Performance Evaluation of SBS Polymer Modified Bituminous Concrete Mixes

S. K. Mishra

Director, E-in-C's Branch, New Delhi
Former M.Tech student, Indian Institute of Technology Madras, Chennai.
Presently serving as Director, E-in-C's Branch, New Delhi

Abstract: **This paper evaluates the performance of Styrene Butadiene Styrene (SBS) polymer modified bituminous concrete mixes. Various tests were carried out to evaluate the physical properties of the conventional bitumen and SBS polymer modified binder. Cylindrical specimens prepared at optimum binder content were tested for the indirect tensile strength tests. Varying loads from 10% to 60% of the failure load were applied on the specimens at test temperatures of 30, 35 and 40^{0}C to determine the number of repetitions to failure to determine laboratory fatigue life. Equations are developed showing the relationship between number of cycles to failure and initial tensile strain to predict the laboratory fatigue life of conventional and polymer modified bituminous concrete mixes. The study revealed that the indirect tensile strength and resilient modulus of the bituminous concrete mix prepared with SBS PMB-70 is higher than the conventional mix. The fatigue life of the bituminous concrete mix prepared with SBS modified binder is higher than BC mixes prepared using 60/70 grade bitumen. However, the benefit is found to decrease with the increase in load levels.**

1. INTRODUCTION

Flexible pavements with bituminous surfacing are widely used in India. However, exponential increase in traffic, overloading of commercial vehicles and significant variations in daily and seasonal temperatures have shown some limitations in asphalt binder performance and this has led to early developments of distress symptoms like cracking, rutting, ravelling, undulations, shoving and potholing of bituminous surfacings. Another cause of concern is that there are regions in the country where extreme climatic conditions persist resulting in very high and very low pavement temperatures. Under these conditions, flexible pavements tend to become soft in summer and brittle in winter. These factors are responsible for poor road conditions in the country increasing the cost of travel for the users and also inviting frequent maintenance by the concerned agency.

Bitumen modified with polymer offers a combination of performance related benefits as they improve the physical properties of the bitumen without changing the chemical nature of it. The polymer usually influences the bitumen by creating an inter-connecting matrix of the polymer through the bitumen. It is this matrix of long chain molecules of the added polymer that modifies the physical properties of the bitumen. These additives increase the elasticity, decrease the brittle point and increase the softening point of the bitumen. This, in turn, will alter the properties of the mix in which such modified bitumen is used and these mixes will exhibit greater stiffness at higher temperature and high flexibility at low temperatures.

2. OBJECTIVES AND SCOPE

The objectives of the present study are to:

i) Carry out various tests on conventional bitumen and polymer modified binder

ii) Compare the rutting parameter of unaged samples and thin film oven residue of both binders

iii) Determine optimum bitumen content and polymer modified binder content for bituminous concrete mixes

iv) Carryout indirect tensile tests on bituminous concrete mixes

v) Carryout fatigue tests on cylindrical specimens with and without modifier

vi) Study the effect of variation in load and temperature on the fatigue behaviour of bituminous concrete mixes

vii) Develop fatigue prediction equations for bituminous concrete mixes with conventional bitumen and modified binder.

The complex shear modulus and phase angle for the two binders i.e. 60/70 grade bitumen and PMB–70 on unaged and TFO aged samples have been determined by dynamic shear rheometer. This has been done with a view to evaluate the rutting parameter ($G^*/Sin\delta$). However, this will not give any indication of the rutting behaviour of the mix as such because the contribution of the other parameters like compaction, gradation and quality of aggregates also needs to be considered [22].

The Marshall mix design has been carried out for Bituminous concrete (BC, Grading 1) to determine the optimum bitumen content for both binders as per Ministry of Road Transport and Highways "Specifications for Road and Bridgeworks", fourth revision (2001) .The fatigue tests have been carried out on the "Repeated Indirect Load Test Set-up" in the Transportation Engineering Department of IIT Madras. The cylindrical specimens with both binders have been prepared separately at optimum binder content obtained by Marshall Mix design and tested to study the effect of variation of load and temperature. The regression analysis has been carried out using SPSS software to develop equations to predict the fatigue life taking initial tensile strain as the independent variable.

