal size of aggregate 19 mm. The physical properties of aggregate are shown in **Table 1** which satisfies the MORTH 2013 specifications.

Table 1 Properties of Aggregates

Property	Test Method	Stone Dust	6mm	10mm	20mm	MORT&H 2013 Specifications
Aggregate Impact	IS: 2386 (Part IV)	11.75				24% max
Specific Gravity	IS: 2386 (Part II)	2.5	2.677	2.762	2.767	2.7
Flakiness and Elongation	IS: 2386 (Part I)	27.93				35% max

1.2 Bitumen Tests Bitumen is often referred to as a Visco-elastic material, behaving as elastic solid at low temperature and liquid at high temperature. In the present study, (viscosity grade)VG-30 grade of bitumen has been used. Tests are conducted to check the suitability of binder for the preparation of bituminous mix. Results obtained from laboratory testing are shown in Table 2, and it satisfies the requirements per IS 73:2013.

Table 2 Properties of Bitumen (VG-30)

Property	Test Method	Test Results	Requirements as per IS 73:2013 for VG 30
Penetration 25°C ,100 g, 5 s, 0.1mm	IS 1203-1978	51	Min 45
Softening point (R & B),°C	IS 1205-1978	47.6	Min 47
Ductility Test, 25°C, cm	IS 1208-1978	100+	Min 75

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1.3 Bituminous Mix Design

In order to determine OBC(optimum bitumen content), Marshall Method of mix design is adopted for Bituminous Concrete (BC-1). The Marshall Test procedures have been standardized by the American Society for Testing and Materials. Procedures are given by ASTM D1559, Resistance to plastic Flow of Bituminous Mixtures Using Marshall Apparatus.

1.4 Design Requirements

As per the specifications **for Bituminous Concrete (BC) mix,** the specimens are compacted **with 75 blows on either face**. The designed BC mix should fulfill the following requirements as given in Table 3.

Table 3 Design requirements for VG paving Bitumen

Property	Specified Value
Compaction Level	75 blows on either side
Minimum stability, (kN) at 60 °C	9.0
Marshall flow (mm)	2-4
Marshall Quotient (Stability/Flow)	2-5
% Air Voids(Va)	3-5
% Voids Filled With Bitumen(VFB)	65-75
Coating Aggregate Particles, Minimum	95%
Tensile Strength Ratio(TSR), Minimum	80%
Loss of stability on immersion in water at 60 °C	>75%

1.5 Sample Preparation Schedule

Bituminous Concrete (BC) design of bituminous mixes requires the preparation of samples for Marshall Mix design and performance evaluation tests. Table 4 shows the sample preparation schedule for the same. More than 150 samples have been prepared to achieve the objective of the present study.

Table 4 Sample Preparation Schedule

Sl. No.	Type of Test	No. of Samples GM	Remarks
1	Marshall Test for OBC(optimum bitumen content)	12	
2	Marshall Test at OBC(optimum bitumen content)	3	
3	Marshall test at different number of blows	21	
4	ITS (Indirect Tensile Strength)	21	Dry and Wet
5	TSR(Tensile Strength Ratio)	21	

1.6.1 Marshall Stability Test

This test is conducted as per ASTM D1075 specifications. The standard Marshall specimens of 100mm diameter and 63.5 height are prepared. Marshall Stability is determined using the standard procedure, i.e. after conditioning one set of specimen at 60*C for 30-40 minutes. Another set of specimen is kept for conditioning in water bath maintained at 60*C for 24 hours, and thereafter tested for Marshall Stability value.

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RESULTS

2.1 Aggregate Gradation selection for BC – 1 Mix

Sieve analysis has been carried out for the aggregate to be tested for their physical properties and Grading of aggregate is to be determining for Mix design for 19 mm nominal size of aggregate.

In present study, using the aggregates blending was done for the Bituminous Concrete mix. The gradations shown in **Table 5** and **Figure 3** are adopted.

Table 5 Gradations Adopted for Present Study

	Aggregate Size				Cumulative % passing		Limits as per MoRTH, 2013	
	20mm	10mm	6mm	Dust				
Is sieve size	35%	16%	16%	33%	Combined gradation	Median	Lower limit	Upper limit
26.5	35	16	16	33	100	100	100	100
19	32.375	16	16	33	97.375	95	90	100
13.2	10.395	15.592	16	33	74.987	69	59	79
9.5	0.742	13.848	16	33	63.59	62	52	72
4.75	0.231	0.98	13.552	33	47.763	45	35	55
2.36	0.2065	0.284	3.296	32.142	35.9285	36	28	44
1.18	0.2065	0.216	1.568	24.552	26.5425	27	20	34
0.6	0.2065	0.192	0.976	16.764	18.1385	21	15	27
0.3	0.2065	0.172	0.768	11.55	12.6965	15	10	20
0.15	0.2065	0.132	0.488	8.349	9.1755	9	5	13
0.075	0.2065	0.036	0.224	5.082	5.5485	5	2	8

2.2 Marshall Mix Design

The Marshall method of mix design as laid in ASTM D1559 was followed to determine optimum binder content (OBC) of the mix. Test include preparation of Marshall samples at Bitumen content ranges from 4.5-6% by weight of aggregate at 0.5% increment, three samples are prepared at each bitumen content and Optimum Bitumen Content (OBC) is found out for BC mix. These were tested for stability, flow, air voids, unit weight and voids in mineral aggregate (VMA). The OBC was calculated as the average of asphalt content for maximum stability, maximum unit weight, and 4.0% air voids. The theoretical specific gravity of aggregate was 2.524.

