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CRUMB RUBBER MODIFIED BITUMEN ANALYSIS

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ABSTRACT
In most parts of India rutting and cracking of roads are widely observed and to prevent these problems the pavement should be strong enough to withstand greater loads and possess high thermal resistance which can be attained by the usage of CRMB in Indian Roadways. To investigate the change of properties incurred into bitumen by the addition of Crumb-Rubber (CR) at different proportions. Some advantages of Crumb Rubber Modified Bitumen (CRMB) is that with adequate addition of CR certain properties of bitumen such as penetration value, softening point, Marshall stability and flow rate are enhanced making it more suitable for roadworks. There are very few ways to recycle end-of-life tires as rubber cannot to reused effectively. Hence, incorporating Crumb Rubber in roadworks to enhance the quality of bitumen and reduce the volume of end-of-life tires in the country is a good way to solve both problems. This study investigates the changes in bituminous properties by the addition of CR at different proportions. Tests such as Softening Point Test, Ductility Test, Penetration Test and Marshall Stability test were conducted on Conventional bitumen, 10%CRMB, 20%CRMB, 30%CRMB and 40%CRMB and their results are tabulated to determine the credibility of Crumb Rubber Modified Bitumen.

Keywords: Crumb Rubber Modified Bitumen (CRMB), prevention of Environmental Hazards, End-of-life tires

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I. Introduction

The roadways in India, especially in rural areas are often subjected to road deformations such as rutting, cracking, etc. To strengthen the surface of roadways various modifications are incorporated into bitumen. One such modification of bitumen is with crumb rubber. Crumb rubber is derived from end-of-life truck tires which allows us to reduce the abundant discarded truck tires that occupy the majority of the space in scrapyards. There aren't many ways through which discarded tires are put to good use other than grinding them to dust using methods such as ambient grinding and cryogenic grinding, this is done to reduce their volume as a whole. Incorporating this crumb rubber dust in bituminous works allows us to strengthen the properties of bitumen to some extent and consume the end-of-life tires resulting in a reduction of scrap volume.

In this analysis study, we determine the changes incurred in bitumen upon adding CR and increasing the percentage of CR added. Experimental tests are conducted on bitumen and Crumb Rubber modified bitumen which is acquired by adding known percentages of Crumb Rubber in bitumen. The differences in every test result are tabulated and compared throughout this project to determine the effectiveness of Crumb Rubber Modified Bitumen. The experiments include the Softening Point Test, Ductility Test, Penetration Test, and Marshall Stability Test, results include the softening point, ductility, penetration value, and Flow rate and Stability of DBM respectively. All the mentioned tests were conducted on conventional bitumen and crumb rubber modified bituminous samples with Crumb Rubber addition being 10%, 20%, 30%, and 40% and these crumb rubber modified bitumen samples are labeled as 10%CRMB, 20%CRMB. 30%CRMB and 40%CRMB respectively throughout this study.

II. Literature Review

The literature covers various significant contributor of authors regarding Crumb Rubber Modified Bitumen Analysis to finalize the process of approaching experimentally analyzing CRMB [3, 4, 7, 11]. The basic experimental tests conducted to determine the rheology of CRMB are the Softening Point Test, Penetration Test, and Ductility Test. Complex experimental analysis was done to further determine the properties of CRMB such as flow rate and stability involved in casting a Dense Bituminous Macadam (DBM). Other approaches made to understand the rheology of CRMB involve in addition of filler materials such as Nanoclay and pyrolyzed tires which are observed to further enhance the properties of CRMB [2, 8,13]. However, in this study, no such additions are made to Crumb Rubber.