3. LABORATORY INVESTIGATIONS

3.1 Properties of Binder

The 60/70 grade conventional bitumen and PMB-70 used in the study were tested in the laboratory. The following tests were carried out.

i) The specific gravity, penetration, softening point and ductility were tested in accordance with IS:1202, IS:1203, IS:1205 and IS:1208-1978 respectivel .

ii) The Viscosity of 60/70 grade bitumen was tested at 60^0C and 135^0C by rotational viscometer. The tests were performed as per ASTM method D- 4402. The viscosity of PMB was tested at 135^0C and 150^0C.

iii) The bitumen was subjected to short-term aging by thin film oven test (TFOT) to study the effect of heat and air. The loss of weight on heating and retained penetration after TFOT were evaluated as per IS: 9382-1992.

iv) The separation test was conducted for PMB-70 to determine the storage stability in accordance with the procedure described in SP: 53-2002.

v) The elastic recovery of polymer modified binder was determined in ductilometer after conditioning the specimen for 1 hour at specified temperature.

vi) The physical properties of 60/70 grade bitumen and PMB-70 are given in Table 1 and 2. The permissible limits for 60/70 grade bitumen are as per IS: 73-1992.

TABLE 1: Physical Properties of 60/70 Grade Bitumen

Properties Tested	Test Results	Permissible Limits
Penetration at 25^0C/100 g/5 s (dmm)	70	60-70
Softening Point (^{0}C)	44	40-55
Ductility (cm)	82	>75
Specific gravity at 27^0C	1.00	>0.99
Viscosity at 60^0C (Poise)	1660	2000 ± 500
Viscosity at 135^0C (cSt)	393	>300
Properties after TFOT (Residue)		
Loss on heating, percent by mass	0.31	1 (max)
Retained Penetration at 25^0C /100 g/5 s, percent of original	67	52 (min)

TABLE 2: Physical Properties of PMB-70

Properties Tested	Test Results	Permissible Limits
Penetration at 25^0C/100 g/ 5 s dmm	69	50-90
Softening point, ^{0}C	63	55 (min)
Ductility, cm	+100	+ 60
Specific gravity at 27^0C	1.03	>0.99

Viscosity at 135^0C (Poise)	13	20 (max) as per ASTM D-5976
Viscosity at 150^0C (Poise)	4	2-6
Separation, difference in softening point R & B, ^{0}C	0.5	3 (max)
Elastic recovery of half thread in ductilometer at 15^0C, (%)	79	75 (min)

3.2 Properties after TFOT (residue)

Loss in weight (%)	0.05	1 (max)
Increase in softening Point, ^{0}C	1.5	6 (max)
Reduction in penetration of residue at 25^0C (%)	18	35 (max)
Elastic recovery of half thread in ductilometer at 25^0C (%)	62.5	50 (min)

3.3 Properties of Aggregates

Grading 1 as per Table 500-18 of MORTH "Specifications of Road and Bridge Works" (fourth revision) 2001 has been adopted for the present study. The aggregates used in the present work were strong, durable and non-flaky. The properties of the aggregates used in this study are reported in Table 3.

TABLE 3: Properties of Aggregates

Property Tested	Results	MORTH Specification
Crushing value	21.59%	45%
Impact value	22.88%	24% (max)
Specific gravity	2.742	2.5-3.0
Combined Index (EI + FI)	29.40%	30% (max)

3.4 Rutting Resistance of the Binder

The rheological tests were performed at three temperatures viz. 45^0C, 55^0C and 65^0C. The tests were carried out on unaged and TFO aged samples of 60/70 grade bitumen and SBS based PMB – 70 in accordance with the procedure prescribed as per AASHTO-TP5 (1994) . The calculated values of complex shear modulus (G*), phase angle (δ), storage modulus (G') and loss modulus (G") are shown in Table 4. The rutting parameter (G*/Sinδ) was calculated for both the binders for unaged and aged conditions. The variation of this parameter with temperature is shown in Fig. 1 and 2.

TABLE 4: Rheological Properties

	Temp.	Complex Modulus G* (kPa)	Phase Angle (δ)	Storage Modulus G' (kPa)	Loss Modulus G" (kPa)	G* / sin δ (kPa)
Unaged 60/70 grade Bitumen	45^0C 55^0C 65^oC	28.7 7.49 1.73	84.3 86.9 88.3	2.84 0.41 0.052	28.6 7.48 1.73	28.84 7.50 1.73
TFO aged 60/70 grade Bitumen	45^0C 55^0C 65^oC	32.5 8.27 1.97	84.3 86.7 88.2	3.25 0.48 0.06	32.4 8.26 1.97	32.66 8.28 1.97
Unaged PMB-70	45^0C 55^0C 65^oC	68.9 17.8 6.01	70.4 70.7 72	23.1 5.90 1.86	64.9 16.8 5.71	73.14 18.86 6.32
TFO aged PMB-70	45^0C 55^0C 65^oC	79.9 22.30 8.74	69.5 70.2 70.3	28.0 7.53 2.95	74.8 21.0 8.23	85.30 23.70 9.28

