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Research Paper

PERFORMANCE OF POLYMER MODIFIED BITUMEN FOR FLEXIBLE PAVEMENTS

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Flexible pavements with bituminous surfacing are widely used in India. Exponential increase in traffic, overloading of commercial vehicles and significant variations in daily and seasonal temperatures have shown some limitations of conventional bitumen performance. Early developments of distress symptoms like cracking, rutting, ravelling, undulations, shoving and potholing of bituminous surfacing have been reported for flexible pavements. A bituminous mixture needs to be flexible enough at low service temperatures to prevent pavement cracking and to be stiff enough at high service temperature to prevent rutting. Bitumen modified with polymer offers a combination of performance related benefits as the physical properties of the bitumen is improved without changing the chemical nature of it. This paper presents the experimental study carried out conventional bitumen and polymer modified binder. It has been shown that rutting resistance, indirect tensile strength and resilient modulus of the bituminous concrete mix with polymer modified bitumen is significantly improved.

Keywords: Flexible pavement, bituminous surfacing, modified polymer, rutting resistance, resilient modulus

INTRODUCTION

Bitumen has been widely used in India for the construction of flexible pavements for more than a century. Flexible pavements with bituminous surfacing are widely used in India. 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 surfacing.

Bitumen as a visco-elastic material plays a prominent role in determining many aspects of road performance. Various types of crude source and refining process lead to extreme complexity in bitumen chemistry and rheology. Furthermore, the rheological behavior of bitumen is also very complex, varying from

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purely viscous to elastic depending on loading time and temperature. A bituminous mixture needs to be flexible enough at low service temperatures to prevent pavement cracking and to be stiff enough at high service temperature to prevent rutting.

Flexible pavements containing conventional bitumen do not always perform as expected. In improving the properties of bitumen, several types of modification have been investigated. These include additive modification, polymer modification and chemical reaction modification. Investigations have revealed that properties of bitumen and bituminous mixes can be improved to meet the growing requirements of pavement with incorporation of certain polymers.

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.

This paper compares the properties on the bituminous mixes using conventional bitumen and polymer modified bitumen. The results of the two mixes with bitumen (60/70) and PMB-70 have been discussed and important conclusions are drawn from the experimental study.

POLYMER MODIFIED BITUMEN

Modified bitumen with polymer offers a combination of performance related benefits the physical properties of the bitumen are improved without changing the chemical nature of it. These modified bituminous binders are reported to have produce softer mixtures at low service temperature to minimize non-load associated thermal cracking. Further, improved fatigue resistances of the bituminous mixes, overall improved performance in extreme climatic conditions and under heavy traffic conditions, reduced life cycle cost of the pavement have been also reported in the literature.

Polymer modified bitumen increases the elasticity of the mix and also increases viscosity at higher temperature (King *et al*., 1986). The viscosity helps to limit the deflection while the elastic recovery reduces the residual deformation. The elastic surface layer bridges the cracks from unmodified layers underneath, thus, maintains the water-tight nature of the asphalt and protects the underlying structure. King *et al*. (1986**)** also carried out a test for testing the rutting resistance and it was found that the PMB was able to withstand 4-10 times more loading cycles before ruts of various specified depths.

Terrel and Walter (1986) have showed that polymers provide considerable improvement in the physical properties of binder – aggregate combinations. However, the improved properties of the PMB should be made use of in order to have increased service life and the thickness should not be reduced on the pretext of using PMB.

Valkcring *et al.* (1990) reported that the utility of the dynamic creep test for better prediction of the strain rate in polymer modified bituminous mixes. The rut depths were calculated under the wheel loading in the laboratory test track tests. It has been shown that satisfactory correlation between the rate of residual strain and rutting rate exists.

Collins *et al.* (1991) reported that selection of appropriate asphalt is essential to obtain a blend with optimal properties. Improved compatibility leads to many advantages. Further, it has been proved that the effectiveness of the added polymer in terms of elastic recovery dropped from a soft to a hard binder.

Lenoble and Nahas (1994) showed that the addition of polymer not only increases the application temperature range of asphaltic binders but also increases the traffic resistance. Further, it was also discussed that the thermal cracking resistance of a pavement is controlled by the temperature at which the binder reaches a modulus close to its glassy modulus.

Oliver and Tredrea (1997) presented test results of dynamic shear rheometer on PMB. It was found that long-term laboratory exposure at a temperature below the maximum encountered in pavement service resulted in large changes in the rheological behavior of the PMB and these changes were likely to reduce the advantages which fresh PMBs have over unmodified bitumen in service.

