Performance Evaluation of Hot Mix Asphalt using Modified Binders for Bituminous Concrete Grade-2

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Abstract

In India, flexible pavements with bituminous surface are widely used. Therefore it is important to study the physical and mechanical properties of the bitumen and bituminous mix. The present study was taken up with the objective of evaluating the effect of various modified bituminous mix on Marshall Stability, indirect tensile ratio, indirect tensile fatigue value. In this study one aggregate gradation, five types of binders; VG-30, PMB-40, PMB-70, CRMB-55, CRMB-60 and one type of mixes, bituminous concrete (BC) are used. The result indicates that the performance of mixes made with the PMB-70 has the higher stability than the other bituminous mix as the neat bitumen has the lower stability value. Indirect tensile ratio of the CRMB-55 is higher than the other bituminous mix whereas neat bitumen has the lowest indirect tensile ratio value. The fatigue performance of the PMB-70 is more compared with the various bituminous mix and neat bitumen has the lower life cycle. Further in this paper regression model and analysis for the obtained indirect load has been recorded using Ansys software.

Keywords - *Marshall Stability, Indirect Tensile Ratio and Indirect Tensile Fatigue.*

I. INTRODUCTION

Versatile/flexible pavements with bituminous surface are widely used in India. In India it is very necessity to improve or develop economical and sustainable technologies in the construction of road due to the rapid growth of traffic, maintenance expenditure and extreme climatic condition in India. Currently, the road projects in India are taken up under Design, Build Operate and Transfer (DBOT) basis due to early development of distress symptoms like undulations, rutting, cracking and pot holing of bituminous surface due to high intensity of traffic due to the rapid growth of over loading of truck, commercial vehicles and also due to variation in seasonal temperature and daily variation significantly. Before the construction of flexible pavements it has to be ensured about the satisfactory performance in the design life of the pavement to meet all the constructional obligations by the highway engineers, which leads to the improvement of strength of the road as bitumen plays important role in the construction of flexible pavement.

From literature review it has been found that modification of bitumen improves the rheological and mechanical properties of the bitumen as well as bituminous mixes which is prepared using neat bitumen and modified binders. Hence bituminous mix increases the susceptibility of the bitumen to daily and seasonal temperature variation by the modifying of binders and the modification of bituminous mix improve the adhesion and resistance properties of the binders to permanent deformation as well as the fatigue life of bituminous mixes. Therefore various types of additives to the normal bitumen are used to modify the properties of the bitumen. Hence, there is a need to understand the fundamental properties and performance characteristics of these mixes with modified bituminous binders and compare the results with the properties of the bituminous mixes with unmodified bitumen.

In construction of pavements, the important part of coating the mixture over the aggregates is bitumen, which increases the strength of the bituminous mix properties. Therefor many investigation has been disclosed by the addition of the additives in the normal bitumen improves the properties of bitumen and bituminous mixes to meet the requirements of pavement. . If bituminous mix is poor in any one of their properties, then that mix ultimately result in pavement failure. Hence, for the construction of pavements the desirable properties of the bituminous mixes requires stability, durability, cohesion, skid resistance and workability. The properties of bitumen and bituminous mixes are often improved to satisfy the necessities of construction of pavement with the incorporation of sure additives. These additives are known as bitumen modifiers and bitumen pre mixed with these modifiers is known as modified bitumen.

A. Present Investigation

To determine the physical properties of the conventional (Neat) bitumen and various modified bituminous binders as per the standards specifications. Determination of the optimum binder content for bituminous concrete mixes containing conventional and various modified binders.

To determine the Marshall stability and their properties for the obtained OBC of the conventional and modified binders

To investigate indirect tensile stress ratio and fatigue life of the bituminous concrete mixes containing conventional and modified binders for the obtained OBCs

Modelling using suitable finite element analysis software

B. Scope of the work

The scope of this project is to determine the physical properties of the aggregate and filler materials used for the bituminous mix of both conventional bitumen and with different modified bitumen, by the laboratory preliminary tests such as specific gravity, softening point, penetration, ductility and elastic recovery tests etc. And also the properties of the bituminous concrete mix grade-2 is predicted by the Marshall Stability method by finding out the optimum binder content of all the bituminous mixes. Comparative study on the physical properties of the unmodified and various modified binders has been carried out. Later for the obtained optimum binder content of various bituminous mixes indirect tensile strength has been carried out to determine the durability and resistance of the compacted asphalt mix. For the same obtained OBC of various bituminous mixes fatigue property has been determined and using FEA software the fatigue behaviour has been validated.

