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Benefits of Using Polymer Modified Bitumen Comparing to Conventional Grade of Bitumen

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Abstract—*Conventional bituminous mixes have previously worked effectively on a wide range of roads, but it is now known that bituminous mixes are now subjected to higher stresses due to the increased scale of commercial vehicles and higher tyre pressures. As a result of the increased magnitude of wheel loads and tyre pressures in present traffic, the performance of neat bituminous mixes for paving applications is often inadequate. The goal of this research is to look into the benefits of polymer modified bituminous mixtures (PG76-10E). The mechanical and physical characteristics of polymer modified and traditional binder (VG30) combinations are investigated. Mixtures are compacted using the Marshall method, and a comparison is made in terms of resilient modulus, fatigue and rutting life, and moisture susceptibility in terms of Tensile Stress Ratio (TSR). The indirect tensile stress test (ITS) is used to determine the modulus of resilience at 35°C and for TSR, ITS test is used in conditioned and unconditioned condition. And the improvement of polymer-modified bitumen over the conventional bituminous mixes is reported. On comparing fatigue life (22.72MSA) and Rutting life (62.45) of PMB is greater than Conventional VG30 grade bitumen i.e. 32.6MSA and 80.97 MSA respectively and TSR (82.17%) of PMB i.e. 82.17 is also greater than TSR of VG30 i.e81.37% which shows that moisture susceptibility of PMB is greater as compare to Conventional VG30*

INTRODUCTION

In India, flexible pavements with bituminous surfacing are very common. High levels of commercial vehicle traffic, truck overloading, and significant daily and seasonal temperature variations have all contributed to the early emergence of bituminous surfacing distress symptoms like rutting, cracking, bleeding, shoving, and potholing. The extremely high and extremely low pavement temperature conditions in some regions of India are one factor that raises safety concerns. In these circumstances, the bituminous surfacing frequently turns brittle in the winter and soft in the summer. According to studies, adding particular additives or a combination of additives can improve/modify the properties of bitumen and bituminous mixes. The bitumen that has been premixed with these additives is referred to as "Modified Bitumen" and is known by the term "Modifiers." It is anticipated that using modified bitumen in the top layers of the pavement will significantly lengthen the life of the surfacing and delay the need for the subsequent renewal. The use of Modified Bitumen in the construction and maintenance of bituminous roads significantly improves the performance, according to full-scale performance studies on overlay conducted by the various research institutions, Indian Institutes of Technology under the supervision of the Ministry of Road Transport and Highways, Central Road Research Institute, Highways Research Station, Chennai, Rubber Board, Kerala, Gujarat Engineering Research Institute, and various state Public Works Departments. The goal of the current research is to examine the advantages of polymer-modified bitumen over conventional grades. Mixtures of conventional and polymer-modified binders are compared for their physical and mechanical qualities. The Marshall method is used to compact mixtures, and the resilient modulus and fatigue properties of the two are compared.

LITERATURE REVIEW

(Ashok et al., 2012)This study Compares the use of conventional bitumen of grades 60/70 and polymer-modified bitumen (PMB-70). The bitumen was utilized in mixtures for bituminous concrete. Basic evaluations of the traditional grade and PMB were done. In this research, Marshall test is used to find out the ideal bitumen content. When PMB was used in the place of traditional bitumen, stability value of the Marshall mix increased by about 27%, according to results of Marshall test. According to the findings, there is a high elastic recovery of about (79%) with PMB. Both types of bitumen were tested for rutting and indirect tensile strength, and PMB greatly beat the traditional binder. He concluded that the elastic recovery of polymer-modified bitumen is found to be high (79%). Modified bitumen has better properties for age resistance. When heated in a thin film oven, weight loss is 6 times greater than when bitumen that is 60/70 percent conventional is heated. Marshall's stability of the mix increases by 27% when PMB is used. The polymer-modified bitumen has a significantly higher rutting resistance [1].

