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Modification of Bitumen by Varying Percentage of the Crumb Rubber in Coarse Graded Aggregates

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Abstract: Bitumen is a black, oily, viscous material that is a naturally-occurring organic by product of decomposed organic materials. Since, the bitumen obtained from refinery cannot resist the higher temperatures, it is common practice that the bitumen is modified by either polymer or crumb rubber to increase to its physical properties. Many developing countries are using Crumb Rubber Modified Bitumen (CRMB) in paving applications for economizing the bitumen cost. CRMB is hydrocarbon binder obtained through physical and chemical interaction of crumb rubber (produced by recycling of used tyres) with bitumen and some specific additives. The Flexural range of CRMB offers binders which are stable and easy to handle with enhanced performances. CRMB is suitable for pavements submitted to all sorts of weather conditions, highways, traffic denser roads, junctions, heavy duty and high traffic sea port roads etc. It is a durable and economical solution for new construction and maintenance of wearing courses. In this paper, the properties of CRMB by varying the percentage of rubber ranging from 5% to 25% with an increment of 5% will be studied.

Keywords: Bitumen, Crumb Rubber, CRMB, Polymer.

I. BACKGROUND OF STUDY

Economic growth might be teetering across the world, but the amount of garbage generated by global cities is only going up. Together, urban centres generate 1.3 billion tonnes of solid waste a year and it is set to grow to 2.2 billion tonnes by 2025, according to projections by the World Bank. Most of the waste is sent to landfills, or worse, to open dumps, raising concerns about air pollution, social unrest, and impact on poverty and so on. Managing solid waste has costs $205.4 billion at present and it's growing. It is set to touch $375.5 billion by 2025. Overall, the local communities generate 16,000 tons of domestic waste per day and the amounts per capita vary from 0.45 to 1.44 kg per day depending on the economic status of the areas concerned (Lau, 2004). With the rapid economic growth and urbanization that is taking place in currently, solid waste generation and management is becoming a major social and environmental issue. One of the approaches towards solving the issue would be recycling of waste materials. Besides that, waste tire is neither categorized as solid waste or hazardous waste. It is generally considered as industrial or trade waste and hence there is no specific law or regulation which governs waste tire management (**Thiruvangodan, 2006**).

Fig1. Discarded Vehicle Tires.

Fig2. Plastic Wastes.

II.INTRODUCTION

A. General

Over the years, road structures have deteriorated more rapidly due to increases in service traffic density, axle loading and low maintenance services. To minimize the damage of pavement surface and increase durability of flexible pavement, the conventional bitumen needs to be improved with regards to performance related properties, such as resistance to permanent deformation (rutting) and fatigue cracking. The modification of bituminous binder has been explored over the past years in order to improve road pavement performance properties.

There are many modification processes and additives that are currently used in bitumen modifications, such as

- Styrene butadiene styrene (SBS),
- Styrene butadiene rubber (SBR),
- Ethylene vinyl acetate (EVA),
- Crumb rubber modifier (CRM).

The use of commercial polymers, such as SBS and SBR in road and pavement construction will increase the construction cost as they are highly expensive materials. However, with the use of alternative materials, such as CRM, will definitely be environmentally beneficial, and not only it can improve the bitumen binder properties and durability, but it also has a potential to be cost effective. In recent times, a serious problem that leads to environment pollution is the abundance and the increase of waste tyre disposal. Large amounts of rubbers are used as tyres for cars and trucks. Despite the long run in service, these tyres are not discarded. Although, the rubber as a polymer is a thermosetting material cross linked to processing and molding, however, it cannot be softened or remodeled by re-heating unlike other types of thermoplastics polymer which can be softened and reshaped when heated. The major approach to solve this issue is the recycle and reuse of waste tyre rubber and the reclaim of rubber raw materials.

B. Bitumen

Bitumen is the residue or by-product when the crude petroleum is refined. A wide variety of refinery processes, such as the straight distillation process, solvent extraction process etc. may be used to produce bitumen of different consistency and other desirable properties. Depending on the sources and characteristics of the crude oils and on the properties of bitumen required, more than one processing method may be employed.

C. Requirement of bitumen

The desirable properties of bitumen depend on the mix type and construction. In general, Bitumen should possess following desirable properties.