Airey and Brown (1998) investigated chemical changes and the rheological of polymer modified bitumen under short-term and long term aging condition. The changes in rheology caused by aging are, decrease in penetration and increase in viscosity & softening point. It was further concluded that any variation in aging behaviour of the PMB is due to the presence of polymer.

Molenaar and Nirmal (1998) carried out tests (resilient modulus, tensile strength and fracture toughness of mixes) with conventional bitumen and polymer modified bitumen. It has been concluded in this study that polymer modified binder has significant increase of pavement life.

Khattak and Baladi (2001) showed that rheological and engineering properties of polymer mixed binders mixtures largely depend on the polymer type and content. The mix design of the conventional bitumen and polymer mixed bituminous mixtures were conducted using the Marshall mix-design procedures. At the optimum polymer content, the strengths of the polymer modified mixtures were approximately 1.45 times higher than the mixtures made with bitumen binder subjected to the same processing conditions. Further, empirical relations for predicting fatigue life of polymer modified bituminous mix were also developed considering different polymer content, plastic deformation, viscosity and indirect tensile strength. Khattak and Baladi (2001) also showed the improvement in the resistance to plastic deformation with polymer modification. It is shown that the required number of load cycles to accumulate any value of plastic deformation increases as the polymer content is increased until 5% optimum polymer content is reached.

Kumar et al. (2004) carried out study for the properties of polymer modified binder and it has been shown that Styrene Butadiene Styrene (SBS) polymer modified binder has better elastic recovery as compared to Linear Low Density Polyetheylne (LLDPE) binder.

Punith *et al*. (2005) studied the effect of various factors on resilient modulus of elasticity under repeated load indirect tensile tests. These studies were carried out on conventional 80/100 grade bitumen and bitumen modified with polyethylene and crumb rubber separately. It has been shown that the performance of polymer modified bitumen with polyethylene is better than conventional 80/100 grade bitumen and binder modified with crumb rubber.

EXPERIMENTAL STUDY

In the present work experimental study was carried out using polymer modified bitumen, PMB-70 and conventional bitumen of 60/70. The objective of the present study is to evaluate the performance of conventional and polymer modified bituminous concrete mixes, the combined grading of the coarse and fine aggregates and filler should fall within the prescribed limits.

Selected bituminous materials for the experimental study, PMB-70 and 60/70 grade bitumen were tested. The results of various tests are shown in Tables 1 and 2. The permissible values as per IS: 73-2001 have been also shown in the tables.

Properties of PMB-70 mixes are compared with those with bitumen mixes using 60/70 bitumen. The design of bituminous concrete mix prepared with both binders (PMB-70 and 60/70 grade bitumen) separately was carried out by Marshall Method of mix design. The test specimens were prepared with 4.5, 5.0 and 5.5% binder content added by weight of aggregates.

Table 1: Physical Properties of 60/70 Grade Bitumen

Properties Tested	Test Results	Permissible Limits
Penetration at 25 °C(unit)	70	60-70
Softening point (°C)	43.75	40-55
Ductility (cm)	82	>75
Specific gravity at 27 °C	1.00	>0.99
Viscosity at 60 °C (Poise)	1660	1000 ± 200
Viscosity at 135 °C (cSt)	393	>150
Properties after TFOT* (Residue)		
Loss on heating, percent by mass	0.31	1 (max.)
Retained Penetration at	67.4	55 (min.)

Note: *TFOT: Thin Film Oven Test.

Table 2: Physical Properties of PMB-70

Properties Tested	Test Results	Permissible Limits
Penetration at 25 °C (unit)	68.67	50-90
Softening point (°C)	63	55 (min.)
Ductility (cm)	100	>60
Specific gravity at 27 °C	1.03	>0.99
Viscosity at 135 °C (Poise)	12.90	20 (max.)
Viscosity at 150 °C (Poise)	3.97	2-6
Elastic recovery of half thread in ductilometer at 15 °C (cm)	79	75 (min.)
Properties after TFOT* (Residue)		
Loss on heating, percent by mass	0.05	1 (max.)
Elastic recovery of half thread in ductilometer at 15 °C (cm)	62.5	50 (min.)

Note: *TFOT: Thin Film Oven Test.

