A Study on the Performance of Crumb Rubber Modified Bitumen by Varying the Sizes of Crumb Rubber

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Abstract—. **The abundance and increase of waste tyre disposal is a serious problem that leads to environmental pollution. Crumb rubber obtained from shredding of those scrap tires has been proven to enhance the properties of plain bitumen since the 1840s. It can be used as a cheap and environmentally friendly modification process to minimize the damage of pavement due to increase in service traffic density, axle loading and low maintenance services which has deteriorated and subjected road structures to failure more rapidly.Use of crumb rubber leads to excellent pavement life, driving comfort and low maintenance. The rheology of CRMB depends on internal factors such as crumb rubber quantity, type, particle size, source and pure bitumen composition, and external factors such as the mixing time, temperature, and also the mixing process (dry process or wet process). The present study aims in investigating the experimental performance of the bitumen modified with 15% by weight of crumb rubber varying its sizes. Four different categories of size of crumb rubber will be used, which are coarse (1 mm - 600 µm); medium size (600 µm - 300 µm); fine (300 µm-150 µm); and superfine (150 µm - 75 µm). Common laboratory tests will be performed on the modified bitumen using various sizes of crumb rubber and thus analyzed. Marshall Stability method is adopted for mix design. Finally a comparative study is made among the modified bitumen samples using the various sizes of Crumb Rubber particles and the best size is suggested for the modification to obtain best results**

***Keywords*— Bitumen, CRMB, Crumb Rubber, Marshall Stability Test and Pavement**

1. INTRODUCTION

India has a road network of over 4,689,842 kilometres in 2013 [1][2] , the second largest road network in the world. It has primarily flexible pavement design which constitutes more than 98% of the total road network. India being a very vast country has widely varying climates, terrains, construction materials and mixed traffic conditions both in terms of loads and volumes. Increased traffic factors such as heavier loads, higher traffic volume and higher tyre pressure demand higher performance pavements. So to minimize the damage of pavement surface and increase durability of flexible pavement, the conventional bitumen needs to be improved. 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) and crumb rubber modifier (CRM).

Crumb rubber is the 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. From physical and chemical interaction of crumb rubber with conventional bitumen Crumb Rubber Modified Bitumen (CRMB) is made. Its advantages are: Lower susceptibility to daily & seasonal temperature variations, higher resistance to deformation at elevated pavement temperature, better age resistance properties, higher fatigue life of mixes, Better adhesion between aggregate & binder, Prevention of cracking & reflective cracking, and Overall improved performance in extreme climatic conditions & under heavy traffic condition.

2. REVIEW OF LITERATURE

A detailed review of research works carried out related to the present study are described as below.

The penetration is a measure of hardness or softness of bitumen binder which shows an effect by adding crumb rubber to bitumen binder; it decreases as rubber content is increased. The penetration shows lower values as rubber content increases at different mix conditions of rubberized bitumen binder, indicating that the binder becomes stiff and more viscous (Mashaan et al, 2011a).

Mahrez (1999) investigated the properties of rubberized bitumen prepared by physical blending of bitumen 80 / 100 penetration grade with different crumb rubber content and various aging phases. The results of penetration values decreased over the aging as well as before aging by increasing the rubber content in the mix. Also, the modified binders have lower penetration values than unmodified binders.

The softening point refers to the temperature at which the bitumen attains a particular degree of softening. The use of crumb rubber in bitumen modification leads to an increase in the softening point and viscosity as rubber crumb content increases (Mahrez, 1999; MAshaan et al , 20011a). Mahrez and Rehan (2003) claimed that there is a consistent relationship between viscosity and softening point at different aging phases of rubberized bitumen binder.

According to a study conducted by Lee et al. (2008), the higher crumb rubber content produced increased viscosity at 135°C and improved the rutting properties. It was also observed that the increased crumb rubber amount (fine crumb rubber) produced rubberized bitumen with higher viscosity and lower resilience. However, optimum crumb rubber content still needs to be determined for each crumb rubber size and asphalt binder. It is believed that a physicochemical interaction that occurs between the asphalt and the crumb rubber alters the effective size and physical properties of the rubber particle, thus influencing pavement performance (Huang et al, 2007)

Becker et al, (2001) claimed that blend properties will be influenced by the amount of crumb rubber added to the bitumen. Higher amounts indicated significant changes in the blend properties. As rubber content generally increases, it leads to increased viscosity, increased resilience, increased softening point and decreases penetration at 25°C.