- The bitumen should not be highly temperature susceptible: during the hottest weather the mix should not become too soft or unstable, and during cold weather the mix should not become too brittle causing cracks.
- The viscosity of the bitumen at the time of mixing and compaction should be adequate. This can be achieved by use of cutbacks or emulsions of suitable grades or by heating the bitumen and aggregates prior to mixing.
- There should be adequate affinity and adhesion between the bitumen and aggregates used in the mix.

Fig3. Bitumen

D. Crumb rubber

Crumb rubber is a term usually applied to recycled rubber from automotive and truck scrap tires. During the recycling process steel and fluff is removed leaving tire rubber with a granular consistency. Continued processing with a granulator and/or cracker mill, possibly with the aid of cryogenics or mechanical means, reduces the size of the particles further. The particles are sized and classified based on various criteria including color (black only or black and white).

Fig4. West tire

E. Source of crumb rubber

Crumb rubber can be obtained from truck tyres or automobile tyres or both. Truck tyres contain 80 per cent more rubber hydrocarbons than automobile tyres and also contain significantly higher amounts of natural rubber. Whole truck tyre contains 18 per cent natural rubber compared to 9 per cent in an automobile tyre and 2 per cent in tyre treads. The amount of natural rubber has shown to affect the properties of CRMB significantly. Each lot of crumb rubber may have different chemical composition depending on the source (truck tyres or automobile tyres or mixture of both) and, therefore, when combined with the same source of bitumen may give different time versus viscosity curve. In other words, the target (plateau) viscosity and the allowable time before degradation are unique to each specific combination of bitumen and crumb rubber. Any time the source of bitumen or crumb rubber is changed, the time versus viscosity must be obtained again

Fig5. Shredding of tires.

III.METHODOLOGY AND EXPERIMENTAL PROGRAMME

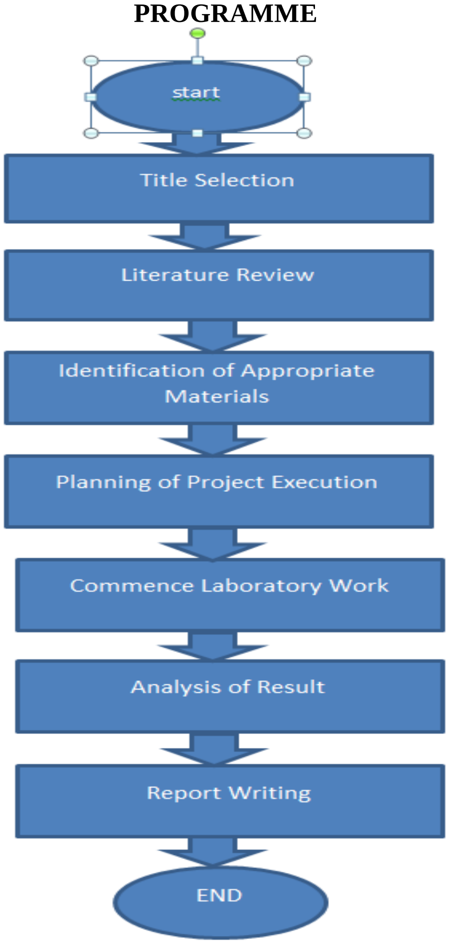

Fig6.

A. Material Selection and Preparation

For this research work aggregate, bitumen (VG30) and crumb of scrap tyre was used. Different properties of bitumen and aggregate have been tested. Then prepare different mixes of bitumen and crumb of waste tire rubber with varying proportions by using wet process. The percentage weight of crumb tyre rubber replace for percentage weight of bitumen taken for test. The feasibility of different mixes of bitumen and crumb tire rubber with varying proportions with aggregate has been tested.

Fig7. Weight crumb rubber.

TABLE. I

crumb rubber	Bitumen	used crumb rubber
5%	500 gr	25gr
10%	500gr	50gr
15%	500gr	75gr
20%	500gr	100gr
25%	500gr	125gr

B. Mixing

In preparing the modified binders, about 500g of the bitumen was heated to fluid condition in a 1.5 liter capacity metal container. The mixing was performed in the laboratory using an oven fitted with a mechanical stirrer and rotated at 1550rpm for mixing the bitumen and modifiers. For blending of crumb rubber with bitumen, bitumen was heated to a temperature of 160°C and then crumb rubber was added. The blend was mixed manually for about 3-4 minutes. The mixture was then heated to 170 °C and the whole mass was stirred using a mechanical stirrer for about 50 minutes. Care was taken to maintain between the temperatures 160°C to 170 °C.