II. LABORATORY STUDIES

One type of aggregate, five types of binders and one types of mixes (Bituminous Concrete (BC) are used in this study. The BC layers are extensively used as wearing course layers respectively on all major highways in India.

Figure.1 show the aggregate size distribution of three grading for the mixes used in the present study. The notation U, M and L describe upper, middle and lower gradation in a mix respectively.

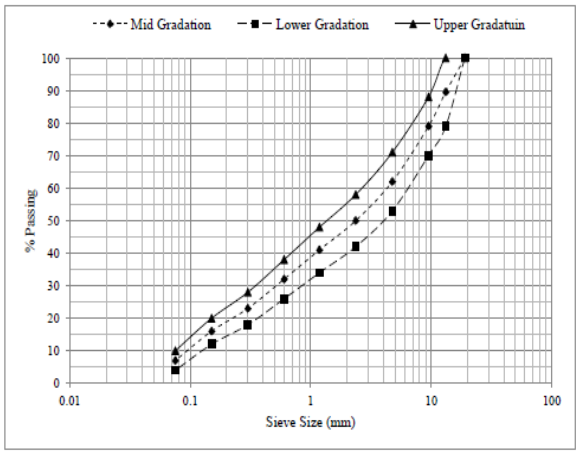

Fig. 1. Aggregate gradation of bituminous concrete mix

A. Materials

Aggregates: Aggregate samples of sizes 19 mm down, 4.75 mm down and Quarry dust are collected from the crusher and sampled aggregates are characterized for the following properties as per MORTH specification. Table.1 shows the properties of the aggregates.

TABLE 1
Aggregate physical properties

SL.NO	Tests	Result	Requirements asper MORTH
1	Specific Gravity 1.Coarse aggregate 2.Fine aggregate	2.53 2.67	2.5-3.2
2	Water Absorption Test, (%)	0.62	2 maximum
3	Aggregate Impact Test, (%)	23	24 maximum
4	Los Angeles Abrasion Test, (%)	29	30 maximum
5	Aggregate Crushing Value Test, (%)	29	30 minimum
6	Combined Flakiness and Elongation Index, (%)	28	35 maximum
7	Stripping value, (%)	98	95

Five types of binders (VG-30 and PMB-40, PMB-70, for their physical properties and test values satisfied all the requirements of paving grade bitumen specified in IS: 73 -2006 and IS: 15462 -2004. Table 2 shows the bitumen physical properties.

Bitumen: Source of the Bitumen used for the project work is modified binders from Hindustan Colas Mangalore Ltd. (HINCOL) and Grade selected is 60/70-VG30 from Nithya private Ltd.

TABLE 2
Neat and Modified bitumen physical properties

Properties	VG 30	PMB 40	PMB 70	CRMB 55	CRMB 60
Specific Gravity Test	1.01 (0.97 - 1.02)	1.02 (0.97 min)	1.03 (0.97 min)	1.03 (0.97 min)	1.01 (0.97 min)
Penetration Testat25° C	63 (60-70)	49 (30-50)	60 (50-90)	58 (<60)	57 (<60)
Ductility Tests at 27° C (cms)	76 (75 min)	74	58	60	58
Elastic Recovery Tests at 27° C (cms)	71	70 (70 min)	77 (70 min)	68 (50 min)	50 (50 min)
Softening Point Test, (°C)	51 (45-55)	62 (60 min)	60 (55 min)	56 (55 min)	60 (60 min)
Flash and Fire point Test, (°C)	280, 305	250, 300	270, 300	220, 290	220, 300

B. Optimum Binder Content

The Marshall method of mix design as laid in ASTM D 1559 was followed to determine optimum binder content (OBC) of different mixes. Three specimens were prepared at 4.5%, 5%, 5.5%, 6.0%, and 6.5% for each of the BC mixes. OBC for five different bituminous mix is determined. Table.3 shows the results of OBC for five different bituminous mix.