Some other literature that is reviewed includes data regarding Asphalt made with CR modification and includes more comparison charts. Additional information such as the amount of Volatile Organic Compounds that are released from pavement surfaces is taken into consideration. Various failure patterns are analyzed by regulating the amount of materials used [1, 5, 6, 9, 10, 12]. Crumb Rubber or Crumb Rubber dust is acquired by grinding discarded truck tires into duct particles. This grinding of tires can be done by using Ambient Grinding or Cryogenic Grinding. In ambient grinding process the tires are directly granulated using heavy machinery. This process consumes more power and the resulting dust particle size would be around 600 microns or 0.6mm. On the other hand, the cryogenic grinding process is more expensive as it includes the use of liquid nitrogen. In simpler terms, the end-of-life tires are firstly granulated to 2-inch pieces and introduced to liquid nitrogen. As liquid nitrogen freezes these rubber particles they are shattered by passing them through a hammer mill. The crumb rubber acquired through cryogenic grinding is comparatively finer, their size is usually below 300 microns or 0.3mm. In this study, we have used Crumb Rubber that is acquired through ambient grinding.

1.1 Methodology

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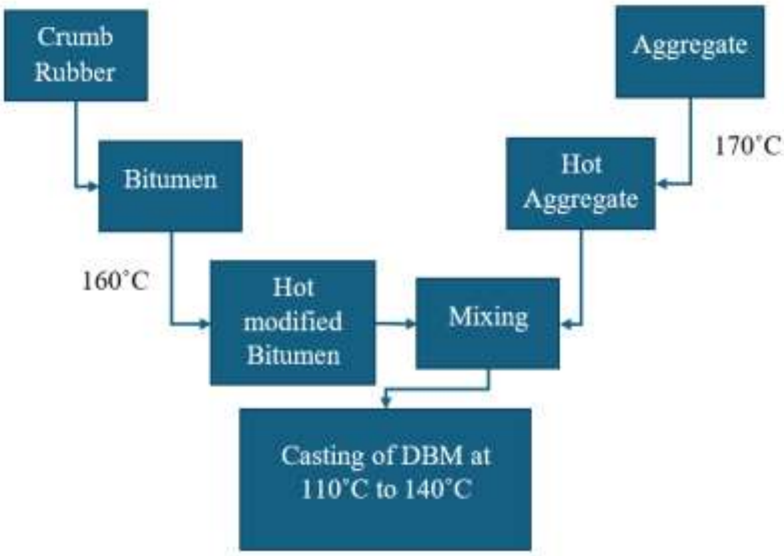

Figure 1: Flowchart showing the wet process of making CRMB and mixing it with Aggregate for Experimental Analysis

The process of making crumb rubber modified Bitumen (CRMB) can be done in two ways i.e. dry process and wet process. In the dry process of making CRMB, crumb rubber of the required proportion is deposited on hot aggregate, and hot bitumen is poured on them before mixing. However, in this study, only a wet process is chosen for modifying bitumen with Crumb Rubber. In the wet process of making CRMB, crumb rubber is directly added to bitumen while heating it. To make Crumb rubber-modified asphalt for the Marshall stability test, this CRMB is added to hot aggregate for mixing.

1.2 Collection of Materials

Bitumen (of any grade), coarse aggregate (10mm), Crumb Rubber Dust. Firstly, we do basic coarse aggregate and bitumen tests on aggregate and bitumen.

1.3 Tests on Coarse Aggregate

The tests on aggregate are conducted to identify their basic properties. In this study, experimental tests such as the Los Angeles Abrasion Test, Impact Value Test, and Specific Gravity Test are conducted as per IS:2386 part 4.

1.4 Los Angeles Abrasion Test

An aggregate sample weighing 3kgs is taken and placed in the hollow steel cylinder of the Los Angeles Abrasion Testing machine. The instrument is started and the cylinder is rotated at a speed of 30 to 33 revolutions per minute. The revolutions are continued until 500 revolutions. Note that the machine should be balanced and driven in such a way that the peripheral speed is uniform.

1.5 Aggregate Impact Value Test

The aggregate impact value test rig consists of measuring cylinders which are to be filled up to $1/3^{rd}$ with aggregate a placed in the impact testing machine. Then the rounded end of the tamping rod is used to tamp the sample 25 times, this is done to minimize the potential air voids present in the cylinder. The process is repeated 2 more times such that the cylinder is filled. Once, the sample is readily placed in the cylinder it is subjected to 15 blows of a hammer. The crushed aggregate is then removed from the cup and the whole of it is sieved on a 2.36mm sieve. The retained aggregate and passed dust are divided and multiplied by 100 to get the Impact value of the sample. The entire process is repeated 2 or three times and the average Impact Value is considered.