Fig8. Mechanical Mixer and Hot Plate.

IV. EXPERIMENTAL PROGRAMME

A. Materials used

Bituminous mixture consists of aggregate finally binder that can bind all of this material together and also to give the mixture its durability. The properties of each material and their function in the bituminous mixture are described in the following sections.

B. Aggregate impact

Toughness is the property of a material to resist impact. Due to traffic loads, the road stones are subjected to the pounding action or impact and there is possibility of stones breaking into smaller pieces. The road stones should therefore be tough enough to resist fracture under impact. A test designed to evaluate the toughness of stones i.e., the resistance of the stones to fracture under repeated impacts may be called an impact test. Impact test may either be carried out on cylindrical stone specimens as in Page Impact test or on stone aggregates as in Aggregate Impact test. The Aggregate Impact test has been standardized by the British Standards Institution and the Indian Standards Institution. This test is designed to evaluate the resistance to an aggregate to sudden impact. The aggregate impact value indicates a relative measure of the resistance of an aggregate to a sudden shock or an impact, which in some aggregates differs from its resistance to a slow compressive load. The method of test covers the procedure for determining the aggregate impact value of coarse aggregates. The weight of the materials passing through 2.36mm IS sieve is expressed as a percentage of the total weight of the sample gives the Aggregate Impact Value. Chief advantage of aggregate impact test is that test equipment and the test procedure are quite simple and it determines the resistance to impact of stones simulating field condition. The test can be performed in a short time even at construction site or at stone quarry, as the apparatus is simple and portable.

C. Los Angeles abrasion value

This test method which is a modification of AASHTO is used to determine the resistance of coarse aggregate to impact in a rotating cylinder containing metallic spheres. Measuring the hardness of coarse aggregate, i.e. the resistance of wear using Los Angeles method to determine the Los Angeles Abrasion Value (L.A.A.V). Los Angeles abrasion test studies all possible reasons causing wear. In the Los Angeles abrasion machine Attrition, Abrasion, and crushing are all present as follows:

- **Attrition**: By the friction between the aggregate particles.
- **Abrasion**: By the friction between the steel balls and the aggregates.
- **Crushing**: By hitting the walls of the testing machine.

Los Angeles abrasion test is suitable for coarse aggregate of different sizes and it is not used for fine aggregate.

Los Angeles Abrasion Value (L.A.A.V.): Is obtained from this test and it measures the wear of the material due to abrasion and attrition

L.A.A.V. = Original mass - retained mass (at sieve # 12) \ Original mass x 100%

This value differs one grading to another, so there was specifications that specifies the samples grading with their masses and the charge of balls needed. The Grading consists of two different sizes of aggregate, the first one passes through sieve 19 mm and retained at sieve 12.5 mm, the second size passes through the 12.5 mm sieve and is retained at 9.5 mm sieve.

Fig9. Aggregates impact test.

According to the specification the total weight of the aggregate that should be used in the test is 5000 ± 10 gm. For grading B it was specified that 11 steel balls shall be placed in the machine with the aggregates. According to the specifications if L.A.A.V. is less than 30% then this aggregate is suitable for all mixture, and if it is more than 50% this aggregate is unusable in any mixture

D. Penetration test

It measures the hardness or softness of bitumen by measuring the depth in tenths of a millimeter to which a standard loaded needle will penetrate vertically in 5 seconds. BIS had standardized the equipment and test procedure. The penetrometer consists of a needle assembly with a total weight of 100g and a device for releasing and locking in any position. The bitumen is softened to a pouring consistency, stirred thoroughly and poured into containers at a depth at least 15 mm in excess of the expected penetration. The test should be conducted at a specified temperature of 25^{o} C. It may be noted that penetration value is largely influenced by any inaccuracy with regards to pouring temperature, size of the needle, weight placed on the needle and the test temperature. A grade of 40/50 bitumen means the penetration value is in the range 40 to 50 at standard test conditions. In hot climates, a lower penetration grade is preferred. The Figure shows a schematic Penetration Test setup.

Fig10. Penetration test.