(Chandrawal et al., 2016)This study focuses on Road rutting which is the vertical depression seen in a longitudinal direction. It occurs because of repeated heavy loads on the route of the wheel. in this study, the bituminous concrete mixture was mixed with crumb rubber and waste plastic. For finding the ideal bitumen content, the Marshall test was conducted. Rutting was done for conventional, waste plastic, and crumb rubber at test temperatures of 40, 50, and 60 degrees Celsius. This finds that the crumb rubber and plastic waste mixture was less prone to deformation than the standard mixture. It was concluded that the Aggregate Impact Value & Los Angeles Abrasion Value of aggregate increased by 15.8% and 13.8%, respectively, when waste plastic is coated on it. Crumb rubber mixed with bitumen enhances the penetration, softening point, and ductility of bitumen. For modified mixes, the 10% crumb rubber and 10% waste plastic content mixture yield the highest Marshall Stability value. When compared to the standard BC mix, the stability of the mix modified by crumb rubber and the waste plastic both increased by 14% and 22%, respectively [2].

(Dehouche et al., 2012**)**In light of this work, it can be said that modification of polymer utilizing both ethylene vinyl acetate (EVA) and styrene butadiene styrene (SBS) copolymers have enhanced physical properties of the virgin bitumen. In fact, the polymer modified bitumen experimental results, which were measured using the usual methods of softening point, penetration and penetration index, a decrease in temperature susceptibility and show an increase in stiffness. These alterations are subject to the kind and composition of the polymer. Additionally, using standard bitumen tests enables quantification of the differences between base bitumen and SBS and EVA-modified bitumen in terms of characteristics. When compared to SBS-modified bitumen, EVA-modified bitumen has demonstrated a poorer enhancement in modification. The effect is stronger for those which are modified with EVA and base bitumen samples during thermo-oxidative aging, where both modified and unmodified samples grow harder Additionally, the treated samples' enhanced PI shows a considerable decrease in temperature susceptibility, especially at high polymer contents of 7%. However, the SBS-treated bitumen exhibits a more pronounced reduction in PI. Bitumen samples that have been treated with 3% SBS and EVA are regarded as stable material. Additionally, bitumen that has additional SBS added to it up to 5 weight percent produces a stable substance. Because of several chemical reactions between the virgin bitumen and the polymers, there has been an improvement in compatibility. According to optical microscopy, the bitumen modified by EVA demonstrates finer polymer dissipation at 3% wt. than SBS [3].

(Singh & Sawant, 2016)This research intends to assess the rutting, rheological, & fatigue behavior of an SBS polymer-modified binder mixed with various percentages of reclaimed asphalt pavement binder such as 0%, 15%, 25%, and 40%. In order to characterize binders, time-temperature sweep tests and the linear viscoelastic range tests were carried out. By using the multi-stress creep recovery and linear amplitude sweep tests, rutting and fatigue performance of PMB 40 bitumen with various percentages of RAP were assessed, respectively. By the addition of RAP, the chemical makeup of PMB 40 bitumen changed, and it was discovered using Fourier transform infrared spectroscopy (FTIS). The findings demonstrated that the addition of RAP stiffens and reduces the temperature sensitivity of PMB 40 bitumen, but that mixing and compaction temperatures were not significantly altered. Contrary to findings published in the paper, the high-temperature performance of PMB 40 bitumen was unaffected by the addition of RAP. The MSCR results revealed rutting resistance poorer of the PMB 40 bitumen due to the addition of RAP, with a considerable increase in nonrecoverable and decrease in recovery creep compliance. The LAS test revealed that the RAP addition reduced the number of cycles required for fatigue failure of PMB 40 binder while increasing the rate of damage. By the addition of RAP quantity of sulfoxide and carbonyl increased, according to the FTIR test. The ISBS and ICO indices from FTIR were well correlated with rheological characteristics of PMB 40 bitumen. so, it is advised that the effects of other sources of RAP on the functionality of modified binder with SBS be further investigated. It should be emphasized that the conclusions provided in the work are depend on 1 modified binder and 1 RAP source. To get insight into the characterization of RAP mixed with binders, it is important of the study of short and long-term effects of aging also. Additionally, it is advised that laboratory testing on asphalt mixtures be used to validate the rheological performance tests of the binder [4].

