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Studies on Resilient Characteristics of modified binder (PMB – 40 & 70 grades with grade-I aggregates) on pavement surface course

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Abstract

The present paper examines the physical and engineering properties of modified binders, specifically Polymer Modified Bitumen (PMB - 40 grade and PMB - 70 grade) with Cement as a mineral filler of 2%, in order to determine the optimal binder content (OBC) for Grade-I aggregates with nominal sizes of 19 mm. In order to cast the specimens for indirect tensile strength (ITS) with moisture susceptibility, OBC was used as the bitumen content and stress levels were changed from 10% to 40%.

The engineering characteristics of specimens tested for ITS and fatigue values made of PMB - 40 grade with grade-I aggregates differ incrementally from those of PMB - 70 grade with grade-I aggregates.

***Keywords*: Stability, Modified binder, In-direct tensile strength, fatigue strength of modified binders**.

I. INTRODUCTION

Resilient modulus

A key design consideration for flexible pavements is the resilient modulus, or MR, which typically quantifies a material's ability to recover from external stress or disturbance. In essence, it is defined as the ratio of applied deviator stress to recoverable or resilient strain.

While the stress-strain curve's slope for slowly moving vehicle wheel loads will be in the linear elastic area and will give way to MR for rapidly applied wheel loads, this property of the material really serves to determine its modulus of elasticity, or E. By comprehending the robust modulus of the pavement substance, one may predict the structural behaviour of the pavement under traffic loading. Testing the bituminous pavement materials in a lab and in the field can reveal that obtaining MR is a very difficult task. The effects of temperature on the pavement were more significant than the effects of traffic.

Aggregates:

The coarse aggregate morphology, as determined by angularity and surface texture features, affects the resilient modulus of asphalt mixes. A reduction in the nominal maximum aggregate size from 19 mm (layer thickness of 50 mm) to 9.5 mm indicated an increasing positive influence of aggregate morphology on the resilient modulus of asphalt mixes, even though the relationship between the coarse aggregate morphology and the resilient modulus was not significantly impacted by changes in aggregate gradation. Aggregates respond linearly elastically until they reach a certain size, producing useful robust features.

Modified binders:

Modified binders are substances with advantageous characteristics like improved resistance to rutting at high temperatures and enhanced resistance to cracking at intermediate and low temperatures. Because they are more workable than neat bitumen or binder, modified asphalt binders are typically employed in high stress applications and have been used in crossroads with stop-and-go traffic, high volume truck routes, and high volume interstates. Modifiers have also been utilised to decrease bitumen ageing in difficult environments including desert regions and places with extremely low temperatures like -34 degrees and -40 degrees. Modified bitumen can be a very cost-effective way to lessen climatically-related pavement distresses and failures when used appropriately and in the right places.

Analysis of elastic modulus characteristics:

When describing the pavement materials under various loading conditions without causing the pavement system to fail, resilient modulus is employed. However, pavement systems can be created to withstand design axle load applications throughout the duration of their design life by adjusting layer thickness & stiffness. Pavements are made to handle a range of design axle magnitudes and their load applications.

It has been found that resilient modulus at low temperatures is somewhat related to cracking because stiffer mixes (higher MR) at low temperatures tend to crack earlier than more flexible mixtures (lower MR).

II. LITERATURE REVIEW

- **D.N. Little and E. Tal** The Department now has the ability to undertake this test in support of both design activities and the validation of non-destructive field testing thanks to the development of a number of methodologies for calculating the modulus of asphalt concrete in this study. Along with procedures centred on mechanistic design methodologies and techniques that are easily adaptable to new research discoveries, a production testing technique was explored. The uniaxial compression test with sinusoidal loading can be used with a variety of materials and stress levels thanks to the development of two test setups[1]. **Amir Modarres and E. Tal** The ASTM D4123-04 method is used to compute the robust modulus of bituminous mixes, one of the stress-strain measures used to evaluate the elastic properties of these mixes. When pressure is applied, the majority of pavement materials, which are often known to be non-elastic, permanently distort.

$$M_R = [\{P*(\mu + 0.27)\} / \{(t * \delta_h)\}]$$

where P is the maximum dynamic load, N; μ is the Poisson's ratio (assumed 0.35); t the specimen length, mm; δ_h is the total horizontal recoverable deformation, mm. In the M_R test the loading frequency was set as equal to

1 Hz, including 0.1 s loading and 0.9 s recovery time. Both ITS and M_R Tests were performed at 20 C. Furthermore, the stress level in the Mr test was selected as equal to 20% of ITS[2].

