Experimental Study of Marshall Stability Test on Dense Bituminous Macadam Layer with Partial Replacement of Bitumen with Crumb Rubber

Veena K, Hema H
Assistant Professors
Dept. of Civil Engineering
NIE, Mysore, Karnataka, India

Akshaya J L, Mahadevaswamy M
Maheshnayaka M C, Nagarjun M
UG students
Dept. of Civil Engineering
NIE, Mysore, Karnataka, India

***Abstract*— Human life style and increase in population has caused an increase in solid waste such as rubber. Rubber wastes are continuously increasing with the rising demand of manufacturing of transportation vehicles. The utilization of waste materials like rubber in the process of road construction provides many benefits. The abundance and increase of waste tyre disposal is a serious major crisis 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. The following study consists of replacing 3, 3.5, 4, 4.5 and 5 percentage of bitumen each with 10, 20 and 30 percentage crumb rubber by weight of bitumen successively. The expected results are to obtain OBC (optimum bitumen content) with that of a maximum replacement of shredded rubber**

Keywords—Crumb Rubber; Bitumen;Marshall Stability Test; OBC;

I. INTRODUCTION

India is a country of villages and roads are the best means of connectivity for transport. Increasing the number of roads and improving its quality helps in the vast development of any country. Due to the rapid rise in transport through roads the usage of automobiles is greatly increased. Hence the usage of rubber tyres is rapidly increased. Replacement of vehicle tyres is necessary for approximately 20000 km – 60000 km of transportation depending on the type of vehicle. Due to this excess quantity of waste tyres are produced. It has been estimated that more or less billions of tons of waste tyres are produced globally every year. The ever increasing tyre waste and its disposal is a serious problem that leads to environmental pollution. The shredded Crumb rubber obtained from the scrap tyres has been proved to enhance the properties of plain bitumen since 1840s.

The quality of pavement is imbibed depending on the type of materials chosen for its making. Pavements are generally of two categories based on structural performance – Flexible pavements and Rigid pavements

A flexible pavement is the one which has a bitumen coating on top and rigid pavements which are stiffer than flexible ones that have PCC or RCC on top. The flexible pavements are built in layers and it is ensured that under application of load none of the layers are overstressed. The maximum intensity of stress occurs at top layer, hence they are made from superior material mainly bitumen.

The mix design should aim at an economical blend with proper gradation of aggregates and adequate proportion of bitumen so as to fulfill the desired properties of mix which are stability, durability, flexibility, skid resistance and workability. Mix design methods should aim at determining the properties of aggregates and bituminous material which would give a mix with these properties. The design of asphalt paving mixtures is a multi-step process of selecting binders and aggregate materials and proportioning them to provide an appropriate compromise among several variables that affect mixture behavior, considering external factors such as traffic loading and climate conditions. In the construction of flexible pavements, bitumen plays the role of binding the aggregate together by coating over the aggregate. It also helps to improve the strength of the road. But its resistance towards water is poor. Anti-stripping agents are being used. Bitumen is a sticky, black and highly viscous liquid or semi-solid which can be found in some natural deposits or obtained as by-product of fractional distillation of crude petroleum. It is the heaviest fraction of crude oil, the one with highest boiling point (525°C) .Various Grades of Bitumen used for pavement purpose:30/40, 60/70 and 80/100. The desirable properties of bitumen for pavement are:

- Excellent binding property with aggregates, both cohesive and adhesive in nature.
- Repellent to water.
- Thermoplastic in nature (stiff when cold, liquid when hot) [Athira and Sowmya, 2015].

An extensively used method to improve the quality of bitumen is by modifying the Engineering properties of bitumen by blending with organic synthetic polymers like rubber. They can return to the earth as beneficial additives in bitumen roads

1.1 BACKGROUND AND RELATED WORK

V. Suganpriya (2016) the aim of the study was to utilize the waste materials i.e. crumb rubber waste for mass scale utilization such as in highway construction in an environmental safe manner. As a first part of this study, an attempt was made to assess the stabilization of the bitumen containing crumb rubber waste in shredded form by performing basic tests such as Penetration Test, Ductility Test, Softening Point Test, Viscosity Test and Flash & Fire Point Tests.