(Glaoui et al., 2012)This investigation's goal was to ascertain how thermally fatigued, aged PMB complicated modulus and phase angle changed over time. Result of this paper show that thermal fatigue (TF) modifies the rheological properties of the modified bitumen, even when it is assumed that TF was created through lab testing method and that the modified binder was exposed only to the hundred cycles of thermal loading (heat and cool). phase angle (PA) and Complex modulus (CM) slightly increased and significantly decreased at low temperatures, respectively, which is not conducive to thermal cracking. While the complex modulus value increased and the PA changed at moderate temperatures, these two parameters tend to remain constant. In terms of fatigue cracking, these alterations are not favorable. We observed a low PA and a high CM at temperatures of 40 and 50 C. The behavior of the binder prior to permanent deformation resistance is not adversely affected in this instance by thermal fatigue. For permanent deformation resistance, however, the increased phase angle at 60C was unfavorable. Thermal fatigue has an impact on pavement performance, including the resistance to irreversible deformation as well as thermal and fatigue cracking [5].

(Gupta & Veeraragavan, 2009)The findings of this study demonstrate that SBS-modified mixes are superior to conventional mixes. Therefore, mixes modified with polymers might be suggested for national highways with a lot of traffic. Empirical approaches are only acceptable when crack initiation is taken into account, not when crack propagation is.

Fracture mechanics principles can be applied to take the harmful effects of the stress concentrations near crack tip, particularly in the design of overlay [6].

(S & Raj, 2015) This study compares bitumen improvement using synthetic fiber to bitumen modification using natural fiber. Here the bitumen employed is VG30, with the value of penetration 50-70 mm. Polypropylene fiber has been used as a synthetic fiber, and sisal fiber has been used as a natural fiber. Fiber improves the fatigue life by boosting the resistance to breaking and the permanent deformation, according to the findings. The fiber reinforcing thereby added tensile integrity to the mixtures, increasing strain energy absorption and preventing the crack formation and propagation [7].

(White et al., 2001)This study describes how Bakelite affected various bitumen binder properties. It is polymer amorphous in nature and has a three-dimensional structure. It offers rigidity, hardness, and strength. An outline of the application of Bakelite in roads is provided in this essay. When added to bitumen mix, Bakelite has the very good effects on environment and economy both. Additionally, extending lifespan of the pavement is the addition of Bakelite to the bitumen mix. The duration of pavement structures can be extended by using Bakelite in the construction of roads [8].

(Al-Fraihat & Abu-Mahfouz, 2017)The marshals test has been used to find out the asphalt mixture rubber's ability to change, and the stability and flow of the prepared material were noted. The outcomes were contrasted with marshal experiments using 0%, 10%, 15%, 20%, 25%, and 30% rubber. The asphalt pavement was given rubber to increase stability and flow. He discovered that rubberized asphalt outperforms conventional pavement in terms of surface resistance. The best percentage of rubber, according to the authors, was 25%. When bitumen content reached its optimum, stability increased initially, then decreased. Additionally, flow increased as bitumen content increased [9].

(Al-Azawee & Qasim, 2018) The effects of the crumb rubber modifier (CRM) on the fundamental characteristics of hot bituminous mixtures with various CRM percentages are summarized in this research. 4 different percentages of CRM were used throughout this study. The lab work involved creating rubberized asphalt by wet-method blending bitumen with varying amounts of crumb rubber. To find out the ideal bitumen content using the Marshall method, Marshall samples were created. Marshall stability and flow tests as well as an ultrasonic test are conducted in the lab. The study's findings demonstrated that adding rubberized bitumen binder to mixes raised the ideal bitumen content and improved the volumetric Marshall stability & flow value of bituminous mixtures. However, addition of the 10% CRM had best impact on the mixture's stability. The result of this experiment demonstrated that adding CRM to mixtures as additives had a significant impact on the mixtures' assessed properties [10]**.**

OBJECTIVE

The aim of the current study is:

1. To examine the advantages of polymer-modified bitumen over conventional grades.
2. Mixtures of conventional and polymer-modified binders are compared for their physical and mechanical qualities.
3. The Marshall method is used to compact mixtures, and the resilient modulus, fatigue and rutting properties and moisture susceptibility of the two are compared.

MATERIALS USED

Aggregates

For mix design of BC -1 according to the MORTH-2013 criteria, two kinds of coarse aggregates (20mm and 10mm), stone dust as fine aggregate, and lime were employed in this work effort. Table-1 showing the physical parameters of both fine and coarse aggregate and lime as determined by the Bureau of Indian Standards.