OPTIMUM BITUMEN CONTENT

The properties of the bituminous concrete mixes prepared with 60/70 grade bitumen and PMB-70 were evaluated by Marshall Method of mix design. Specimens were prepared with bitumen content of 4.5, 5.0 and 5.5 as per standard procedure. The specimens were allowed to cool overnight and extracted from the mould using specimen extractor. The specimen weight in air and water were noted to calculate the bulk specific gravity of the mix and other related properties. The specimens were kept in thermostatically controlled water bath maintained at 60 °C for 30-40 min. The specimens were taken out of water bath and tested in Marshall testing machine to determine the stability and flow value.

The properties of bituminous mix prepared with 60/70 grade bitumen are shown in Table 3. Similarly, the properties of mix PMB-70 are shown in Table 4. It can be observed from these tables that the optimum binder content using 60/70 grade bitumen is 4.74% whereas the optimum binder content using PMB-70 is 5.02%. The stability, flow value and related factors for mix with 60/70 grade bitumen and PMB-70 are shown in Table 5. Although, the bitumen content for mix with PMB-70 is higher but the stability value for mix prepared with PMB-70 is 23.50 kN. This value is 27% higher than the stability value (18.55 kN) obtained for the mix prepared with 60/70 grade bitumen.

RUTTING RESISTANCE OF THE BINDER

Dynamic shear modulus is evaluated for determining the linear viso-elastic properties of asphalt binders. In this test, the determi-

Table 3: Properties of Bituminous Concrete Mix to Determine Optimum Bitumen Content

S. No.	Property Tested	Bitumen Content		
		4.5%	**5.0%**	**5.5%**
1.	Marshall stability (kN)	15.60	17.21	13.65
2.	Flow value (mm)	2.81	3.33	3.74
3.	Bulk density (g/cc)	2.43	2.46	2.45
4.	Volume of voids (Vv) (%)	4.4	2.45	2.00
5.	Voids in mineral aggregate VMA (%)	15.34	14.75	15.48
6.	Voids filled with bitumen VFB (%)	71.30	83.39	87.08
7.	Optimum bitumen content	4.74%		

Table 4 : Properties of Polymer Modified Bituminous Concrete Mix to Determine Optimum Bitumen Content

S. No.	Property Tested	Bitumen Content		
		4.5%	**5.0%**	**5.5%**
1.	Marshall stability (kN)	19.22	23.20	22.00
2.	Flow value (mm)	2.23	3.14	3.47
3.	Bulk density (grams/cc)	2.42	2.43	2.45
4.	Volume of voids (Vv) (%)	5.10	3.99	2.55
5.	Voids in mineral aggregate VMA (%)	15.67	15.79	15.62
6.	Voids filled with bitumen VFB (%)	67.48	74.74	83.69
7.	Optimum bitumen content	5.02%		

nation of dynamic shear modulus is performed when sample is tested in oscillatory shear using parallel plate test geometry. The control and data acquisition system provides the record of temperature, frequency, deflection angle and torque. In addition to this information, the system calculates and records shear stress, shear strain, complex shear modulus G* and phase angle δ. The calculated values of G* and δ are displayed on the computer after the completion of the test.

The dynamic shear modulus test (Figure 1) was performed at three temperatures, 45 °C, 55 °C and 65 °C as rutting is predominant on the pavements at these temperatures. The tests were carried out on unaged and TFO

Table 5 : 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
Optimum bitumen content	4.74%	5.02
Marshall stability (kN)	18.55	23.50
Flow value (mm)	2.95	3.10
Bulk density (g/cc)	2.45	2.43
Volume of voids (Vv) (%)	3.40	3.60
Voids in Mineral Aggregate (VMA) (%)	14.97	15.40
Voids filled with bitumen (VFB) (%)	75	74

aged samples of 60/70 grade bitumen and PMB - 70. The rutting parameter (G*/Sin δ) was calculated for both the binders for unaged and aged conditions.

The variation of rutting parameter for PMB-70 and 60/70 bitumen has been compared in Table 6 for the two cases, before aging and after aging, respectively. It can be observed