Foad Ali *et al.*, (2014) studied the varying percentage of the CRMB in the Bitumen mix. The Flexural range of CRMB offers binders which are stable and easy to handle with enhanced performances. In this paper, the properties of CRMB by varying the percentage of rubber ranging from 5% to25% with an increment of 5% was studied.

Eme and Nwofor (2015) studied ground scrap tyres in asphalt mixtures as a binder and modifier. A laboratory investigation was conducted on a range of dense graded dry process with 4.75 mm, 2.36 mm and 0.600 mm particle size rubber modified asphalt mixtures containing 0 (control), 2, 4, 6, 8 and 10% ground rubber by mass.

1.2 OBJECTIVE

The main objectives of the study are:

- To determine the optimum binder content for nominal Marshall mix
- To select the optimum percentage of crumb rubber modified bitumen to produce maximum compressive strength.
- To study the Marshall properties of the bitumen concrete mixes and crumb rubber to determine how they affect the properties of mixes.

II. MATERIAL

2.1 Bitumen

VG30 bitumen was used in this investigation to prepare the samples. Table 1 shows the test results of basic properties of bitumen.

Table 1: Basic Properties of Bitumen

Properties	Results
Specific gravity	1.02
Penetration	36 mm
Softening point	37°C
Flash point	330°C
Fire point	350°C
Ductility	79 mm
Viscosity	60/70

2.2. Fine Aggregate

Aggregates of size below 4.75 mm as per MORTH Specifications (5th revision) [Anonymous, 2013] were used as fine aggregate. Table 2 shows the test results of basic properties of fine aggregates.

Table 2: Basic Properties of Fine Aggregates

Properties	Results
Specific gravity	2.64
Water absorption	1.45%

2.3. Coarse Aggregate

Aggregates of 20mm as per MORTH Specifications (5th revision) [Anonymous, 2013] down size were used as Course aggregate. Table 3 shows the test results of basic properties.

Table 3: Basic Properties of Coarse Aggregates

Properties	Results
Specific gravity	2.67
Impact value	18.75%
Water absorption	0.39%

2.4. Crumb Rubber

Uniformly shredded Rubber pieces were used in the study. Crumb rubber passing 150µm and retaining 300µm was used.

Table 4: Basic Properties of modifiers

Properties	Results
Specific gravity	0.707

III. EXPERIMENT METHODS

3.1. Rothfutch's Method

Sieve Analysis for different materials A, B and C has to be done and percentage finer has to be calculated for each range of particle size for all materials and grain size distribution curves of these three materials are plotted. Desired Gradation lines represent the proportion in which the materials A, B and C are to be mixed. The results from Rothfutch's method are shown in table 5.

Table 5: Results obtained from Rothfutch's graph

IS Sieves	% used	Wt. of Materials (g)
20 mm	25	300
12.5 mm	30	360
6 mm	25	300
S Dust	17	204
Filler	3	36
Bitumen	-	-
Crumb Rubber	-	-
Total	100	1200

3.2. Marshall Stability Test

The Marshall Stability and flow test provides the performance prediction measure for the Marshall Mix design method. The original Marshall Method is applicable only to hot asphalt paving mixes. Marshall Stability of a test specimen is the maximum load required to produce failure when the specimen is preheated to a prescribed temperature placed in a special test head and the load is applied at a constant strain (50.8 mm/minute). While the stability test is in progress dial gauge is used to measure the vertical deformation of the specimen. The deformation at the failure point expressed in units of 0.25 mm (0.01 inch) is called the Marshall Flow value of the specimen.