Table 1: Properties of Aggregates

Tests	Type	Observed value
Water absorption	20 mm	0.15%
	10 mm	0.2%
Bulk Specific Gravity	Stone Dust	2.59
	Lime	2.24
	20 mm	2.69
	10 mm	2.67
Los Angeles Abrasion Value	20mm	20.5%
Aggregate Impact Value	20mm	15.71%
	10mm	22.6
Flakiness Index	20mm	14.25%
Elongation Index	20mm	14.73%

Bitumens

In this research work, VG30 and PMB(PG76-10E)) bitumen is used as asphalt binder. Properties of which are given in the Table below:

Table 2: Properties of bitumen (VG30)

Tests	Standard (IS)	Observed value
Penetration value in mm	IS :1203	60
Ductility value at 25°C in cm	IS :1208	67
Softening point value (R&B) in °C	IS :1205	48
Flash point in °C	IS :1209	230
Specific Gravity	IS :1202	1.02
Dynamic Viscosity at 60°C in poise	IS :1206, (Part 2)	3300

Table 3: Properties of bitumen (PMB PG (76-10E))

Tests	Standard (IS)	Observed value
Penetration value in mm	IS :1203	24
Ductility value at 25°C in cm	IS :1208	36
Softening point value (R&B) in °C	IS :1205	49
Flash point in °C	IS :1209	240
Specific Gravity	IS :1202	1.035
Dynamic Viscosity at 60°C in poise	IS :1206, (Part 2)	17103

LABORATORY WORK

5.1 Marshall mix design

The Marshall mix design is used to calculate the optimum binder content in BC-1 according to the standard ASTM D1559 [47]. To find out required aggregate gradations according to specifications of MORTH2013, proportioning of the aggregates is determined. For each of the Marshall's mould, 1200gm of aggregates is taken out and heated to 150-160°C before being mixed with the necessary quantity (5% to 6% with the increment of .5%) of bitumen heated to about 155-165°C. The mixture is vigorously stirred to a temperature of about 145-165°C. The mix is then put in the mould and compacted manually by a normal Marshall hammer of 75 blows on each side of the form. After compaction, the mould is taken from the pedestal and allowed for cooling at ambient temperature for 1 day now after one day specimen is taken out from mould and weighed in air and water for the estimation of density. At the same binder content, three samples are prepared. Before testing, prepared samples is placed in the water bath at temperature of 60°C for half an hour. A strain-controlled test is performed by delivering a load through a curved surface at the rate of 50 mm/mi And Maximum load and accompanying deformation observed are the stability (KN) and flow values(mm) respectively. The percentage air voids (V_V), voids in mineral aggregate (VMA), and voids filled with bitumen (VFB) is determined by using the specific gravity of constituents and density of the specimen. For the determination of optimum bitumen content, all of these factors are plotted against bitumen content.

Fig. 1: Marshall's testing apparatus

Modified Lottman test

Many researchers have employed modified Lottman test (AASHTO T283) to determine resistance to water susceptibility. For each mixture, a set of six specimens (Marshall's Specimen with standard dimensions) is to be prepared and divided into two subsets dry subset (unconditioned) and wet subset (conditioned). The ultimate height, specific gravity, bulk density, and percentage air voids (Vv) of prepared specimens is evaluated. Vv is determined using AASHTO T 269, and the specimens have been divided into two groups with Vv of these two are roughly same. For the dry subset, samples are placed in a water bath at 25°C for two hours. and for Wet subset samples are placed in a water bath at 60°C for 24 hours. After 24 hours samples are returned to water bath again for conditioning at 25°C for two-hour. All of the samples are removed from water bath after conditioning and evaluated on Marshall Stability equipment with edge loading. The maximum load at which the sample failed is determined and Eq- (i) is used to calculate indirect tensile strength (ITS).

ITS = (2P⁄πDH) ……………………………Eq- (i)

Here

ITS = Indirect tensile strength in (KPa)

H= height of the specimen in (m)

P= maximum load in KN

D= dia of the specimen in (m)

The average the ITS value of conditioned (wet) and unconditioned (Dry) subset is evaluated and the ratio of ITS value under conditioned (wet) and unconditioned (Dry) subset shows the tensile strength ratio (TSR) (%) which is an indicator of moisture damage effect on bituminous mixes. Mathematically TSR is calculated using Eq-(ii).