TABLE 3
OBC of both neat and modified bitumen

Bituminous Binders	Optimum Binder Content (%)
VG 30 (neat bitumen)	5.1
Polymer Modified Binder-40	5.25
Polymer Modified Binder-70	5.4
Crumb Rubber Modified Binder-55	5.7
Crumb Rubber Modified Binder-60	5.4

For the obtained OBC 5.1%, 5.25%, 5.4%, 5.7%, 5.4% three specimens each were prepared to tests their stability, flow, air voids, unit weight and voids in mineral aggregate (VMA). Table 4 shows the stability result for each of the bituminous mix.

TABLE 4
Stability results for the obtained OBC for different bituminous mix

Parameter	Specification	VG 30	PMB 40	PMB 70	CRMB 55	CRMB 60
Obtained OBC (%)	-	5.1	5.25	5.4	5.7	5.4
Marshall Stability, Kg	900 (minimum)	2441	2443	2864	2791	2814
Flow Value, mm	2-4	2.2	3.5	3.40	2.17	3.3
Air Voids in the total mix, Vv %	3-6	3.83	4.12	3.99	3.43	4.34
Voids Filled with the Bitumen, VFB %	65-85	73.6	74.09	76.54	80.35	79.07

C. Indirect Tensile Strength (ITS) test

This test was performed by loading a Marshall specimen with a single load parallel to the vertical diametric plane and conducted as per ASTM D 6931-07. The horizontal deformation at peak load was measured during the test by using strain gauges. The test is conducted at 25°C to evaluate mix properties at low temperature. The equation for tensile strength and tensile strain at failure are given below:

$$S_t = \frac{2P}{\pi t D}$$

Where ST is ITS (kPa), P is applied load (N), D is diameter of specimen (mm), t is thickness of specimen (mm). Table 5 shows the tensile strength ratio.

TABLE 5
Tensile strength ratio result of different modified binders

Bitumen Type	Un-conditioned (dry) Mpa	Conditioned (soaked) Mpa	Tensile Strength Ratio (TSR) %	MORTH specification
VG 30	1.04	0.9	86.54	Minimum 80%
PMB 40	0.95	0.84	88.42	
PMB 70	0.98	0.88	89.42	
CRMB 55	0.85	0.81	95.29	
CRMB 60	0.89	0.82	92.13	

D. Indirect Tensile Fatigue test

Test was conducted for different stress ratios 10, 20 and 30 for Virgin and different modified bituminous mix.

Table 6 shows the Fatigue life cycle of different bituminous mix.

TABLE 6
Fatigue life of the different modified bituminous mix

Sl No	Materials	Stress level in %	No of cycle
1	VG-30	10	1128
		20	998
		30	899
2	PMB-40	10	1367
		20	1048
		30	918
3	PMB-70	10	1879
		20	1019
		30	917
4	CRMB-55	10	1220
		20	983
		30	879
5	CRMB-60	10	1425
		20	960
		30	900

III. ANALYSIS OF TEST RESULTS AND DISCUSSION

E. Comparison of optimum binder content for different types of bituminous mix

After finding the OBC at the various bituminous mix i.e., VG-30, PMB-40, PMB-70, CRMB-55, and CRMB-60 it says that VG-30 requires the less bitumen content and CRMB-55 needs more bitumen content. Below figure 2 shows the comparative study of OBC of different bituminous mix.

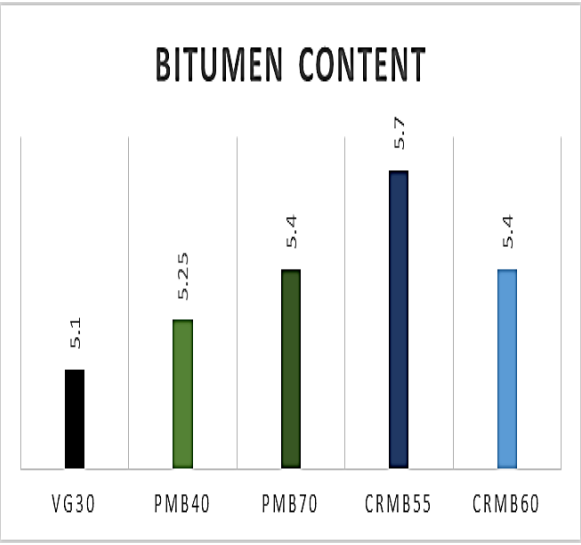

Fig. 2. Comparison of OBC of different bituminous mix

F. Comparison of stability for different types of bituminous mix

The Marshall Stability value has been on the increase trend with the addition of additives in the normal bitumen which is known as the modified bitumen which has been used in this study. Hence this study shows that the stability value of PMB-70 has the higher value when compared with the other bituminous mix. When all modified bitumen is compared with the conventional bitumen is proves that the addition of modifiers in the normal bitumen increases its stability value and provides more strength to the pavement. Below figure 3 shows the comparative study on the stability value of the obtained OBC for different bituminous mix.