Bitumen with Rubber Content%	Plain Bitumen	5%	10%	15%	20%	25%
Penetration Value	49	45	41	31	26	21

Bitumen with Rubber Content%	Plain Bitumen	5%	10%	15%	20%	25%
Softening Point	53	55	56.5	63.9	70.1	72.3

Fig11. Diagrams penetration and softening point tests

E. Aggregate Blending

Aggregate blending is a process that blends available aggregates to create a blend that meets gradation specifications while minimizing the unit cost of the blend. Mathematical and graphical procedures are available to determine an optimum combination of aggregates, but the "Trial and Error Method" guided by a certain amount of reasoning is the most practical procedure to determine a satisfactory combination.

Trial and Error Method:

Step 1- Obtain the required gradation data from MORT & H specification.
Step 2- Select a target value for trial blend.
Step 3- Estimate the proportions.
Step 4- Calculate the combined gradation.
Step 5- Compare the result with the target value.
Step 6- Repeat the calculations if the calculated gradation is close to the target value otherwise proceed forward.

F. Objective

To design the Bituminous mix using Marshall method. In this method, the resistance to plastic deformation of a compacted cylindrical specimen of bituminous mixture is measured when the specimen is loaded diametrically at a deformation rate 53 of 50 mm per minute. There are two major features of the Marshall method of mix design.

1. Density-voids analysis and
2. Stability-flow tests.

The Marshall stability of the mix is defined as the maximum load carried by the specimen at a standard test temperature of 60°C. The flow value is the deformation that the test specimen undergoes during loading up to the maximum load. Flow is measured in 0.25 mm units. In this test, an attempt is made to obtain optimum binder content for the type of aggregate mix used and the expected traffic intensity.

3 Steps of design:

1. Select aggregate grading to be used.
2. Determine the proportion of each aggregate size required to produce the design grading.
3. Determine the specific gravity of the aggregate combination and asphalt cement.
4. Prepare the trial specimens with varying asphalt contents.
5. Determine the specific gravity of each compacted specimen.
6. Perform stability tests on the specimens.
7. Calculate the percentage of voids, and percent voids filled with Bitumen in each specimen.
8. Select the optimum binder content from the data obtained.
9. Evaluate the design with the design requirements.

G. Procedure

In the Marshall Test method of mix design three compacted samples are prepared for each of binder content. At least four binder contents are to be tested to get the optimum binder content. All the compacted specimens are subject to the following tests:

- Bulk density determination.
- Stability and flow test.
- Density and voids analysis.

H. Preparation of Test Specimen

The coarse aggregate, fine aggregate, and the filler material should be proportioned so as to fulfill the requirements of the relevant standards. The required quantity of the mix is taken so as to produce compacted bituminous mix specimens of thickness 63.5mm. Approximately 1200 gm of aggregates and filler are required to produce the desired thickness. The aggregates are heated to a temperature of 175° to 190°C the compaction mould assembly and rammer are cleaned and kept pre-heated to a temperature of 100°C to 145°C. The bitumen is heated to a temperature of 121°C to 138°C and the required amount of first trial of bitumen is added to the heated aggregate and thoroughly mixed. The mix is placed in a mould and compacted with number of blows specified. The sample is taken out of the mould after few minutes using sample extractor.

Fig11. Marshall moulds

I. Design Requirements of the Mix

As per IRC: 29-1968, when the specimens are compacted with 75 blows on either face, the designed CRMB mix should fulfil the following requirements.
(i) Marshall stability value kg (minimum) = 340
(ii) Marshall flow value, 0.25 mm units <= 8 to 16
(iii) Voids in total mix, Vv % = 3 to 5
(iv) Voids in mineral aggregates filled with bitumen, VFB% = 75 to 85

The highest possible Marshall Stability values in the mix should be aimed at consistent with the other three requirements mentioned above. In case the mix designed does not fulfill anyone or more of the design requirements, the gradation of the aggregates or filler content or bitumen content or combination of these are altered and the design tests are repeated till all the requirements are simultaneously fulfilled.

J. Discussion

The Marshall Stability test method is very simple and rapid method for designing bituminous mixes scientifically. The stability values obtained in this test procedure indirectly represent the strength of a paving mix at a zero vertical stress level which is critical. Mixes with very high Marshall stability values and very low Flow values are not desirable as the pavements of such mixes may be brittle and are likely to crack under heavy traffic.