2.2.1 Volumetric analysis and mechanical test of the Marshall specimens

The volumetric analysis includes calculation of Bulk Density, Percent Air voids, Percent Voids in Mineral Aggregates (VMA), Percent Voids Filled with Bitumen (VFB). The Mechanical test includes finding the Marshall Stability and Flow value of Marshall Specimens. This has been carried out at different binder contents. At each binder content three specimens are made. The average bulk density of three specimens is found out in terms of gm/cc.

The OBC calculations are shown below

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% of Bitumen	Gmm	Gmb	Gsb	VMB	Va	VFB (Voids Filled with Bitumen)
4.5	2.59	2.39	2.66	14.15	7.69	45.88
5	2.57	2.42	2.66	13.58	5.83	57.09
5.5	2.55	2.44	2.66	13.31	4.28	67.97
6	2.53	2.45	2.66	13.39	3.11	77.24

% of Bitumen	Stability	Flow
4.5	12.7	2.8
5.0	14.2	3.2
5.5	15.0	3.8
6.0	12.5	4.3

2.2.2 Determination of Optimum Binder content (OBC)

The optimum binder content for the mix design is the binder content usually the most economical and will satisfied all of the established MoRTH Specifications. The design optimum bitumen content should be compromise selected to balance all of the mix properties. The design mix produced narrow range of bitumen content which passes all the criteria. From that narrow range, the mid value is taken as the OBC for all five gradations and is shown in

Table 6: Optimum Binder Content

	Determination of Optimum Binder content for BC-1 by Marshal Method	Bitumen %
A	Maximum Marshal Stability at bitumen content at peak	5.41
B	Maximum density at Bitumen content at Peak	6.0
C	% air Voids at 4%	5.63
D	VFB (Voids Filled with Bitumen) at 70	5.6
E	Flow at 3mm	4.75
F	VMA (Voids in Mineral Aggregates)	5.58
	Optimum Bitumen Content:-	5.50

The Optimum Bitumen Content (OBC) for BC-1 is 5.50% by wt of mix. This is the densest gradation. The volumetric parameters i.e. Bulk Density, Air Voids, Voids Filled with Bitumen, Voids in Mineral Aggregates(VMA) and Marshall Stability and Flow value at Optimum Binder Content (OBC) are given in **Table 4.3** and all gradations satisfies the MoRTH 2013 Specifications.

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Table 7 Volumetric Properties at OBC

Property	BC-1	Specified Values as per MORT&H, 2013
Corrected Stability, KN	14.97 KN	> 9
Avg Flow, mm	3.77 mm	2 – 4
Air Voids(Va), %	4.28%	3 – 5
Voids Filled with Bitumen(VFB), %	68%	65 – 75
Avg Density, gm/cc	2.438	-

CONCLUSION

Asphalt mixes designed by the Marshall method in accordance with the guidelines of MS-2 and MoRT&H specifications have been performing poorly under heavy traffic conditions. 75-blow Marshal Compaction is inadequate to represent the in place densities attained by the fields mixes under heavy axle loads. The mixes fail for one or more of the following reasons.

- Inadequate initial compaction, making the mix vulnerable to high secondary compaction under traffic.
- Relatively high asphalt content that allows the reduction of air voids to lower than 3 percent under secondary compaction thereby leading to rutting when pavement temperatures rise in summer.
- Low asphalt content and high air voids, leading to top down cracking, raveling and stripping, thereby making the mix less durable.

An asphalt mix must have 'enough' bitumen and 'enough' air voids to be both stable and durable. To fulfill this requirement the VMA (Voids in Mineral Aggregates) of the mix should be high. To achieve high VMA we should use rough textured (crushed) angular aggregate and an aggregate grading that is not too dense.

Our field observations and laboratory investigations suggest that for bituminous concrete with 20 mm nominal maximum size of aggregate (NMSA), a grading coarser in the fine fractions up to 2.36 mm sieve size and finer in the coarse fractions from 10 mm sieve size upwards relative to the 0.45 power grading offers the best VMA (Voids of mix in aggregates)values and also better overall Marshall characteristics. These results are reported in this project.

The propensity of an asphalt mix for rutting under secondary compaction due to traffic was judged by studying the air voids levels under increased Marshall Compaction up to 'refusal density'.

It is observed that a grading which offers higher VMA values not only permits the use of higher asphalt content but also records safer air void levels under refusal density compaction.

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