1.6 Determination of Specific Gravity of Coarse Aggregate

To determine the specific gravity of coarse aggregate pycnometer is required. Firstly, the empty pycnometer is weighed and its weight is recorded as W_1, then the aggregate is filled up to 1/3rd of the pycnometer and it is weighed again and recorded as W_2. Now the remaining 2/3rd of the pycnometer is filled with water up to the tip of the pycnometer and it is weighed again, this weight is recorded as W_3. Finally, the pycnometer is filled up to the tip only with water weighed and recorded as W_4. These values are substituted in the formula below. The experiment is to be repeated 3 times and the average specific gravity is considered. The formula for specific gravity is shown below.

$$\frac{W_2 - W_1}{(W_2 - W_1) - (W_3 - W_4)}$$

1.7 Tests on bitumen and CRMB

Preliminary tests such as softening point test, ductility test, and penetration test are conducted on bitumen to identify its properties before modification. CRMB of 10% CR, 20%CR, 30%CR, and 40%CR are firstly made using a wet process and used in the following experiments (refer to 4.4 for making of CRMB).

1.8 Modifying Bitumen with Crumb Rubber

In this study crumb rubber proportions of 10%, 20%, 30%, and 40% are added to bitumen while heating and mixing the bituminous sample, and each of these crumb rubber modified samples are labeled as 10%CRMB, 20%CRMB, 30%CRMB, and 40%CRMB respectively.

1.9 Procedure For Bitumen Tests

The IS codes used for procedures of Softening point test and Penetration test are IS:1205-1978 & IS:1203-1978 respectively.

1.9.1 Softening Point Test

To determine the softening point of the bitumen sample by using ring & ball apparatus firstly, hot bitumen with the known percentage of crumb rubber (note that for conventional bitumen sample mixing of crumb rubber is not required) is poured into the ring. After 30 minutes we place the ring with bitumen in a water bath of 25˚C for 24 hours. Then the ring & ball set are placed in the beaker for heating. A thermometer is also placed in the beaker such that the thermometer tip touches the bottom plate of the ring & ball apparatus. Then, the water in the beaker is heated and the temperature at which the bitumen sample in the ring softens up and touches the bottom plate of the apparatus is recorded. This is the softening point of the bitumen sample. The same process is repeated for every CRMB sample consisting of 10%, 20%, 30%, and 40% crumb rubber.

1.9.2 Ductility Test

To determine the ductility of the bitumen sample using a ductility testing machine firstly, the ductility moulds are applied with glycerine. Then hot bitumen with a known percentage of crumb rubber (note that for conventional bitumen sample mixing of crumb rubber is not required) is poured into the ductility moulds. After 30 minutes we put the ductility moulds with the bitumen sample in a water bath of 25˚C for 24 hours. Then the ductility mould is removed from the water bath and placed in the ductility testing machine. The ductility testing machine is started and the separation of the bitumen sample starts. The distance at which the sample separates is recorded. This is the ductility value of the bitumen sample.


(a)


(b)


(c)

Figure 2: Softening point apparatus (a) Beaker (b) Thermometer (c) Brass ring and steel ball

1.9.3 Penetration Test

To determine the penetration value of the bitumen sample by using a penetrometer firstly, hot bitumen with the known percentage of crumb rubber (note that for conventional bitumen sample mixing of crumb rubber is not required) is poured into the penetrometer canister. After 30 minutes the canister is placed in a water bath of 25˚C for 1 and half hours such that the water level reaches the brim of the canister but does not enter the canister. Then the canister is placed under the needle of the penetrometer and the needle is released for exactly 5 seconds and the needle is immediately lifted without disrupting the reading on the dial of the penetrometer. This process is repeated at least two more times, such that each time the needle is released, it is 10mm away from the initial penetration point. The average of penetration on these points in the canister is calculated and the penetration value of bitumen sample is determined


(a)


(b)

Figure 3: (a) Ductility testing machine (b) Brass Ductility Moulds used for Ductility Test.