IV.ANALYSIS AND RESULTS

It is mentioned earlier that 60/70 penetration grade bitumen have been used in the bituminous concrete mixes with hydrated lime as filler and crumb rubber is added for modification.

TABLE II: Results of Impact test for Aggregates

Description	Trail number		
	1	2	3
Total weight of aggregate sample filling the cylindrical measure (g)	355	351	353
Weight of aggregate retained on 2.36mm sieve after the test(g)	73	71	72
Weight of aggregate passing 2.36mm sieve after the test(g)	279	283	281
Aggregate Impact Value (%)	20.56	20.23	20.39

TABLE III. Results of Penetration Test for Plain bitumen

Trail no.	Initial reading		Final reading		Penetration (mm)	Average Penetration Value (mm)
	Sample1	Sample2	Sample1	Sample2		
1	0	0	62.3	61.9	62.1	62.8
2	0	0	63.4	64.1	63.75	
3	0	0	62.1	63	62.55	

A. BC Gradation

Aggregate Blending for BC												
(Spec. Limits As per MORT & H,Table 500-18,Grading-1)												
Aggregate size (mm)	Description	% Passing I.S Sieves										
	I.S Sieve Size (mm)	26.5	19.0	13.2	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
20mm	Individual Gradations	100	85.67	31.87	2.9	0.00	0	0	0	0	0	0
10mm		100	100	99.5	75.26	9.8	2.4	1.7	2	1.51	1.34	1.04
Stone dust		100	100	100	100	96.6	76.9	54.6	40.4	25.4	14.0	6.2
Filler		100	100	100	100	100	100	100	100	100	100	90.3
	% Feed											
20mm	35	35.0	30.0	11.2	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10mm	24	24.0	24.0	23.9	18.1	2.4	0.6	0.4	0.4	0.4	0.3	0.2
Stone Dust	40	40.0	40.0	40.0	40.0	38.6	30.8	21.8	16.2	10.2	5.6	2.5
Filler	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.90
Combined Grading (JMF)		100.0	94.98	76.02	60.07	41.98	32.33	23.25	17.55	11.53	6.92	3.62
Spec.Upper Limits		100	100	79	72	55	44	34	27	20	13	8
Spec.Lower Limits		100	79	59	52	35	28	20	15	10	5	2
Mid Limits		100	90	69	62	45	36	27	21	15	9	5
Permissible variation		+/-7	+/-7	+/-6	+/-6	+/-5	+/-4	+/-4	+/-4	+/-3	+/-3	+/-1.5
JMF Upper Limit		100	100	79	72	47	39	27	22	15	10	5.5
JMF Lower Limit		100	92	72	60	37	30	20	14	10	5	2.5

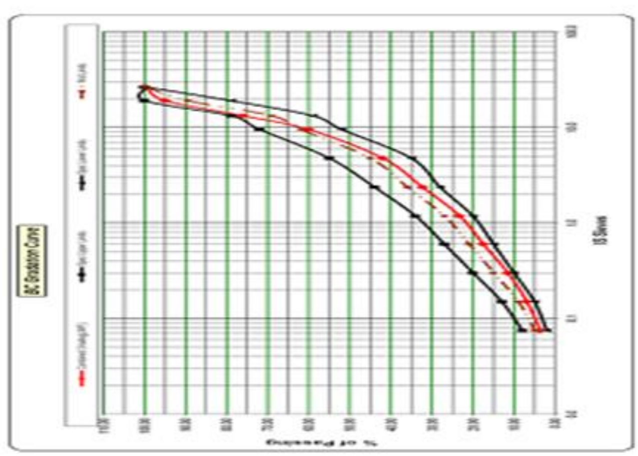

Fig12. BC Gradation.