Table 6: Rheological Properties

	Temperature (°C)	Complex Modulus G^* (kPa)	Phase Angle (δ)	Storage Modulus G' (kPa)	Loss Modulus G" (kPa)	Rutting Parameter $G^*/\sin\delta$ (kPa)
Unaged 60/70 Bitumen	45	28.7	84.3	2.84	28.6	28.84
	55	7.49	86.9	0.41	7.48	7.50
	65	1.73	88.3	0.05	1.73	1.73
TFO aged 60/70 Bitumen	45	32.5	84.3	3.25	32.4	32.66
	55	8.27	86.7	0.48	8.26	8.28
	65	1.97	88.2	0.06	1.97	1.97
Unaged PMB-70	45	68.9	70.4	23.1	64.9	73.14
	55	17.8	70.7	5.90	16.8	18.86
	65	6.01	72	1.86	5.71	6.32
TFO aged PMB-70	45	79.9	69.5	28.0	74.8	85.30
	55	22.30	70.2	7.53	21.0	23.70
	65	8.74	70.3	2.95	8.23	9.28

that the complex shear modulus of both the binders decreases with increase of temperature and phase angle. The value of rutting parameter (G*/ Sin δ) at 65 °C after aging in case of 60/70 grade bitumen drops down to less than 2.2 kPa (the minimum specified value beyond which this bitumen will contribute to rutting). The value of the rutting parameter for PMB-70 at the same temperature is very high (9.28 kPa).

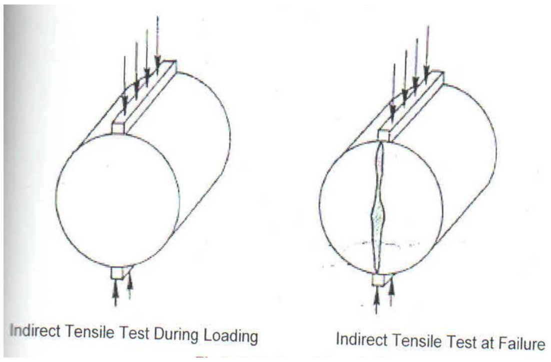
Figure 1: Dynamic Shear Rheometer with Data Acquisition System

INDIRECT TENSILE STRENGTH

The indirect tensile strength test is carried out on the Marshall Specimen prepared at the optimum bitumen content. The test was performed by loading the cylindrical specimen at 30 °C. The compressive load acts parallel and along the vertical diametric plane and tensile stress are developed (Figure 2). The specimen fails by splitting along the vertical diameter.

The indirect tensile strength and resilient modulus of the mixes were worked out by repeated loads. The indirect tensile strength of conventional and polymer modified bituminous concrete mixes were found to be 492 kPa and 591 kPa respectively (Table 7). It shows that the tensile strength of the PMB mix is 20% higher.

Figure 2: Indirect Tensile Test



RESILIENT MODULUS

In the resilient modulus test the cylindrical specimen was heated in the controlled temperature cabinet so that the specimen attains uniform desired temperature. The specimen was placed in the loading apparatus and repeated sine load in the range of 10 to 50% of the tensile strength was applied for a minimum period sufficient to obtain uniform deformation observation. A frequency of 2 Hz and rest period of 1 sec was selected.

Table 8 show the variation of the resilient modulus with temperature for conventional bitumen (60/70) and PMB-70. It is observed that the modulus decreases rapidly with the increase in temperature. The resilient modulus of the PMB mix is more by 19 to 30% than bituminous concrete mix at the test temperatures ranging from 30-40 °C. It can be observed that the resilient modulus increases by 75% with decrease in temperature from 40 to 30°C.

Table 7: Indirect Tensile Strength of Bituminous Concrete Mixes

Test Sample	Indirect Tensile Strength (kPa)	
	Bituminous Concrete Mix with 60/70 Grade Bitumen	Bituminous Concrete Mix with PMB-70
1	444	592
2	553	621
3	480	561
4	492	591

Table 8: Resilient Modulus of Bituminous Concrete Mixes

Test Temperature (°C)	Resilient Modulus (MPa)	
	Bituminous Concrete Mix with 60/70 Grade Bitumen	Bituminous Concrete Mix with PMB-70
30	3,153	3,764
35	2,580	3,366
40	1,800	2,147

CONCLUSION

The results of the experimental study show that performance of Polymer Modified Bitumen is better than that of conventional bitumen (60/70). Following conclusions can be drawn from this study:

1. Polymer modified bitumen is found to have a high elastic recovery (79%).
2. Modified bitumen has better age resistance properties. The loss in weight on heating in thin film oven is 6 times higher as compared to conventional bitumen of 60/70.
3. When PMB was used Marshall stability of the mix increases by 27%.
4. The rutting resistance of the polymer modified bitumen is significantly higher.
5. The indirect tensile strength of the bituminous concrete mix with polymer modified bitumen is 20% higher at 30 °C.
6. Resilient modulus of the mix prepared with PMB is significantly higher at the test temperatures of 30 to 40 °C.

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