1.9.4 Marshall Stability Test

Marshall stability test is required for determining the flow rate and stability of the Dense Bituminous Macadam (DBM) specimen that is usually cast in Marshall stability moulds. In order to conduct the Marshall Stability Test, the mixing of bitumen and coarse aggregate while being heated is done. Then the mixture is poured into a Marshall stability mould that is on a collar which is lubricated and set in the compaction pedestal beforehand. Then a rammer of 4.54kg is placed on top of the pedestal and 65 blows are given. Then the mould and collar are reversed and another 65 blows are given in the same way. The mould is left to cool down in room temperature for 24 hours. Finally, the cylindrical (DBM) specimen is extracted from the mould using a specimen extractor. The extracted cylindrical

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 8, No.2, August : 2025

specimen is later placed in the breaking head and fitted to the Marshall apparatus for crushing. The Marshall Apparatus consists of a dial Gauge (proving ring) that shows the amount of load being applied on the specimen and the breaking head consists of another dial gauge (flow rate gauge) which indicates the flow rate in the specimen.


(a) (b)

Figure 4: (a) Penetration Test (b)Penetrometer and Canisters containing CRMB samples with varying Crumb Rubber proportion

When the Marshall apparatus is started the dial gauge indicating load applied on the specimen begins to rotate clockwise. Once the deformation occurs in the specimen the dial gauge indicating the load application on the specimen reverts and turns anti-clockwise. The value is recorded at this particular point. Simultaneously the dial gauge in the breaking head which indicates flow rate also starts rotating clockwise when the Marshall apparatus is started. The flow rate of the specimen is determined by recording the value in the dial gauge present in the breaking head up to the point of deformation (note that the dial gauge indicating flow rate is unlikely to move anti-clockwise when deformation occurs). 3 specimens of the same composition are to be tested and their average is to be considered. The test procedure used in the Marshall Stability Test is the same as the test procedure in ASTM D6927-06 Hence, the value of the flow rate and Marshall stability of the DBM specimen is determined.


(a) (b)


(c) (d)

(e)

Figure 5: (a) Compaction Pedestal, (b) Bitumen Extractor (c) Conventional DBM Specimen, (d) Weighing machine used to calculate submerged weight of DBM (e) Rammer used for applying blows to make DBM specimen

III. ANALYSIS AND RESULTS

3.1 Tests on Aggregate

The coarse aggregate used for conducting the required experimental tests (Los Angeles Abrasion test, Impact Value Test, and Specific Gravity Test) is sieved, and aggregate passing through a 12.5mm sieve and retaining on a 10mm sieve is selected. The test procedures are done by following IS:2386 part 4.

S.no	Experiment	Result	IS:2386 requirements
1.	Los Angeles Abrasion Value (%)	23.83%	<30%
2.	Aggregate Impact Value (%)	17.03%	<30%
4.	Specific Gravity	2.54	2.5-3

Table 1: Results and requirements of Los Angeles Abrasion test, Impact test and Specific Gravity Test on Aggregate as per IS:2386 part-4

Since it is observed that the Abrasion value, Impact Value, and Specific Gravity of the selected aggregate satisfy the requirements of IS:2386 to be used in pavement surface of road works it can used in making DBM specimen for the Marshall Stability test.

3.2 Tests on Bitumen

Crumb Rubber Modified Bitumen samples are made using the wet process of making CRMB.

3.2.1 Softening Point Test

In this study, the softening point of Conventional Bitumen, 10%CRMB, 20%CRMB, 30%CRMB and 40%CRMB are determined through experimental analysis. The softening points of each sample is represented in line graph in Figure 6.