3.5 Properties of Bituminous Concrete Mixes

The following properties of the bituminous concrete mixes prepared with 60/70 grade bitumen and PMB–70 were evaluated by Marshall Mix design method

i) Marshall stability value (kN)
ii) Flow value (mm)
iii) Bulk density (g/cm^3)

iv) Percent air voids in total mix (V_v) and Percent voids filled with bitumen (V_{FB})

The properties of bituminous concrete mix prepared with 60/70 grade bitumen and PMB-70 are presented in Table 5 and 6 respectively. The properties of both the mixes at optimum binder content are shown in Table 7.

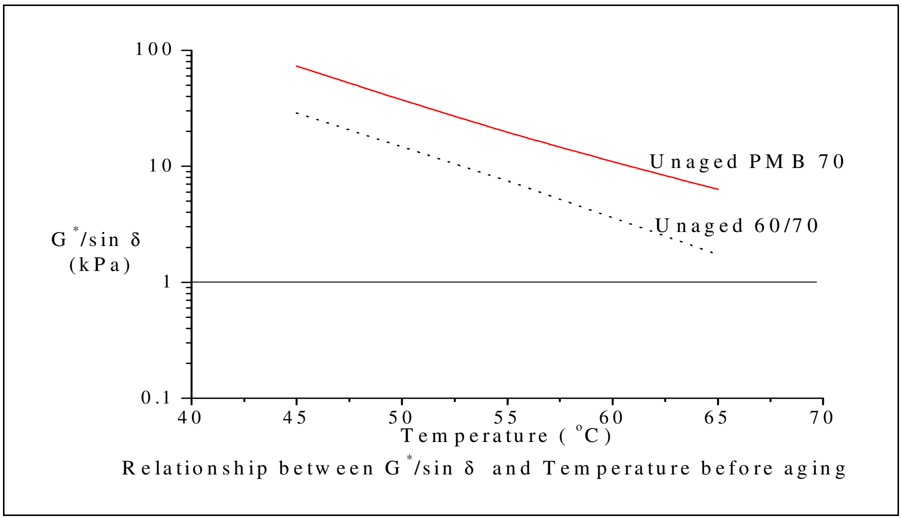

Fig. 1. Variation of Rutting Parameter before Aging

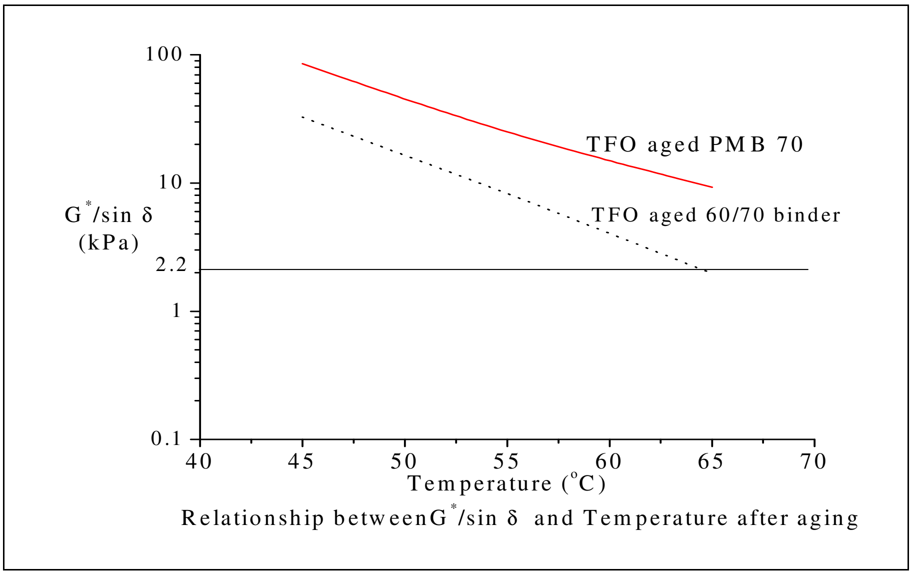

Fig. 2. Variation of Rutting Parameter after Aging

TABLE 5 Properties of Bituminous Concrete Mix

Sl. No.	Property Tested	Bitumen Content			
		4.50%	4.75%	5.00%	5.50%
1	Marshall stability (kN)	15.60	18.60	17.21	13.65
2	Flow value (mm)	2.81	2.89	3.33	3.74
3	Bulk density (g/cm^3)	2.431	2.437	2.460	2.452
4	Volume of voids Vv (%)	4.40	3.75	2.45	2.00
5	Voids in mineral aggregate VMA (%)	15.339	15.32	14.75	15.48
6	Voids filled with bitumen VFB (%)	71.30	75.50	83.39	87.08
7	Optimum bitumen content	4.90%			