The 'Marshall Stability' of the bituminous mix specimen is defined as a maximum load carried in kg at the standard test temperature of 60°C when load is applies under specified test conditions. It involves mainly 2 processes:

- Preparation of Marshall Samples
- Marshall Test on samples

3.3. Preparation of Marshall Samples

- For DBM mixes the coarse aggregates, fine aggregates and filler were mixed with bitumen and modifier used according to the adopted gradation, such that each aggregates are weighed and added.
- This will be about 1200 g referring to Rothfutch's graph results.
- Each material is graded, weighed and placed in an oven until a uniform temperature of 60°C is attained.
- Nominal bitumen mix specimen is prepared; Course aggregate is added to a preheated pan and stirred.

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When they heat up to around 100°C, melted bitumen is added and mixed thoroughly.

- When the mixture shows well coated by bitumen, fine aggregate and cement (filler material) is slowly added.
- The ingredients are heated until they reach 130°C.
- The CRMB samples are obtained by following the above procedure; the only change being the variation in crumb rubber which is heated and melted along with bitumen before the hot liquid mix is poured over coarse aggregate.

Fig. 1: Placing compacted sample in 60°C water bath

3.4. Marshall test on samples

Marshall Stability test is conducted on compacted cylindrical specimens of bituminous mix of diameter 101.6 mm, thickness 63.5 mm. The load is applied perpendicular to the axis of the cylindrical specimen through a testing head consisting of a pair of cylindrical segments, at a constant rate of deformation of 51 mm per minute at a standard test temperature of 60°C. The 'Marshall Stability' of the bituminous mix specimen is defined as a maximum load carried in kg at the standard test temperature of 60°C when load is applies under specified test conditions. The flow value is the total deformation of Marshall Test specimen at the maximum load, expressed in mm units.

Fig. 2: Marshall Stability testing Machine

In the Marshall method of mix design, each compacted test specimen is subjected to the following tests and analysis.

- Bulk specific gravity (Gb) determination
- Stability and Flow test and
- Void analysis

Bulk specific gravity (G_b) determination

Bulk specific gravities of saturated surface dry specimens are determined.

Stability and flow tests

After determining the bulk specific gravity of the test specimens, the stability and flow tests are performed. Place the specimen centrally on the lower testing head and fit upper head carefully. Fix the flow meter with zero as initial reading. The load is applied at a constant rate of deformation of 51 mm (2 inches) per minute. The total load at failure is recorded as its Marshall Stability Value. The reading of flow meter in units of 0.25 mm gives the Marshall Flow value of the specimen. The entire testing process starting with the removal of specimen from bath up to measurement of flow and stability shall not take more 30 seconds. While the stability test is in progress, hold the flow meter firmly over the guide road and record.

Density and voids analysis

After completion of the stability and flow test, a density and voids analysis is done for each set of specimens. The calculations are given in section 5. Average the bulk density is determined for asphalt content. This average value of G_b is used for further computations in void analysis.

(a) Determine the theoretical density (G_t) for at least 2 bitumen contents nearer to the optimum binder content.

(b) V_v, VMA and VFB are then computed using the standard equations.

Table 6: Marshall Stability and flow values for control mix

Bitumen%	Stability in kg	Flow value in mm
3.0	2300.0	3.60
3.5	2650.0	3.65
4.0	2725.0	3.75
4.5	2825.0	3.80
5.0	2112.5	4.30
5.5	2100.0	4.80
6.0	2087.5	5.00

Table 7: Density and void analysis for control mix

Bitumen%	G_b	V_v	VMA	VFB
3.0	2.272	9.168	15.917	42.523
3.5	2.300	6.9120	14.925	53.688
4.0	2.249	7.9272	15.853	49.994
4.5	2.302	7.420	15.389	51.841
5.0	2.021	7.2905	16.347	55.402
5.5	2.327	10.3793	19.134	45.755
6.0	2.090	8.835	17.741	50.579