B. Marshall Stability test

Bitumen Content %	Sample No.	Wt. in Air	Wt. in Water	SSD Wt. in Air	Avg Ht.	Vol. of specimen	Unit Wt.	Gmb	Gmm	(Va) %	VMA %	VFB %	MARSHALL STABILITY				Flow (mm)
													Reading	Load(Kg)	C.F	Corrected	
4	1	1.240	0.709	1.258	7.03	551.984	2.276	2.267	2.456	6.56	17.06	62.74	218	1166.4	0.89	1038.10	2.15
	2	1.230	0.711	1.235	6.58	516.607	2.381	2.347					231	1463.4	1	1463.40	3.84
	3	1.241	0.712	1.255	6.73	528.385	2.373	2.285					223	1204.2	0.96	1156.03	1.98
	AVERAGE						2.347	2.300	AVERAGE							1219.18	2.59
4.5	1	1.253	0.709	1.238	6.45	508.788	2.439	2.340	2.493	5.93	16.84	67.21	238	1285.2	1.04	1336.61	2.78
	2	1.241	0.707	1.244	6.50	510.714	2.436	2.311					264	1425.6	1	1425.60	4.03
	3	1.250	0.710	1.255	6.75	530.357	2.360	2.302					214	1155.6	0.96	1109.38	2.87
	AVERAGE						2.412	2.318	AVERAGE							1290.83	3.18
5	1	1.209	0.715	1.251	6.53	512.679	2.440	2.330	2.441	4.47	16.74	73.31	282	1522.8	1	1522.80	4.01
	2	1.251	0.713	1.252	6.63	520.538	2.403	2.321					258	1393.2	1	1393.20	3.23
	3	1.252	0.719	1.253	6.95	546.071	2.293	2.345					238	1285.2	0.93	1195.24	2.87
	AVERAGE						2.380	2.332	AVERAGE							1370.41	3.57
5.5	1	1.251	0.713	1.253	6.83	536.250	2.337	2.312	2.406	3.87	17.89	78.38	248	1339.2	0.96	1285.63	4.39
	2	1.249	0.713	1.250	6.75	530.357	2.357	2.328					216	1166.4	0.96	1119.74	3.64
	3	1.253	0.710	1.255	6.78	532.321	2.358	2.299					237	1279.8	0.96	1228.61	4.44
	AVERAGE						2.350	2.312	AVERAGE							1211.33	4.16
6	1	1.281	0.717	1.285	6.70	526.429	2.403	2.301	2.392	3.95	18.86	79.03	166	896.4	0.96	860.54	4.04
	2	1.259	0.716	1.270	7.05	553.929	2.293	2.273					236	1274.4	0.89	1134.22	6.03
	3	1.259	0.719	1.262	6.85	538.214	2.345	2.319					184	993.6	1	993.60	5.55
	AVERAGE						2.347	2.297	AVERAGE							996.12	5.21

Figure 13 shows the variation of Marshall stability values with the binder content. It can be observed that with increase in binder content the stability value increases up-to certainbinder content then decreases as per the normal trend for a given bituminous mix. The maximum value can be noted.

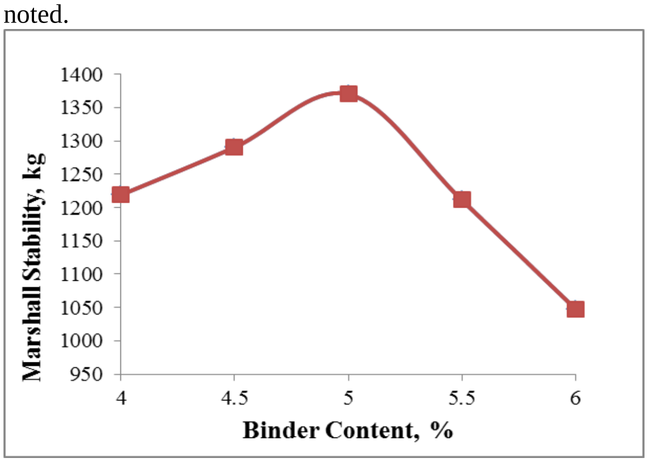

Fig13. Variation of Marshall stability values with Binder content.

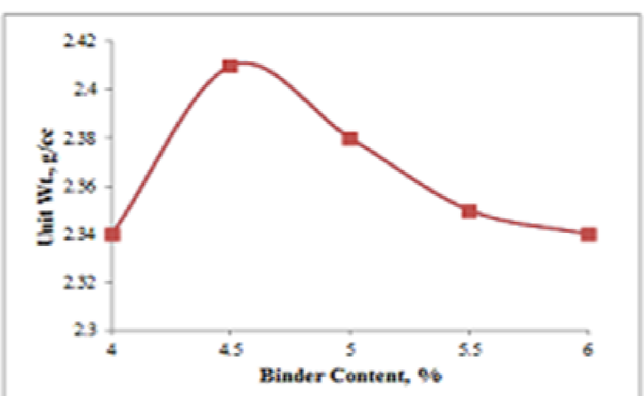

Fig14. Variation of Unit Wt. with Binder Content.