TSR=(ITSconditioned/ITSunconditoned) x100… Eq-(ii)

Here,

TSR = Tensile strength ratio in (%).

Fatigue and Rutting analysis

For the fatigue analysis ITS test is performed at 35°C on both the bituminous mixes which is further related to equation 9.2 of IRC:37-2018 which are (M_r = 1.1991 x ITS + 1170) to calculate the modulus of resilience. After calculating the M_r, fatigue life in terms of CSA or MSA are calculating using equation 3.4 and equation 3.2 which are

$N_f = 0.5161 \times C10^{-4} [1/\varepsilon_t]^{3.89} \times [1/M_{Rm}]^{.854}$ and

$N_r = 1.4100 \times 10^{-8} \times [1/\varepsilon_v]^{4.5337}$ for 90% reliability. Horizontal tensile strain(ε_t) at bottom of bituminous layer and vertical compressive strain(ε_v) at top of subgrade is calculated using IIT pave software using input as 3 layers which are discussed in the result section.

RESULTS AND DISCUSSION

Result of marshall mix design

After obtaining the appropriate aggregate gradations according to MORTH-2013 standards, the gradation of aggregates components and aggregate proportioning as shown in Fig. 2. Using the Marshall Method of mix design, various controlling factors (Marshall Stability value (KN), flow value(mm), voids filled with bitumen, voids in mineral aggregate, air voids, and bulk density) are studied at three bitumen contents of 5, 5.5, and 6% and Tables 4 and 5 show the results of the same. The optimum bitumen content for BC(Grade-1) which satisfies the all requirements is 5.4%. with both the bitumen.

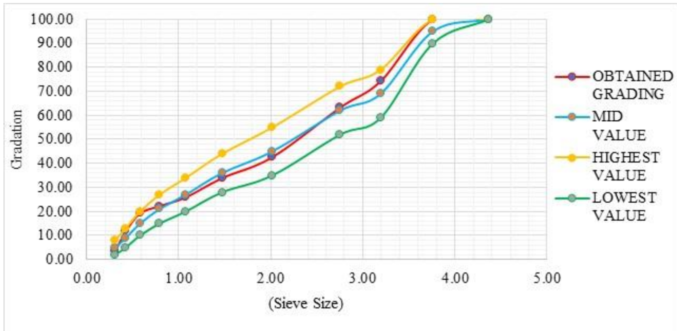

Fig. 2: Gradation of aggregates

Table 4. Result of Marshall's test at different bitumen contents (VG30)

VG30								
Bitumen content (%)	**Gm**	**Gt**	**Vv %**	**Vb %**	**VMA**	**VFB**	**Stability (KN)**	**Flow Value (mm)**
5	2.33	2.45	4.87	11.54	16.42	70.33	10.6	2.8
5.5	2.35	2.43	3.59	12.78	16.37	78.06	15.8	3.4
6	2.33	2.42	3.50	13.85	17.36	79.81	9.3	3.7

Table 5: Result of Marshall's test at different bitumen contents (PMB (PG 76-10E))

PMB (PG 76-10E)								
Bitumen content (%)	**Gm**	**Gt**	**Vv %**	**Vb %**	**VMA**	**VFB**	**Stability (KN)**	**Flow Value (mm)**
5	2.34	2.45	4.74	11.28	16.02	70.40	14.3	2.5
5.5	2.36	2.43	3.21	12.52	15.73	79.57	18.6	3.3
6	2.34	2.42	2.99	13.59	16.58	81.99	14.5	3.6

Results of Modified Lottman Test

Table 6 indicates the percentage air voids in the specimen (wet and dry) of modified Lottman test. The moisture damage effect is inversely proportional to the Tensile strength ratio (TSR) value means higher the TSR value lower is the moisture damage effect on the bituminous mix. According to standards of MORTH, TSR value should be greater than 80%. Fig. 3 and 4 demonstrate the ITS value of dry and wet subsets, respectively. According to the result, the TSR value of the specimens prepared with PMB is more than VG30, as shown in Fig. 5.