TABLE 6: Properties of Polymer Modified Bituminous Concrete Mix

Sl. No.	Property Tested	Binder Content		
		4.50%	**5.00%**	**5.50%**
1	Marshall stability (kN)	19.22	23.20	22.00
2	Flow value (mm)	2.23	3.14	3.47
3	Bulk density (g/cm^3)	2.421	2.431	2.448
4	Volume of voids Vv (%)	5.096	3.989	2.547
5	Voids in mineral aggregate VMA (%)	15.673	15.791	15.619
6	Voids filled with binder VFB (%)	67.48	74.74	83.69
7	Optimum binder content	5.02%		

TABLE 7: Properties of Bituminous Concrete Mixes at Optimum Binder Content

Property Tested	Bituminous Concrete mix with 60/70 grade bitumen	Bituminous Concrete mix with PMB-70	Desirable Values as per MORTH Specifications
Optimum bitumen content, %	4.90*	5.02	5.0 – 6.0
Marshall Stability (kN)	18.55	23.50	> 9.0
Flow value (mm)	2.95	3.10	2 - 4
Bulk density (g/cm^3)	2.446	2.435	-
Volume of voids Vv (%)	3.40	3.60	3 - 6
Voids in mineral aggregate VMA (%)	14.97	15.40	>12.6
Voids filled with binder VFB (%)	75	74	65 - 75

**Minimum binder content of 5% was adopted in further investigations.*

4.5 Indirect Tensile Strength

The indirect tensile strength of the cylindrical specimen was tested at 30^0 C by applying load in static mode at the uniform deformation rate of 50 mm/ minute and the failure load was recorded.. It is observed that indirect tensile strength of the polymer modified bituminous mix is 20% higher than that of conventional bituminous mix.

4.6 Resilient Modulus of The Mixes

The resilient modulus of the bituminous concrete mixes prepared with 60/70 grade bitumen and SBS based PMB-70 was calculated in accordance with ASTM procedure D-4123 at three test temperature of 30^{0}C, 35^{0}C and 40^{0}C. It is seen that the resilient modulus for PMB mixes is 19 to 30% higher than the same for conventional bituminous mix.

4.7 Fatigue Life of the Bituminous Concrete Mixes

The horizontal tensile stress, vertical compressive stress and horizontal tensile strain caused by application of varying loads have been worked out. The variation in number of load repetitions to failure with horizontal tensile strain for bituminous concrete mixes prepared with 60/70 grade bitumen and PMB-70 are presented in Fig. 3, 4 and 5 at temperatures of 30^{0}C, 35^{0}C and 40^{0}C respectively.