The mixture showed improved performance in dynamic stability, 48 h residual stability, flexural strength and strain value. Asphalt containing 0.2 and 0.4 mm size rubber indicated the best laboratory results (Souza and Weissman , 1994). The particles size disruption of crumb rubber influenced the physical properties of bitumen rubber blend. In general, small difference in the particles size has no significant effects on blend properties. However, the crumb rubber size can certainly make a big difference.

According to a study of Shen et al. (2009), the particle size effects of CRM on high temperature properties of rubberized bitumen binders was an influential factor on visco- elastic properties. The coarser rubber produced a modified binder with high shear modulus and an increased content of the crumb rubber decreased the creep stiffness which in turn showed significant thermal cracking resistance.

When crumb rubber is blended at high temperatures with bitumen to produce a modified binder (i.e wet process), the two materials interact once bitumen components migrate into the rubber causing it swell (Bahia and Davies, 1994). Initially, the interaction between crumb rubber and bitumen is a non-chemical reaction, where the rubber particles are swollen by the absorption of the aromatic oils of bitumen (Heitzman, 1992).

Modified bitumen using crumb rubber showed an improvement in the performance of pavements over the base binders as a result of the interaction of crumb rubber with base binders. Due to this interaction, there are noticeable changes in the viscosity, physical and rheological properties of the rubberized bitumen binder (Airey et al , 2003; Bahla and Davies, 1995), leading to high resistance of rutting of pavements (Huang et al, 2007).

The rubber particles are considered in their movement into the binder matrix to move about due to the swelling process which limits the free space between the rubber particles. Compared to the coarser particles, the finer particles swell easily thus, developing higher binder modification (Abedlrahman and Carpenter, 1999).

3. MATERIALS

VG-30 bitumen, Fine crumb rubber, Softening point apparatus, Penetration test Apparatus, Bitumen mixing setup, Marshall test apparatus, Air voids apparatus

4. EXPERIMENTAL PROGRAMS

4.1. Mixing of crumb rubber with plain bitumen

In preparing the modified binders, about 500 g of the bitumen was heated to fluid condition in a 1.5 litre capacity metal container. For blending of crumb rubber with bitumen, it was heated to a temperature of 160 °C and then crumb rubber was added. For each mixture sample 15% [3] of crumb rubber by weight of four different sizes is used, which are coarse (1 mm - 600 μm); medium size (600 μm - 300 μm); fine (300 μm-150 μm); and superfine (150 μm - 75 μm). The blend is mixed manually for about 3-4 minutes. The mixture is then heated to 160 °C and the whole mass was stirred using a mechanical stirrer for about 50 minutes. Care is taken to maintain the temperature between 160 °C to 170 °C. The contents are gradually stirred for about 55 minutes. The modified bitumen is cooled to room temperature and suitably stored for testing.

4.2 Common tests on the modified bitumen

Penetration test and Softening point tests on both the plain and modified CRMB are performed and the results are analyzed for further study.

4.3 Preparation of Bituminous mix

For the present study Bituminous concrete mix gradation was used following specifications stated by MORT & H table 500-19.

Three specimens of Marshall moulds and one loose mix (uncompacted) are prepared for each size of crumb rubber. Aggregates are oven dried and sieved according to BC gradation and separated. The amount of each size of fraction required to produce a mixed aggregate of 1200gm as per gradation is weighed. The required height of specimen is 63.5(+/-1). Bitumen and aggregate is heated separately to 160 °C and 150 °C respectively. Then bitumen is poured in aggregate as per requirement. Then the mixture is mixed till a uniform coating is obtained on aggregate while the mixture is being heated together maintained at around 170 °C. The specimens mould and compaction hammer are cleaned thoroughly and mould assembly is heated in hot air oven to a temperature about 150 °C. A little grease is applied to the mould before the mix is placed. The mould is assembled and the mix is transferred and tampered using spatula. Then 75 blows are applied on either sides of the mould manually. Then the specimen is extracted after 24 hours.