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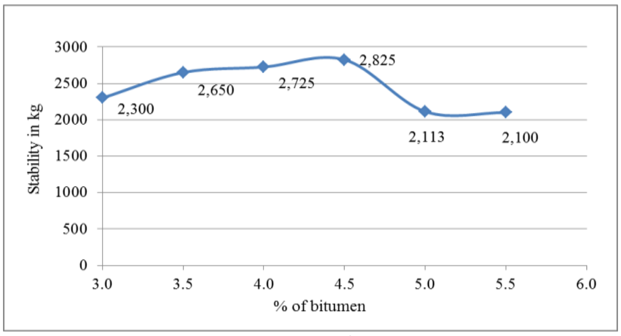

Fig. 3: Marshall Stability for Regular DBM

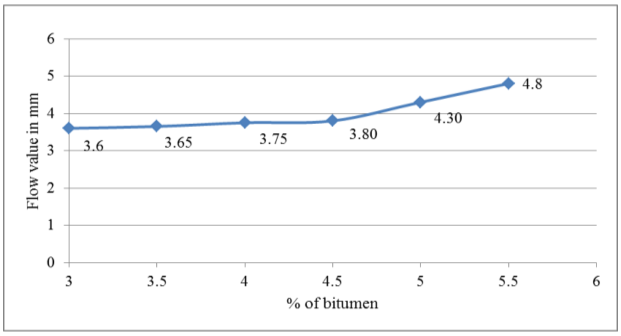

Fig. 4: Flow Value for Regular DBM

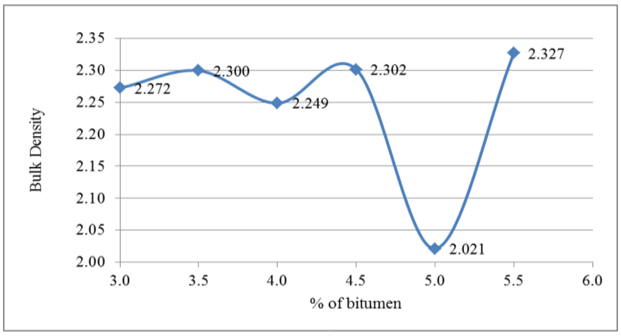

Fig. 5: Bulk Density for Regular DBM

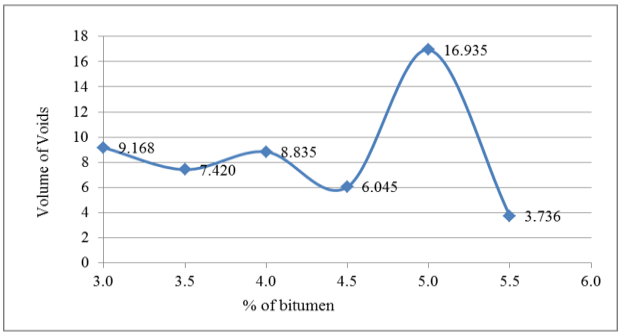

Fig. 6: Volume of Voids in Regular DBM

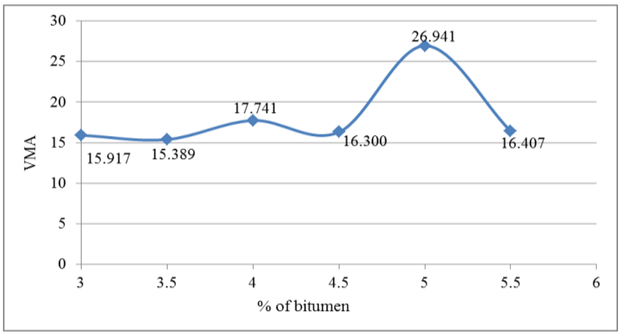

Fig. 7: VMA in Regular DBM

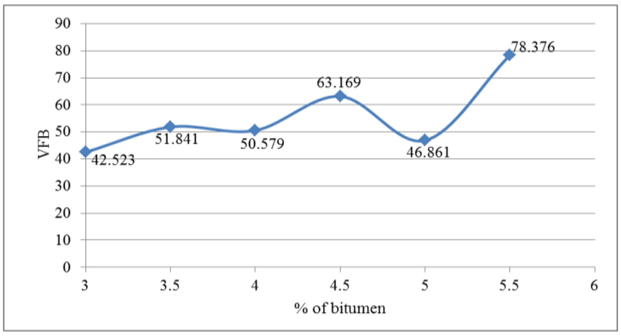

Fig. 8: VFB in Regular DBM

Table 8: Marshall Stability and flow values for CRMB mix

Bitumen%	Crumb Rubber%	Stability in kg	Flow value in mm
3.0	10	1075.0	1.605
	20	1162.5	1.31
	30	1437.5	1.825
3.5	10	1925.0	3.15
	20	2000.0	3.35
	30	2112.5	3.8
4.0	10	2125.0	3.15
	20	2325.0	3.3
	30	2787.5	3.4
4.5	10	1000.0	1.65
	20	1565.0	2.65
	30	1700.0	3.7

Table 9: Density and void analysis for CRMB mix

Bitumen%	Crumb Rubber%	G_b	V_v	VMA	VFB
3.0	10	2.176	10.82	16.11	32.81
	20	2.313	4.90	9.74	49.68
	30	2.118	12.68	17.35	26.92
3.5	10	2.044	15.19	21.32	28.75
	20	2.125	11.53	17.19	32.93
	30	2.084	12.81	17.67	27.50
4.0	10	2.044	14.88	22.05	32.51
	20	2.103	11.29	17.69	36.21
	30	2.081	11.89	17.44	31.80
4.5	10	2.190	6.89	15.33	55.07
	20	2.136	8.78	16.10	45.46
	30	2.118	9.11	15.46	41.07