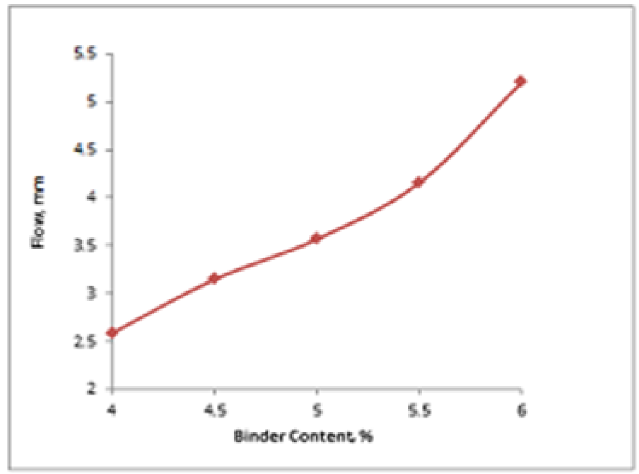

Fig15. Variation of Flow Values with Binder Content.

C. Marshall Stability tests on CRMB

% of crumb	sample no	Wt of specimen			Avg.Ht	Vol.	Unit Wt	(Gmb)	(Gmm)	VMA	VFB	Stability(kg)			Flow (mm)
		in air (A)	in water (B)	SSD (C)								Reading	CF	Corrected value	
5%	1	1259	532	1266	7.28	571.396	220.184	2.314	2.37	17.65	1.00	1080	0.86	928.8	6.13
	2	1259	530	1265	7.2	565.438	222.640	2.310		17.87		1020.8	0.93	949.178	2.73
	3	1266	724	1275	7.276	571.377	221.570	2.298		18.23		1063.8	0.86	914.868	3.13
Average							221.465	2.307		17.92		1054.8		930.942	3.99
10%	1	1258	718.5	1270	7.27	570.864	220.321	2.285	2.38	18.67	0.73	1517.4	0.86	1304.964	3.36
	2	1264	721	1276	7.2	565.438	223.524	2.277		18.91		1350	0.86	1161	4.70
	3	1267	718	1280	7.15	561.539	221.632	2.254		19.77		1441.8	0.88	1239.948	5.09
Average							223.156	2.272		18.13		1436.4		1235.304	4.75
15%	1	1262	719	1281	7.2	565.48	223.175	2.248	2.34	20.09	0.84	1242	0.86	1068.12	6.32
	2	1262	723	1273	6.5	547.42	230.538	2.288		18.64		1350	1.14	1539	5.02
	3	1252	716	1266	6.5	547.42	228.709	2.276		19.00		1329	1.14	1508.22	5.02
Average							227.475	2.269		19.24		1306		1371.78	5.55
20%	1	1252	718	1268	7.02	551.34	227.083	2.276	2.39	19.00	0.75	1020.6	0.89	908.334	5.7
	2	1250	710	1275	7.3	573.34	218.500	2.264		18.43		1004.4	0.86	863.784	6.58
	3	1265	726	1280	7.07	555.27	227.817	2.283		18.75		945	0.89	841.05	5.94
Average							224.830	2.274		18.06		990		871.056	6.07
25%	1	1256	706	1275	7.3	573.34	219.067	2.267	2.43	20.07	0.85	820.8	0.86	705.888	7.72
	2	1265	723	1280	7.12	560.55	222.269	2.271		19.11		734.4	0.88	631.584	7.02
	3	1258	720	1272	7.12	559.2	224.964	2.279		18.93		761.4	0.89	677.646	7.62
Average							222.100	2.266		19.39		772.2		671.706	7.45