Fig1 : Preparation of sample

Fig 2: Marshall moulds for OBC determination

Fig 3: Loose mix(uncompacted) for air voids calculation

4.4 Marshall Stability tests

Before testing the moulds their dimensions is measured to note the volume and their weight in air, weight in water, and weight of dry SSD are taken. After that they are kept in water bath maintained at 25 for 30 minutes. The moulds are tested within 3 to 4 minutes after taken out from water bath. The mould is put out on Marshall Apparatus and Marshall Stability and flow dial gauge readings are recorded.

Fig 4: Marshall Stability Test Setup

4.5 Density and Air Void Analysis

The following quantities are worked out by carrying out density voids analysis: Bulk specific gravity of Compacted Mixture, Theoretical Maximum specific Gravity, Percent air voids, Percent air voids in mineral aggregates (VMA), Percent aggregate voids filled with bitumen (VFB) and further graphs are plotted .

a. Bulk Specific Gravity (G_{mb}) = [A / (B – C)]

Where;

A= Weight in grams of the specimen in air.

B= Weight in grams, surface dry.

C= Weight in grams, in air.

b. Theoretical Maximum Specific Gravity (G_{mm}) = A / (A + D –E)

Where;

A= mass of oven-dry sample on air

D = mass of flask filled with water up to neck at (25°C)

E = mass of container filled with sample and water up to neck at (25°C)

c. % Air Voids (V_a)= 100 [1-(G_{mb} / G_{mm})]

Where;

G_{mb} = Bulk specific gravity

G_{mm} = Theoretical maximum specific gravit

d. Voids in mineral aggregate (VMA) = 100 [1–((G_{mb} (1- P_b)) / G_{sb})]

Where;

G_{mb} = Bulk Specific Gravity of compacted mix.

G_{sb} = Bulk Specific Gravity of total aggregate.

P_b = Percent of bitumen by weight.

e. Voids Filled With Bitumen (VFB) = 1- (V_a/VMA)

Where;

Va = % Air voids

VMA = Voids in mineral aggregate

Fig 5: Air Voids determination setup

The bitumen content corresponding to 4% air voids is taken as optimum bitumen content (OBC). With that OBC the Marshall tests are repeated for the CRMB mixes prepared using four different sizes of crumb rubber as stated earlier. And the results are analyzed and compared to identify the best size of crumb rubber to be added for modification.

5. TESTS RESULTS

Common Tests on Plain and Modified Bitumen

Penetration value of VG-30 bitumen =**62.78mm**

Softening Point of plain VG-30 bitumen = **49.82** °C

TABLE 1: Penetration Results for CRMB of different crumb

Sample No.1:(1mm-600) µm Crumb rubber
Sample No.2:(600 -300) µm Crumb rubber
Sample No.3:(300 -150) µm Crumb rubber
Sample No.4:(150 -75)µm Crumb rubber

Test Property	Sample No.1		Sample No.2		Sample No.3		Sample No.4	
Temperature (°C)	Ball No.1	Ball No.2	Ball No.1	Ball No.2	Ball No.1	Ball No.2	Ball No.1	Ball No.2
	57.1	56.5	57.4	58.7	60.6	61.1	63.3	64.1
Mean Softening point	**56.8°C**		**58.05°C**		**60.85°C**		**63.7°C**	

rubber sizes

TABLE 2: Softening Point test results for CRMB of different crumb rubber sizes

Test Property	Sample No.1	Sample No.2	Sample No.3	Sample No.4
penetration (mm)	**43.33**	**41.17**	**38.33**	**36.17**

5.1. OBC Determination

The Marshall stability test and air voids analysis results are tabulated as under:

TABLE3**:** Observation table for Marshall tests

Bitumen Content %	Unit Wt.	Stability (Kg)	Flow (mm)	Air Voids %	VMA %	VFB %
4	2.35	1219.18	2.59	6.36	17.06	62.74
4.5	2.41	1290.53	3.15	5.52	16.84	67.21
5	2.38	1370.41	3.57	4.47	16.74	73.31
5.5	2.35	1211.33	4.16	3.87	17.89	78.38
6	2.34	993.60	5.21	3.95	18.86	79.03

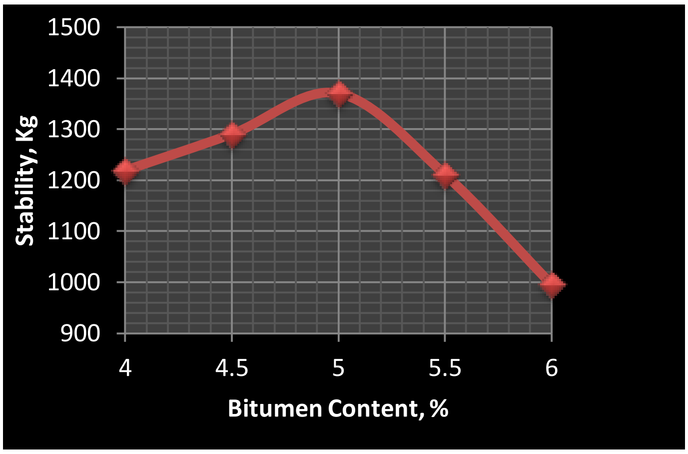

Fig 6**:** Bitumen Content vs. Stability

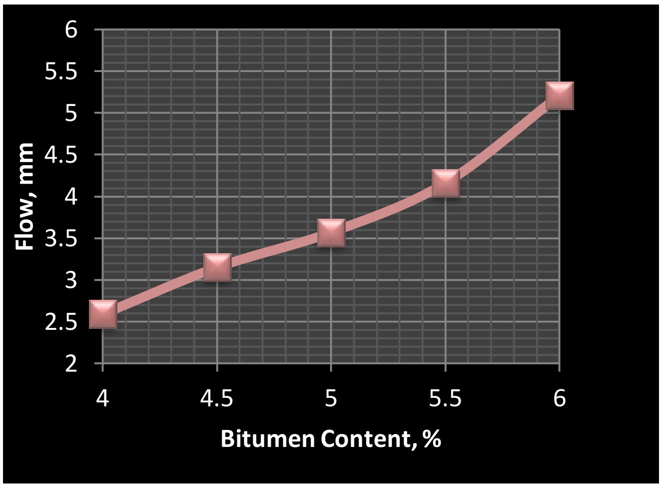

Fig 7**:** Bitumen content vs. Flow

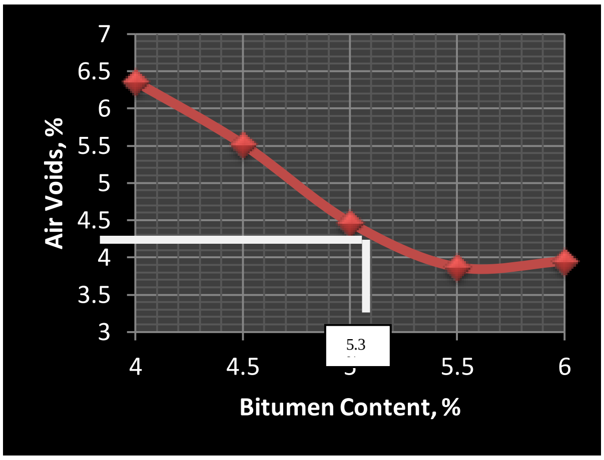

Fig 8**:** Bitumen Content vs. Air Voids

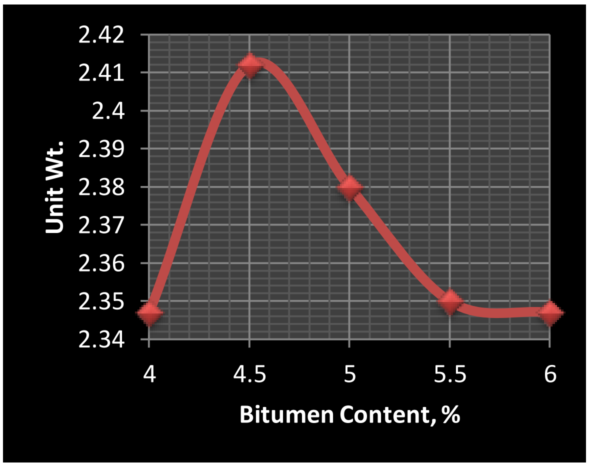

Fig 9: Bitumen content vs. Unit Wt.