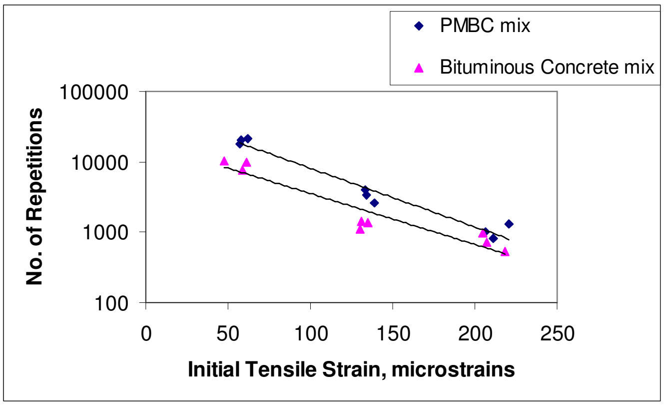

Fig. 3. Variation in No. of Repetitions with Tensile Strain at 30^{0}C

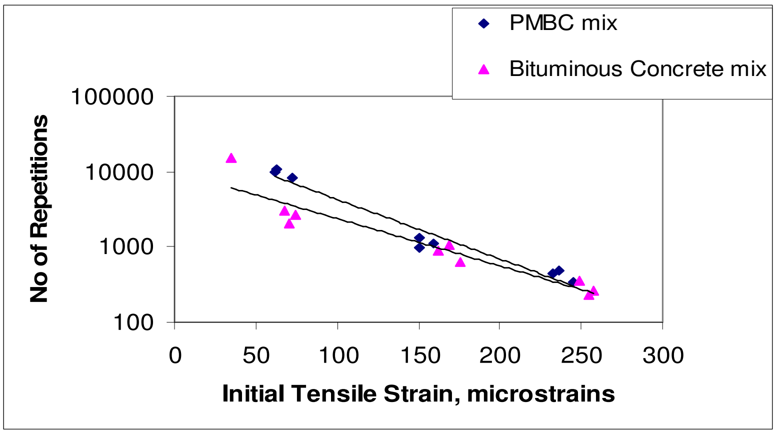

Fig. 4. Variation in No. of Repetitions with Tensile Strain at 35^{0}C

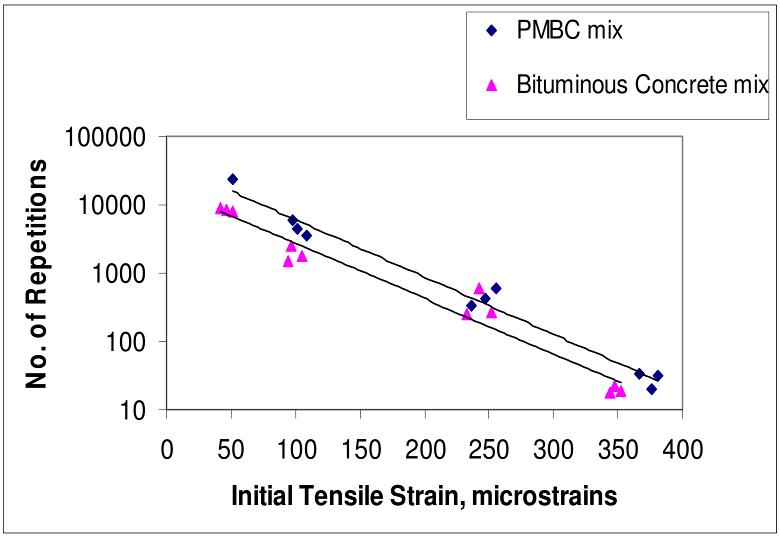

Fig. 5. Variation in No. of Repetitions with Tensile Strain at 40^{0}C

The variation in number of repetitions with respect to temperature at constant tensile stress values of 100, 200 and 300 kPa have been worked out and the same are plotted in Figures 6, 7 and 8.