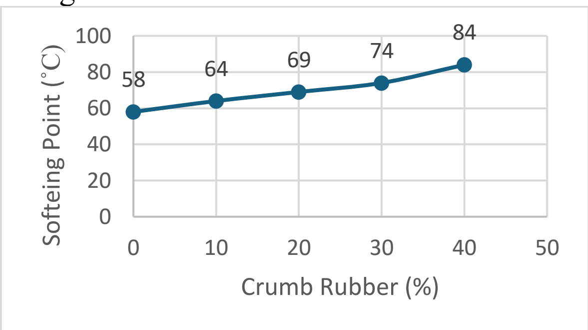

Figure 6: Softening Point Graph

The softening point is observed to increase with the percentage of Crumb Rubber in the samples. This increase in softening point proves that CRMB has comparatively more thermal resistance than conventional bitumen and pavements made using CRMB as binder possess more thermal resistance preventing cracks on the surface due to high temperatures.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 8, No.2, August : 2025

Ductility Test

In this study, the ductility of Bitumen, 10%CRMB, 20%CRMB, 30%CRMB, and 40%CRMB are determined through experimental analysis are shown in Figure 7. It is observed that the ductility of the 10 %CRMB sample is higher than the conventional bituminous sample. However, the ductility of 20%CRMB, 30%CRMB, and 40%CRMB are lower than the ductility of conventional bitumen. It can be determined that an excess concentration of Crumb Rubber in Bitumen leads to a decrease in ductile strength

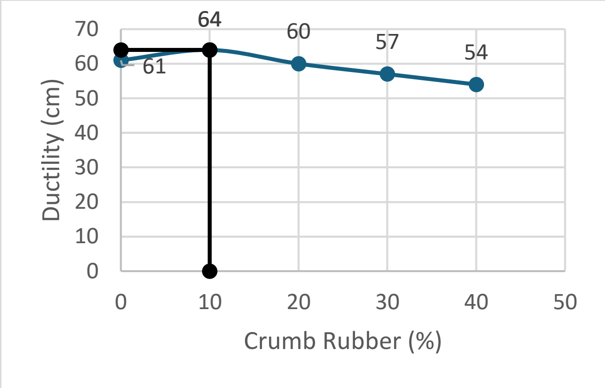

Figure 7: Ductility Graph

3.2.2 Penetration Test

In this study, it is observed that the penetration resistance of samples increased with an increase in the Crumb Rubber percentage of samples indicating that Crumb Rubber Modified Bitumen samples have more penetration resistance than conventional bitumen sample. Note that excess concentration of Crumb Rubber (such as 40%CRMB) hardens and makes the sample more resistant to temperature, this will lead to a need for higher temperatures to mix and use the sample for pavements, and in some drastic cases, it may violate the requirements of sample provided in IS:1203-1978 and IS:1205-1978.

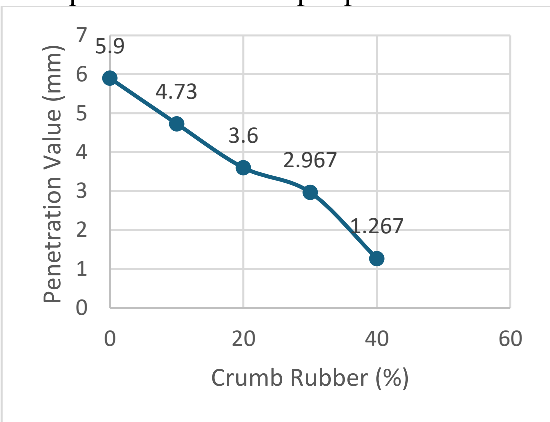

Figure 8: Penetration Graph

3.2.3 Marshall Stability Test

The Marshall stability test is carried out to calculate the flow rate and stability of Dense Bituminous Macadam (DBM) specimens. The table 2 and 3 shows the detailed information of Marshall Stability Test Input and output Data such as Bulk Density, Specific Gravity of mix, Percentage of Air Voids in specimen, Voids in Mineral Aggregate, Voids Filled by Bitumen, Stability of specimen and Flow rate of the DBM specimens. For calculation of Air Voids i.e. Column 'J', Voids in Mineral Aggregate (VMA) i.e. column 'K' and Voids Filled by Bitumen (VFB) i.e. column 'L' in the table, the formulae mentioned below are used respectively.