Table 6: Result of % air voids in modified Lottman test

Type of Mixture	Conditioned subset	Unconditioned subset
VG 30	6.3	5.9
PMB	5.4	4.9

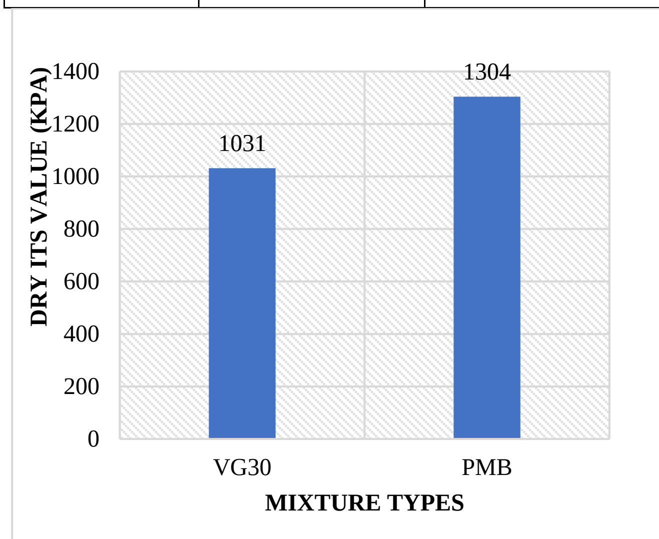

Fig. 3: ITS value of unconditioned subset

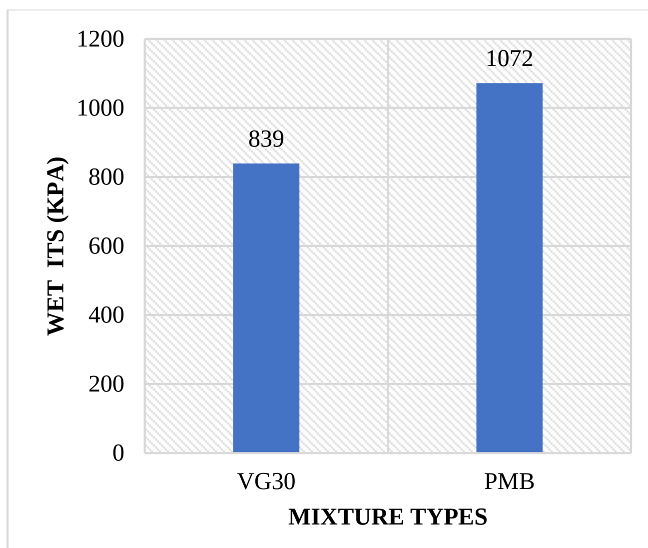

Fig. 4: ITS value of unconditioned subset

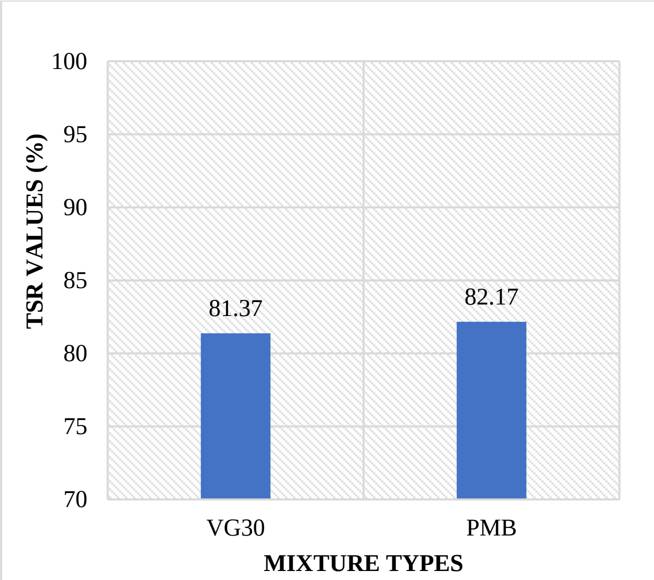

Fig. 5: TSR Values in (%)

Result of Fatigue Analysis

Assume

CBR=7%

Thickness of granular layer =450mm

Cumulative Thickness of upper layer=150mm

So M_r of subgrade is calculated using Eq- 6.2 of IRC:37-2018 which are

M_{rSub} =17.6xCBR$^{.64}$ on calculating M_r of Subgrade comes out to be 61 MPA.