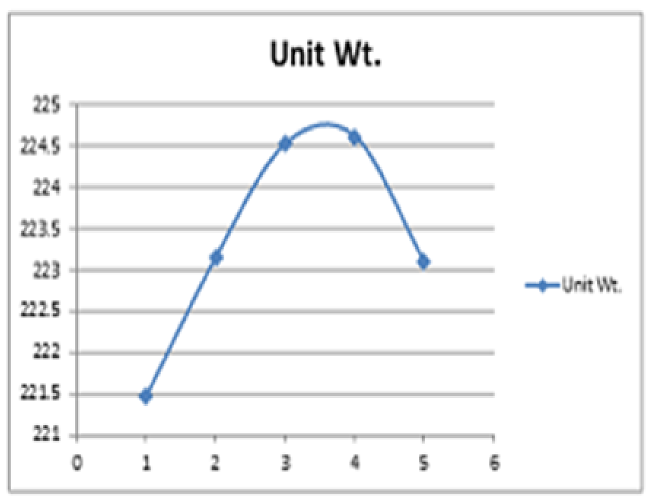

Fig16. Effect of Percentage of Crumb Rubber Unit Wt.

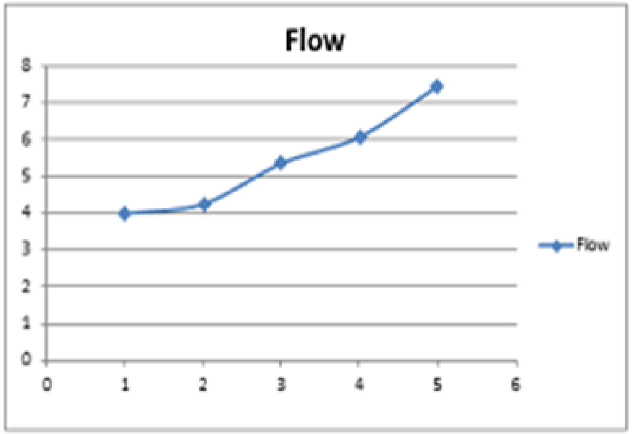

Fig17. Effect of Percentage of Crumb Rubber in Flow Values.

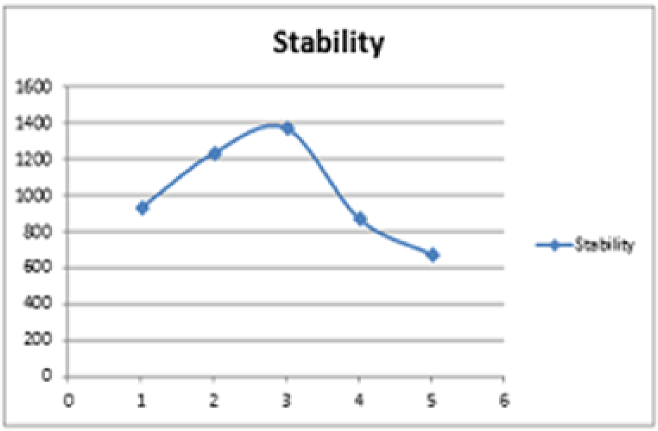

Fig18. Effect of Percentage of Crumb Rubber in Stability Values.

V.CONCLUSIONS

One of the problems currently faced by tire companies, the problem is the tires wear out on environmental issues. So always think of using old tires in industrial societies has been storage or disposal of high space requirements, the possibility of devastating fires worn tires in stock, breeding a variety of microbes, unusable land dedicated for the disposal of tires and such problems are available. The addition of the asphalt rubber powder benefits, such as reduced sensitivity to temperature, greater flexibility at low temperatures, reducing the percentage of sand in the mix, improve the impact resistance of asphalt mixtures.

1. By using the recycled rubber powder, there can be improve in the properties of asphalt used in road and also cleans not only help the environment but also to reduce the final price of asphalt producer.
2. The properties of CRMB by varying the percentage of rubber ranging from 5% to 25% with an increment of 5% has been studied found that:
   - The optimum bitumen content of VG30 bitumen using Bituminous concrete was found to be 5.3 % which is within the limits as stated in the MORT & H specifications.
   - The stability value of crumb rubber modified bitumen is found to be increasing from 5% to 15% of crumb rubber as seen in the table and graphs. At 15% the stability value was found to be 1427.05 kg which is increased by 5.25% than the unmodified bitumen.
   - The unit weight was found to be maximum at 15 % with a value of 2.275 gm/cc than the other percentages of crumb rubber content

Hence it can be concluded that for best results the crumb rubber content can be taken as 15% by weight of bitumen.

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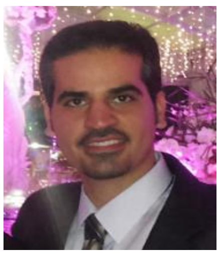

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