$$\text{Air Voids } = \frac{I-H}{H} \times 100$$

$$\text{VMA } = 100 - \frac{A \times H}{Specific\ gravity\ of\ aggregate}$$

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 8, No.2, August : 2025

$$VFB = \frac{K-J}{K} \times 100$$

Table 2: Marshall Stability Test Input Data

Crumb Rubber %	Total Bitumen % by weight of mix (%)	Total agg % by total weight of mix (%)	Mass of Specimen in grams			Bulk Volume [E-D] (%)	Bulk Density (gm/cc) [C/F]
			In Air	In Water	SSD		
	A	B	C	D	E	F	G
0	90	10	1327	760	1329	569	2.330
	90	10	1319	754	1321	567	2.326
	90	10	1316	751	1317	566	2.325
10	90	10	1323	770	1324	554	2.380
	90	10	1329	749	1331	582	2.280
	90	10	1314	745	1316	571	2.300
20	90	10	1326	735	1328	593	2.236
	90	10	1334	735	1335	600	2.223
	90	10	1309	720	1310	590	2.219
30	90	10	1311	725	1312	587	2.233
	90	10	1316	738	1318	580	2.269
	90	10	1305	734	1306	572	2.281
40	90	10	1278	695	1276	581	2.200
	90	10	1284	692	1286	594	2.161
	90	10	1280	714	1278	564	2.269

Table 3: Marshall Stability Test Output Data

Bulk Average Density (gm/cc) [(G1 + G2 + G3) / 3]	Specific Gravity of Mix (Gmm)	Air Voids (%)	VMA (%)	VFB (%)	Stability (KN)		Flow Rate (mm)	
					Stability (PRR) (KN)	Average stability (Avg-PRR) (KN)	Measured flow rate (mm)	Average flow rate (mm)
H	I	J	K	L	M	N	O	P
2.327	2.410	3.44	12.737	72.992	13.64	13.57	3.75	3.72
					13.55		3.73	
					13.52		3.68	
2.320	2.420	4.13	13.00	68.231	15.28	15.30	4.89	4.9
					15.37		5.56	
					15.25		4.25	
2.226	2.323	4.175	13.758	69.654	14.08	14.10	4.66	4.61
					14.18		4.68	
					14.04		4.49	
2.261	2.363	4.316	15.212	71.628	13.74	13.78	4.45	4.43
					13.92		4.47	
					13.68		4.38	
2.210	2.345	5.75	17.125	66.423	7.42	11.00	4.20	4.26
					13.23		4.33	

Industrial Engineering Journal
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Volume : 54, Issue 8, No.2, August : 2025

					12.35		4.22	

3.2.4 Marshall Stability of the DBM specimens

In this study, it is observed that the stability is highest for 10%CRMB in comparison to the remaining DBM specimens. 20%CRMB and 30%CRMB DBM specimens are observed to be more stable compared to the conventional DBM specimen. However, the 40%CRMB specimen displays the least stability.

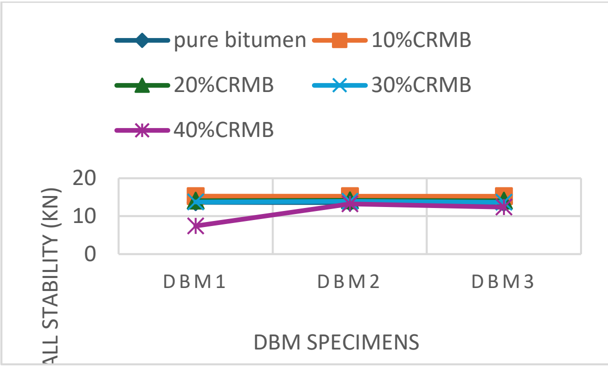

Figure 9: Comparison of Marshall Stability Values of DBM specimens made with Conventional Bitumen and CRMB