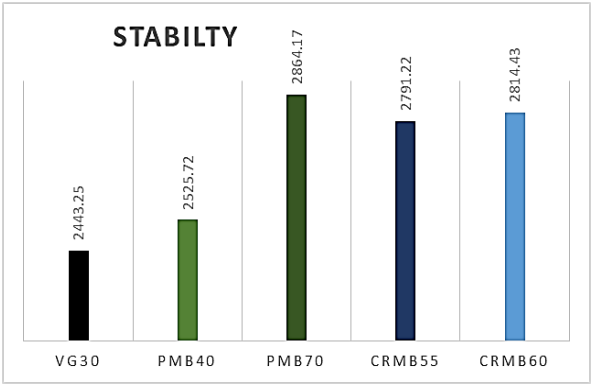

Fig. 3. Comparison study of the stability values of different bituminous mix

G. Comparison of tensile strength ratio for different types of bituminous mix

The tensile strength ratio of all the bituminous mix satisfies the MORTH standard value. The tensile strength ratio of the virgin bitumen is less when compared with the other modified bituminous mix. Whereas CRMB-55 has the more tensile ratio. Figure 4 shows the comparative study on the tensile strength ratio of different bituminous mix**.**

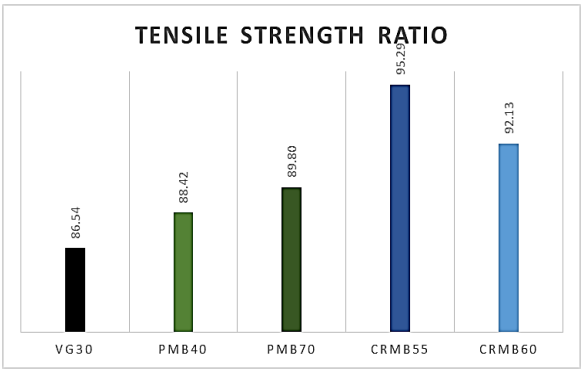

Fig. 4. Comparison study of the tensile strength ratio value of different bituminous mix

H. Comparison of indirect tensile fatigue test for different types of bituminous mix

The indirect tensile fatigue test of all the bituminous mix were found to know there life period on the pavements. The test results shows that the life

cycle of the PMB-70 is more compared with the other bituminous mix and conventional bitumen has less life period on the pavement. It proves that addition of the modifiers in the bitumen increases the physical and mechanical properties of the bituminous mix. Hence the modified bituminous mix increases the life period of the pavements and decreases the maintenance cost of the pavements. Figure 5, 6 and 7 shows the comparative study on the fatigue life of the bituminous mix with different stress level.

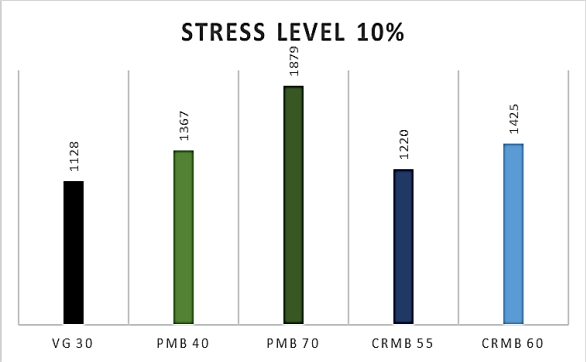

Fig. 5. At stress level 10% the results of the fatigue life of different bituminous mix

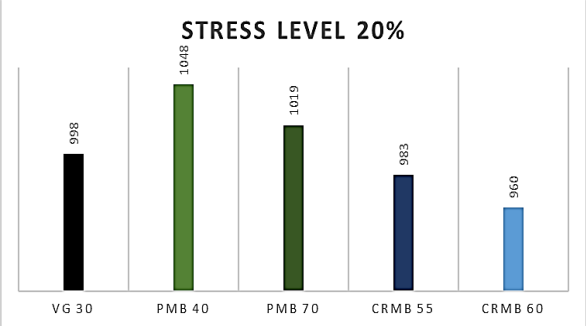

Fig. 6. At stress level 20% the results of the fatigue life of different bituminous mix