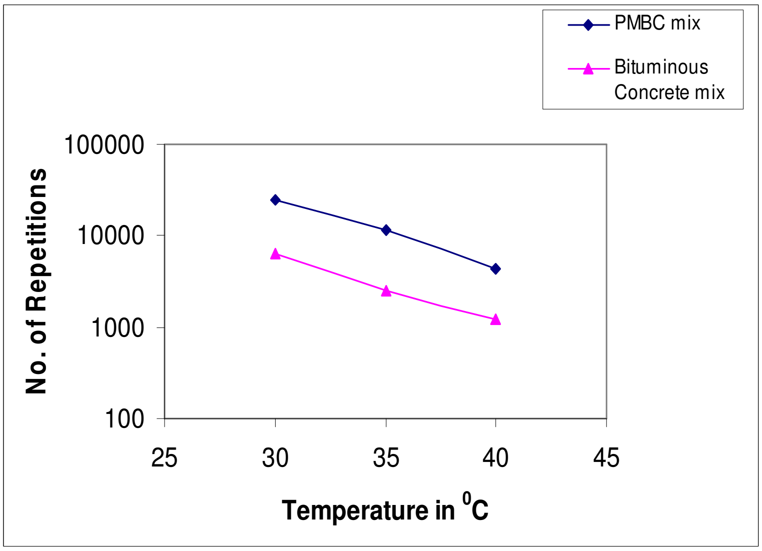

Fig. 6. Number of Repetitions to Failure at the Tensile Stress of 100 kPa

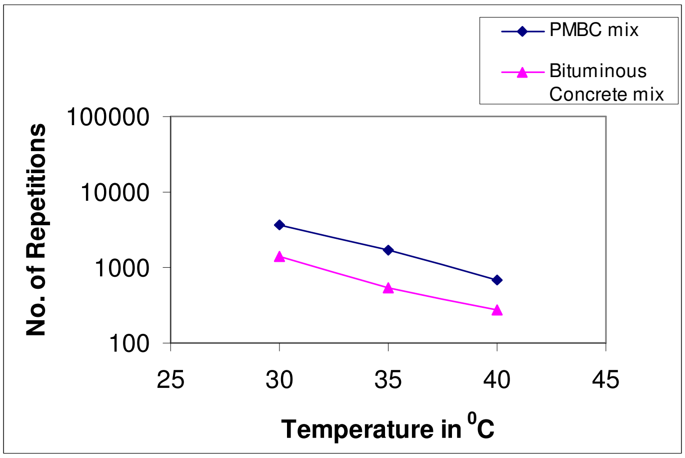

Fig. 7. Number of Repetitions to Failure at the Tensile Stress of 200 kPa

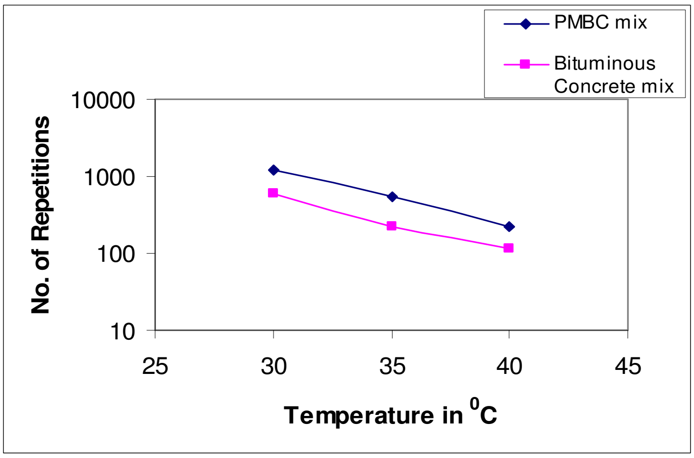

Fig. 8. Number of Repetitions to Failure at the Tensile Stress of 300 kPa

4.8 Design Of Pavements With Modified Binders

The thickness of various pavement layers was selected for CBR value of 8% and traffic of 150 msa as provided for in IRC:37-2001 and analysis of pavement was carried out using F- pave software to calculate the tensile strain at the bottom of the bituminous layer. The elastic modulus of subgrade and granular base was worked out as under.

Elastic modulus of subgrade = 10 CBR (5)

Elastic modulus of granular base

$E = K.\ E_{subgrade}$ (6)

Where, $K = 0.2\ (H)^{0.45}$

H = Thickness of the granular base in mm

The Elastic modulus, thickness and Poisson's ratio of various layers for the analysis is tabulated below in Table 8.

TABLE 8: Details of Various Layers of Pavement

Layer	Thickness (mm)	Elastic modulus (MPa)
Bituminous	210	As calculated in repeated load test
Granular	350	223
Subgrade	∞	80

The horizontal tensile strains developed in the pavement corresponding to varying contact pressures at temperatures of 30^0C, 35^0C and 40^0C as calculated from F-pave analysis are presented in Table 9 for BC mixes of both types. Since the tensile strain varies depending upon the contact pressure, the weighted average value of the tensile strain has been worked out to arrive at a single value of the tensile strain caused by a vehicular load. The loads to cause the contact pressure of 0.56, 0.63 and 0.70 MPa have been assumed to be in the ratio of 30%, 35% and 35% respectively for this purpose. It can be seen from Table 9 that a particular spectrum of load produces 11% lower tensile strain in polymer modified bituminous concrete mix and this will lead to longer fatigue life.

TABLE 9: Tensile Strain Variation in Field for Bituminous Concrete Mixes

Contact Pressure (MPa)	Tensile strain (micro strains) for BC Mix			Tensile strain (micro strains) for PMBC Mix		
	30^0 C	35^0 C	40^0 C	30^0 C	35^0 C	40^0 C
0.56	144	162	198	129	138	180
0.63	191	215	260	172	184	237
0.70	237	265	319	214	228	292
	218			193		

4.9 Development of Equations to Predict Laboratory Fatigue Life

The number of load repetitions to failure in the laboratory corresponding to various loads is noted and the tensile strain generated by the load is calculated. The SPSS software is used to carryout the regression analysis to develop the relationship between number of repetitions and tensile strain in the form as shown hereunder.

$$N_f = K_1 \left(\frac{1}{\varepsilon}\right)^{n_1} \tag{7}$$

Where

N_f = Number of cycles to failure
K_1= Constant
n_1 = Regression coefficients
ε = Initial horizontal tensile strain (micro strains)

The constants in equation (7) obtained for the three test temperatures of 30^0C, 35^0C and 40^0C for the bituminous concrete mixes prepared with 60/70 grade bitumen and SBS PMB-70 are shown in Table10. The constants reported in various other studies are summarised in Table 11. It is seen that the regression coefficient n_1 arrived at in the present study for both conventional and PMB mixes is comparable with the other studies except for the work by Kumar et al. wherein the constants in both the cases are higher which may be on account of the different failure criteria chosen. In the present study, the authors have taken 5 mm vertical deformation as the failure criteria.