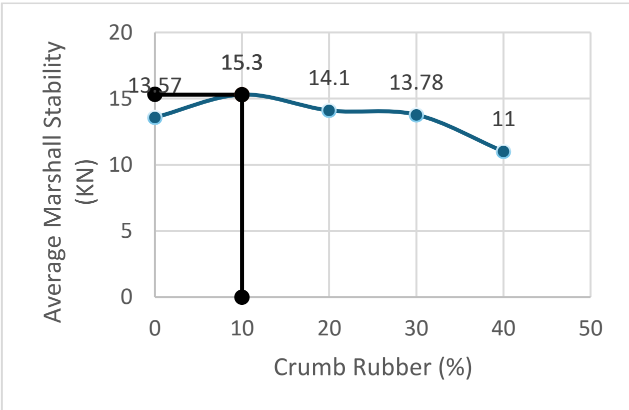

Figure 10: Graphical Representation of Average Marshall Stability of each DBM specimen

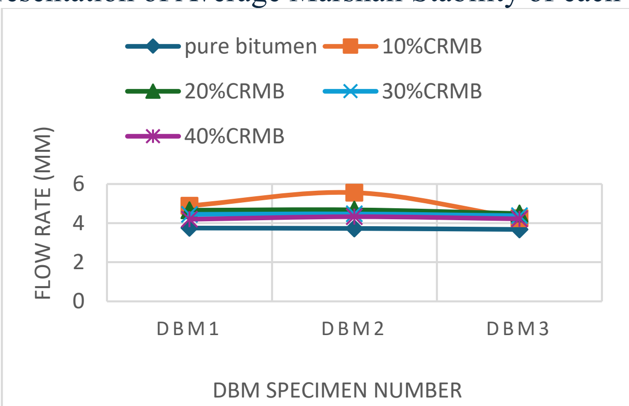

Figure 11: Comparison of DBM specimens made using Conventional Bitumen and CRMB or varying crumb rubber percentages in Graphical Form

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 8, No.2, August : 2025

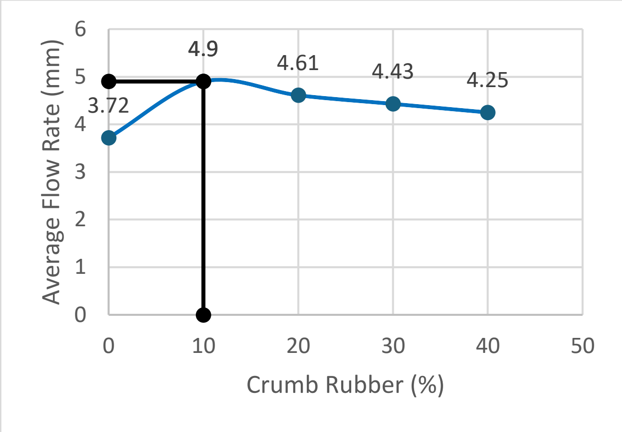

Figure 12: Average Flow Rate of DBM specimens made using Conventional Bitumen, 10%CRMB, 20%CRMB, 30%CRMB and 40%CRMB in graphical form

3.2.5 Flow Rate Of The DBM Specimens

In this study, it is observed that 10%CRMB specimen offers the highest Flow rate. The flow rates of DBM specimens of CRMB are all observed to have comparatively higher flow rates than conventional DBM specimen. Hence, it can be derived that DBM specimens made using CRMB possess a higher flow rate. So, CRMB is capable of filling up more voids in the Pavement surface than Conventional Bitumen.

IV. Conclusion

Based on the observations of the above test results, it can be concluded that 10%CRMB, 20%CRMB, and 30%CRMB offer enhanced properties of bitumen when compared to the test results of conventional bitumen and they can be further investigated for efficient usage on Indian Roads. Amongst the three CRMB samples, 10%CRMB offers reasonable softening point, ductility, penetration value, Marshall Stability, and Flow Rate as 20%CRMB and 30%CRMB samples offer low ductility which makes them more credible. Although 40%CRMB samples offer the best penetration value and softening point they have extremely less ductility and Marshall Stability which makes them unusable. This likely happened because of the high Crumb Rubber concentration in the specimens. Overall, it is observed that 10%CRMB, 20%CRMB, and 30%CRMB all satisfy the criteria provided for CRMB 65 as per the IS-code: 15462: 2004. In summary, we conclude that using Crumb Rubber Modified Bitumen can potentially upgrade the quality of pavements and make them more durable against high temperatures and the possibility of deformations are likely to be lower than before.

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