And M_r of granular layer calculated using Eq-7.1 of IRC:37-2018 which are

M_{rGrain} = 0.2(h)$^{.45}$x M_{rSub} on calculating M_r of granular layer comes out to be 191 MPA.

Here, h= thickness of granular layer

M_r of bituminous layer calculated using equation 9.2 of IRC-37 which are

(M_r = 1.1991 x ITS + 1170) on calculating values are comes out to be reported in table 7

Table 7: ITS value and Resilient modulus at 35°c

TPYE OF BITUMEN	FAILURE LOAD (KN)	ITS (KPA)	M_r (MPA)	Recommended values (MPA) as per IRC:37-2018
VG30	9.4	950.36	2309.58	2000 or tested value (whichever is less)
PMB	12.1	1223.34	2636.90	3000 or tested value (whichever is less)

Putting input as 3 layers in IIT pave software

As

Wheel load =20KN

Tyre Pressure =0.56 MPA

Poisson ratio =0.35

And thickness and Resilient modulus as above mentioned value we found Horizontal tensile strain at bottom of the bituminous layer and vertical compressive strain at top of the subgrade

For VG30

ε_t = 0.2328x10^{-3} and ε_v = 0.3539x10^{-3}

And PMB

ε_t = 0.2032x10^{-3} and ε_v = 0.3342x10^{-3}

After that fatigue life

N_f = 0.5161xCx10^{-4} x[1/ε_t]$^{3.89}$x[1/MRm]$^{.854}$ …. Eq-(iii)

And Rutting life

N_r =1.4100x10^{-8} x [1/ε_v]$^{4.5337}$…………………Eq-(iv)

Here,

C = 10^M

$M = 4.84\ ((V_{be}\ /V_a{+}V_{be}) - 0.69))$

V_a = percent volume of air void in the mix

V_{be} = percent volume of effective bitumen in the mix

N_f = fatigue life of bituminous layer (CSA)

ε_t = maximum horizontal tensile strain at bottom of bottom bituminous layer

ε_v = maximum vertical compressive strain at top of the subgrade.

M_{Rm} = resilient modulus (MPa) of the bituminous mix used in the bottom bituminous layer**.**

For VG30

At optimum bitumen content = 5.4%

V_a =3.9%

And V_{be}=12.2%

So,

M =4.84((12.2/3.9+12.2)-.69) =.33

C =10^M = 10$^{.33}$ =2.14

Putting all the values in Eq - (iii) and Eq – (iv) we found

N_f =22.72 MSA

N_r =62.45 MSA

Similarly,

For PMB

At optimum bitumen content = 5.4%

V_a =3.7%

And V_{be}=12%

So,

M =4.84((12/3.7+12)-.69) =0.36

C =10^M = 10$^{.36}$ =2.29

Putting all the values in Eq – (iii) and Eq – (iv)

N_f =32.6 MSA

N_r =80.97

From here it is clear that fatigue and rutting life of PMB is greater than Conventional VG30 bitumen putting all other parameters same.

CONCLUSIONS

i. On testing penetration value of PMB (PG 76-10E) is lower than VG30 which means PMB (PG 76-10E) is stiffer than VG30.
ii. The viscosity of PMB (PG 76-10E) is much greater than VG30 which means PMB (PG 76-10E) is more viscous than VG30
iii. The maximum value of marshal's stability of PMB (PG 76-10E) is 18.6 at a bitumen content of 5.5% while for VG30 it is 15.8 at the same bitumen content.
iv. Optimum bitumen content obtained in this research is 5.4% For the grade BC -1 with both the bituminous mixes.
v. ITS value also comes out to be higher for PMB as compare to VG30
vi. TSR for PMB is 82.17% and for that of the VG30 is 81.37% Which shows that PMB has less damaging effect due to moisture as compare to VG30.
vii. Fatigue and Rutting life of PMB is greater than VG30 which clearly shows that if pavement made by PMB it more durable and longer lasting.

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