TABLE 10: Constants of the Equation

Type of Mix	Test Temp (^{0}C)	K_1	n_1	Coefficient of Determination (R^2)
Conventional Bituminous Concrete Mix	30^0C	$5 * 10^7$	2.151	0.927
	35^0C	$3.5 * 10^7$	2.183	0.987
	40^0C	$3 * 10^7$	2.136	0.974
Polymer Modified Bituminous Concrete Mix	30^0C	$1.5 * 10^9$	2.755	0.940
	35^0C	$1 * 10^9$	2.769	0.983
	40^0C	$1 * 10^9$	2.705	0.992

TABLE 11: Constants of the Eqn in Published Literature

Type of Mix	Test Temp.	K_1	n_1	Type of Modifier Used	Remarks	Authors
Bituminous Concrete Mix	20^0C	$1.5*10^3$	2.17	-	Fatigue Life- Tensile Strain Relationship	Pandey, 1990
	25^0C	2 786.6	2.165	-	Fatigue Life- Stress Difference Relationship	Punith et al, 2005
	25^0C	$1*10^9$	2.67	-	Fatigue Life- Tensile Stress Relationship	Kumar et al, 2005
	35^0C	$6*10^7$	2.65			
Polymer Modified Bituminous Concrete Mix	25^0C	4 978.2	2.886	Poly ethylene	Fatigue Life- Stress Difference Relationship	Punith et al, 2005
	25^0C	3 556.8	2.479	Crumb Rubber		
	25^0C	$1*10^{11}$	3.23	Styrene Butadiene Styrene	Fatigue Life- Tensile Stress Relationship	Kumar et al, 2004

4. DISCUSSIONS

4.1 Physical Properties of the Binder

The physical properties of 60/70 grade bitumen and PMB-70 were determined and the results in respect of ductility, viscosity, loss in weight on heating in thin film oven, separation test and elastic recovery were compared.

The following can be observed from the results

- Styrene Butadiene Styrene modified binder showed increase in ductility by 22%. The elastic recovery of the binder is found to be 79%.
- Modified binders show increased viscosity at a given temperature. The viscosity of 60/70 grade bitumen at 135^0C is 3.93 poise which is approximately equal to the value of 3.97 poise for PMB-70 at 150^0C. This shows that the mixing and laying temperatures for polymer modified binder should be higher by approximately 15^0C.
- Modified binders have better age resistance properties. The loss in weight on heating in thin film oven is 6 times higher in case of 60/70 grade bitumen.
- The separation test did not indicate any phase separation. This test was carried out after storage of the binder at room temperature for few months. The difference in ring and ball softening point of top and bottom samples was observed as 0.5^0C as against a maximum of 3^0C specified.

4.2 Rheological Properties of the Binder

The complex shear modulus of both the binders decreases and phase angle increases with increase in temperature. However, the short term aging test carried out in laboratory has shown increased modulus and marginally low phase angle. The value of rutting parameter $G^*/\sin\delta$ at 65^0C drops to less than the minimum specified value of 2.2 kPa after aging in case of 60/70 grade bitumen indicating that this bitumen will contribute to rutting beyond this temperature. The value of the rutting parameter at 65^0C for PMB-70 is more than three times higher at 9.28 kPa.

4.3 Properties of the Bituminous Concrete Mixes

The properties of the bituminous concrete mixes prepared with 60/70 grade bitumen and PMB-70 evaluated by Marshall method of mix design showed that the optimum binder content in case of 60/70 grade bitumen is 4.90% whereas the same in case of PMB-70 is 5.02%. Since the MORTH specifications recommend minimum binder content as 5% for BC mixes, both the mixes were prepared at 5% binder content only for the tests in the study. The stability value for mix prepared with PMB-70 is 23.50 KN which is 27% higher than the stability value of 18.55 KN obtained for the mix prepared wit 60/70 grade bitumen. The indirect tensile strength and resilient modulus of the mixes were worked out by repeated load test set-up. The indirect tensile strength of conventional and polymer modified bituminous concrete mix were found to be 492 kPa and 591 kPa respectively. The tensile strength of the PMB mix is 20% higher.