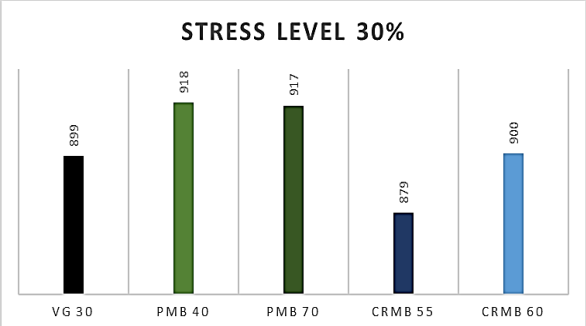

Fig. 7. At stress level 30% the results of the fatigue life of different bituminous mix

I. Comparison of regression model calculated for different types of bituminous mix

In statistical modelling, regression analysis is a set of statistical processes for estimating the relationships among variables. It includes many techniques for modelling and analysing several variables, when the focus is on the relationship between a dependent variables and one or more independent variables. More specifically, regression analysis helps one understand how the typical value of the dependent variables changes when any one of the independent variables is varied, while the other independent variables are held fixed. In this method dependent variable is continuous, independent variables can be continuous or discrete and nature of regression line is linear. Linear regression establishes a relationship between dependent variables (y) which is considered as fatigue life and one or more independent variables (x) which is considered as stress level using a best fit straight line which is known as regression line.

Regression line is represented by an equation

$$Y=a+b*X + e$$

Where, a = intercept, b = slope of the line and e = error term. Hence this equation can be used to predict the value of target variables based on given predictor variables.

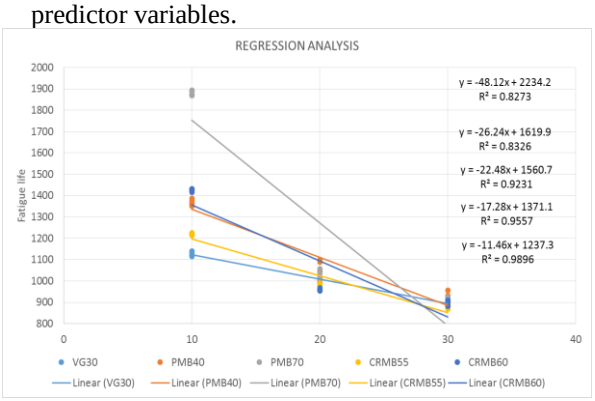

Fig. 8. Comparison of regression model calculated for different types of bituminous mix

TABLE 7
Comparison of regression model calculated for different types of bituminous mix

BITUMEN TYPE	STATISSTICAL MODEL	R^2
VG30	y = -11.46x + 1237.3	0.9896
PMB40	y = -22.48x + 1560.7	0.9231
PMB70	y = -48.12x + 2234.2	0.8273
CRMB55	y = -17.28x + 1371.1	0.9557
CRMB60	y = -26.24x + 1619.9	0.8326

IV. CONCLUSIONS

- The physical properties of the aggregates, conventional (Neat) and modified (PMB, CRMB) satisfy the requirement as per MORTH specification.
- Comparing obtained optimum binder content (OBC) is more for crumb rubber modified

bitumen (CRMB-55) - 5.7 % when compared with the normal bitumen VG-30-5.1 % of 0.6 %

- There is considerable increase in Marshall stability in the modified bituminous mix especially in Polymer modified bituminous mix by 30%
- Static indirect tensile strength ratio of CRMB-55 grade bitumen- 10% is greater compared to unmodified bitumen
- Fatigue life of bituminous concrete mix prepared using polymer modified bitumen has the highest life cycle of 1879 as compared with the other mixes
- Comparing normal (Neat) and modified bitumen , modified bitumen increases the mechanical properties of the bituminous mix than the normal bitumen
- Based on the present study, the relative order of performance of the bituminous concrete mix grade 2 with different binders are as follows :
    - Polymer modified bitumen-70
    - Crumb rubber modified bitumen-55
    - Polymer modified bitumen-40
    - Crumb rubber modified bitumen-60
    - Viscosity grade- 30

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