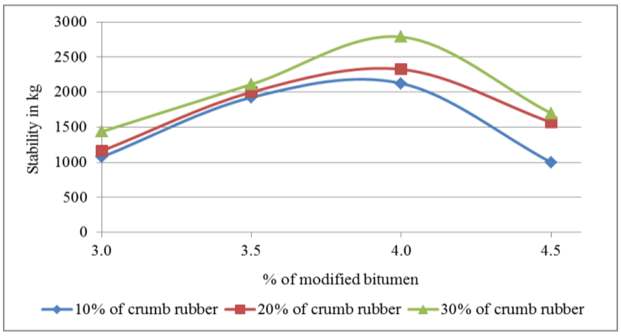

Fig. 9: Marshall Stability for CRM DBM

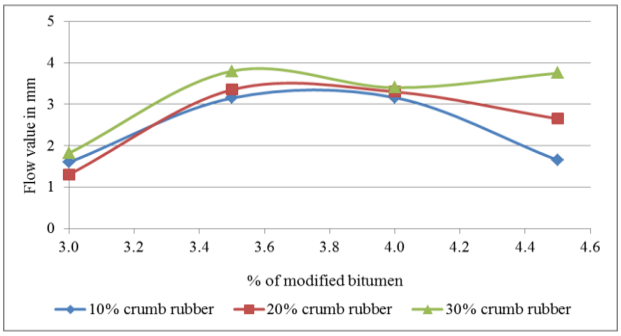

Fig. 10: Flow Value for CRM DBM

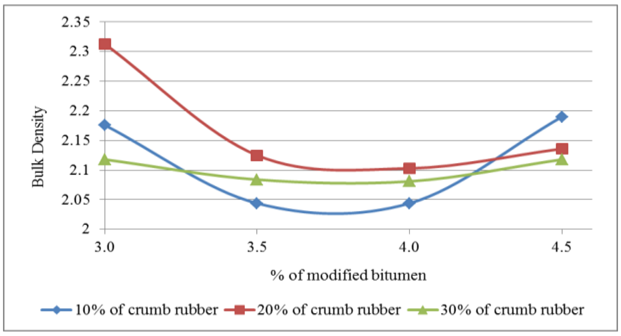

Fig. 11: Bulk Density for CRM DBM

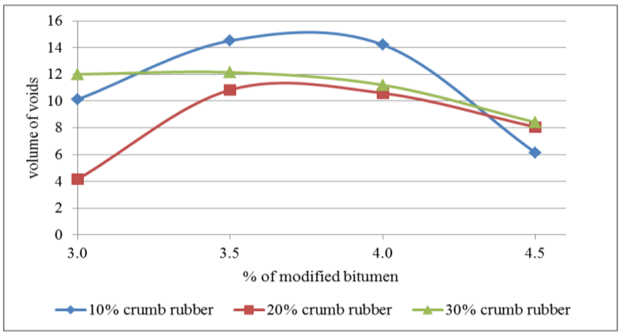

Fig. 12: Volume of Voids in CRM DBM

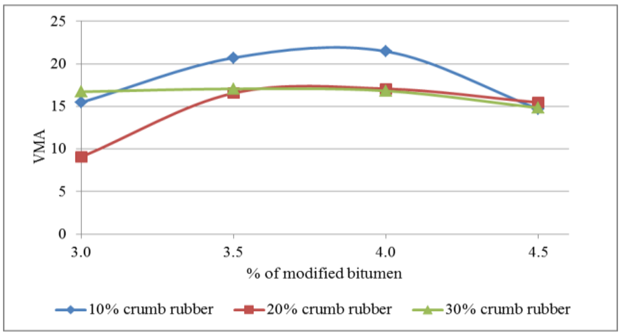

Fig. 13: VMA in CRM DBM

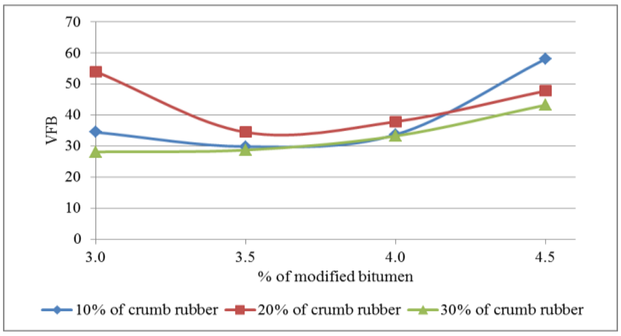

Fig. 14: VFB in CRM DBM

IV. DISCUSSIONS

It is observed from graphs that with increase in bitumen concentration the Marshall stability value increases up to certain bitumen content and there after it decreases. Thus, the maximum stability was obtained at 4.5% from bitumen% v/s stability graph (Fig.3). The flow value appears to be high in graph 4 at 4.5% of bitumen mix. From graph 9 it is evident that higher value is obtained at 3.5% bitumen with 30% replacement of crumb rubber. The highest stability value is obtained at 4.5% of bitumen mix. Whereas, CRMB shows a slight decrease in bitumen content about 4% at 30% replacement. Bulk specific gravity for the given compaction is least at a high value of 5%. Similar peak is obtained below 4% at 10% modification. More voids are present at 5% for bitumen mix and 4% with 10% rubber replacement. VMA in regular DBM has maximum value at 5%, whereas modified mix is reduced to about 4% bitumen at 10% replacement.
VFB in regular DBM has minimum value at 5%, whereas modified mix is reduced to about 4% bitumen at 30% replacement.

V. CONCLUSION

- By carrying out Marshall Test for control mix samples which were prepared by adding 3%, 3.5%, 4%, 4.5%, 5%, 5.5% and 6% bitumen by weight of aggregate to form BC mix, OBC was obtained as 4.5%.
- Addition of crumb rubber in 3%, 3.5%, 4%, 4.5% bitumen at 10%,20% and 30% replacement to BC mix samples yields an OBC of 4% bitumen at 30% crumb rubber.
- The use of rubber in roads can solve the problem of environmental damage which can be caused by their disposal.

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