The resilient modulus of the PMB mix is more by 19 to 30% than conventional bituminous concrete mix at the test temperatures ranging from 30 to 40^0C. It is observed that the resilient modulus value increases by 75% with decrease in temperature from 40^0C to 30^0C.

4.4 Variation in Number of Repetitions with Stress Level and Temperature

Table 12 shows the variation in number of repetitions with stress level and temperature for conventional and polymer modified bituminous concrete mixes. It can be observed from the table that there is a significant increase in the number of repetitions with the reduction in stress level indicating thereby that reduction in horizontal tensile strain enhances the fatigue life significantly. Also, the fatigue life reduces substantially with increase in temperature from 30^0C to 40^0C.

TABLE 12: Variation in Number of Repetitions with Stress Level and Temperature

Stress Level (% of Failure Load)	No. of Repetitions to Failure					
	Conventional Bituminous Concrete Mix			Polymer Modified Bituminous Concrete Mix		
	30^0C	35^0C	40^0C	30^0C	35^0C	40^0C
10%	-	15 335	8 441	-	-	23 532
20%	9 357	2 582	1 896	20 054	9 595	4 585
40%	1 307	858	372	3 380	1 133	448
60%	737	284	20	1 047	355	28

4.5 Variation in No. of Repetitions with Temperature at Constant Tensile Stress

The number of repetitions has been worked out at different temperatures but at constant tensile stress of 100, 200 and 300 kPa and the results are tabulated in Table 13, 14 and 15. It can be observed from the results that the fatigue life of SBS polymer modified bituminous concrete mix is significantly higher, but the magnitude of increase in life reduces with increase in tensile stress.

TABLE 13: Variation in No. of Repetitions at the Tensile Stress of 100 kPa

Temp.	Number of Repetitions to Failure		(N_2/ N_1)
	Conventional Bituminous Concrete Mix (N_1)	Polymer Modified Bituminous Concrete Mix (N_2)	
30^0C	6 297	24 725	3.93
35^0C	2 489	11 438	4.60
40^0C	1 215	4 409	3.62

TABLE 14: Variation in No. of Repetitions at the Tensile Stress of 200 kPa

Temp.	Number of Repetitions to Failure		(N_2/ N_1)
	Conventional Bituminous Concrete Mix (N_1)	Polymer Modified Bituminous Concrete Mix (N_2)	
30^0C	1 418	3 663	2.58
35^0C	548	1 678	3.06
40^0C	276	676	2.45

TABLE 15 Variation in No. of Repetitions at the Tensile Stress of 300 kPa

Temp.	Number of Repetitions to Failure		(N_2/ N_1)
	Conventional Bituminous Concrete Mix (N_1)	Polymer Modified Bituminous Concrete Mix (N_2)	
30^0C	593	1 199	2.02
35^0C	226	546	2.41
40^0C	116	226	1.95

6. CONCLUSIONS

The following conclusions are drawn from the present study.

1. SBS polymer modified binders have high elastic recovery.
2. SBS modified binders have better age resistance properties. The loss in weight on heating in thin film oven is 6 times higher in case of 60/70 grade bitumen.
3. SBS modified binders show increased viscosity at a given temperature. The viscosity of 60/70 grade bitumen at 135^0C is 3.93 poise which is approximately equal to the value of 3.97 poise for PMB-70 at 150^0C.
4. SBS polymer modified binder shows significant increase in rutting resistance of the binder.
5. Marshall stability of the mix increases by about 27% for the gradation and the materials used in the present study when polymer modified binder was used.
6. The indirect tensile strength of the bituminous concrete mix prepared with SBS polymer modified binder is high when compared to conventional mixes.
7. Resilient modulus of the mix prepared with SBS polymer modified binder is 19 to 30% higher at test temperatures of 30 to 40^0C.
8. The tensile strain increases by about 83% with increase in temperature from 30 to 40^0C and the increase in tensile strain reduces the fatigue life of the mix significantly.
9. At constant tensile stress and pavement temperature, the fatigue life of the SBS polymer modified bituminous concrete mix increases significantly. The magnitude of increase in fatigue life, however, decreases with increase in tensile stress.
10. The improvement in properties reported in the paper is in conformity with published literature cited in the paper. High elastic recovery and increased rutting resistance of the SBS polymer modified binder and increase in the fatigue resistance of the bituminous concrete mix prepared with such binders are likely to improve the pavement life substantially. This may prove to be economical in the long run as life cycle cost will come down.

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