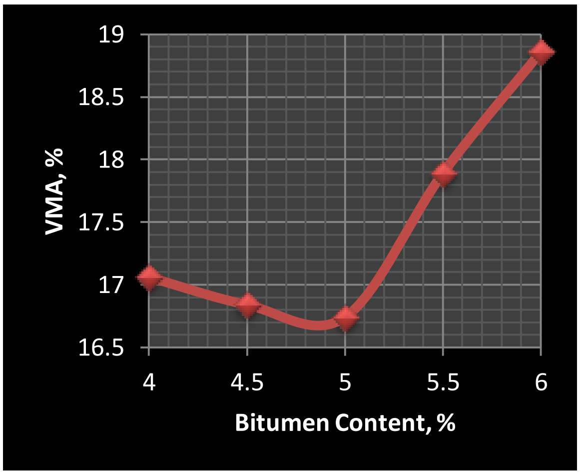

Fig 10:Bitumen content vs. VMA

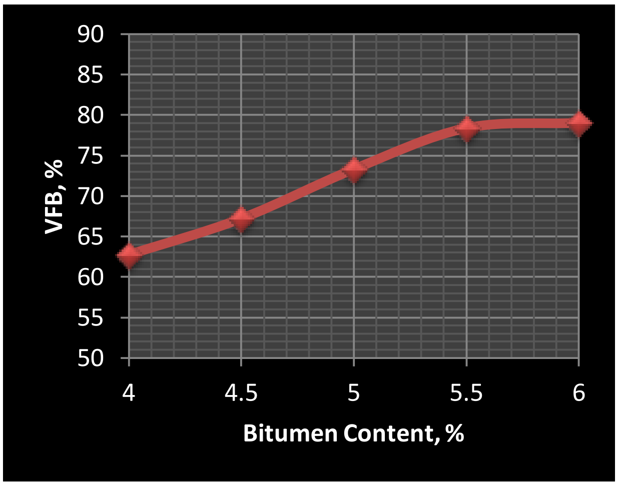

Fig 11: VFB vs. Bitumen Content

5.2. Marshall tests using CRMB prepared by different sizes of crumb rubber

Using OBC 5.3% as obtained from figure 8:, three CRMB marshall samples and one loose mix (uncompacted) are prepared taking 5.3% by weight of modified bitumen. Then Marshall stability tests and density void analysis tests are performed as mentioned earlier for the plain bitumen and the results are tabulated as below.

Crumb rubber Size(mm)	Unit Wt.	Stability (Kg)	Flow (mm)	Air Voids%	VMA %	VFB %
(1-0.6)	2.29	1312.22	3.33	4.55	18.68	80.83
(0.6-0.3)	2.27	1512.79	4.25	3.93	19.75	76.45
(0.3-0.15)	**2.34**	**1597.64**	**3.74**	**4.84**	**16.72**	**71.06**
(0.15-0.075)	2.31	1231.45	4.9	2.33	17.89	86.97

TABLE 4:Observation table for Marshall Stability tests on CRMB mix

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6. CONCLUSIONS

By studying the test results of common laboratory tests on plain bitumen and crumb rubber modified bitumen it is concluded that the penetration values and softening points of plain bitumen can be improved significantly by modifying it with addition of crumb rubber which is a major environment pollutant.

From the table 2 it can be observed that the sample prepared using crumb rubber size **(0.3-0.15mm)** give the highest stability value of 1597.64 kg, minimum flow value, maximum unit weight, maximum air voids and minimum VMA and VFB % values. So the best size to be used for crumb rubber modification can be suggested as (**0.3-0.15mm**) size for commercial production of CRMB.

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