- **A. Patel, E. Tal** By taking core samples from the pavements, the resilience properties of the regions where thick and semi-dense asphalt concrete experimental studies have been undertaken. The thorough characterisation of these cores was part of the suggested method for calculating MR. The pavements at these airports had cores removed from the wearing and binder courses. These cores underwent testing for flow value, Marshall Stability, and density-void analysis in accordance with ASTM D6927 [14]. The results are displayed[3].
- **Kalhan Mitra Etal** The samples of the binder mix are put through an indirect tensile test setup where the load is applied at a fixed rate of deformation. The experimental results of the binder mix are used to calibrate the suggested numerical model of the binder mix. The properties of the aggregate and binder blend are used as input to the numerical model of the asphalt mixture. The asphalt blend sample is also put through the indirect tensile test setup at a predetermined deformation date. Typically, "5% asphalt mix" refers to an asphalt mixture that has an asphalt binder content of 5% (by weight) of the total weight of the mixture[4].
- **H. Di Benedetto E. tal** Only when the behaviour of the material can be viewed as linear can these qualities be added. An evaluation of the linear viscoelastic domain of the bituminous mixtures considering the axis the proportion between the tension's amplitude's base-10 logarithm and the number of cycles used. Verdicts on test facilities, specimen preparation, testing, and calibration techniques for stiffness properties In order to improve the repeatability and reproducibility of this form of testing, findings from inter-laboratory tests carried out by 15 laboratories were used to create tests of bituminous mixes under cyclic (and not dynamic, as discussed further) loading[5].
- **David H. Timm** describes the composition and material characteristics of the various pavement layers. Tests on the triaxial resilient and dynamic moduli were done in the lab, and the results are described. Following statistical analysis of the data from the laboratory and field, models were developed to explain correlations between relevant pavement metrics and mechanistic material qualities. The investigation revealed that air voids, binder quality, gradation, and asphalt content were not particularly significant, and the HMA layer demonstrated the highest effects of cracking on moduli [6]**.**
- **Ramprasad, D.S., and E. Tal** The performance characteristics that are listed in the requirements for bituminous binders in India are based on a range of empirical experiments that scarcely have any relevance. This article describes the physical and rheological properties of bituminous binders, which are widely employed in India, in terms of their performance traits at high and moderate field temperatures. Along with other factors that affect how bituminous binders behave, the impacts of temperature fluctuations, loading rates, and loading volumes are considered[7].
- **Moe Aung Lwin E. Tal** By recycling tyres as crumb rubber tyres and putting them into bituminous paving mixtures, the recycling rate may be raised while the cost of incineration is decreased. Dry mixing was used to produce five (5) separate Open Graded Wearing (OGW) course road samples, each weighing 1.15 kg. Each OGW mix had 1% fixed crumb rubber tyres and 4% to 6% bitumen Pen 60/70, for a total of 14% to 20% crumb rubber tyres in the bituminous samples. Bitumen Pen 60/70 and 20% crumb rubber tyre content were

combined to create PG 76 bitumen, which had the desired qualities. When compared to bitumen alone, OGW produced from crumb rubber modified bitumen (CRMB) had better physical properties[8].

- **Nabiin Rana Magar** Both internal and external factors, such as the quantity, kind, size, source, and composition of the crumb rubber as well as the mixing period, temperature, and procedure, have an impact on CRMB's rheology. (either a dry or wet technique). The current study's objective is to examine the experimental findings of bitumen modified with 15% by weight of various-sized crumb rubber. The sizes of crumb rubber that will be used are coarse (1 mm - 600 m), medium (600 - 300 m), fine (300 - 150 m), and superfine (150 - 75 m). Standard laboratory tests will be performed on the modified bitumen using various sizes of crumb rubber, and the results will be analysed[9].
- **Ambika Kuity and E. Tal** Locally-sourced aggregates, asphalt binder, and filler were all employed in this study. The asphalt mixture utilised in the current study is bituminous concrete (BC), which is produced in accordance with Indian standards. Mid-point grading is employed during the BC samples' processing. The performance of five different fillers—brick dust, fly ash, lime dust, recycled concrete waste aggregates dust, and traditional stone dust—used in asphalt mix is thoroughly analysed in this paper. The asphalt concentration was kept at 5.66% of the weight of the aggregates, excluding the filler[10].
- **Georges A.J. Mturi and E. Tal** Locally-sourced aggregates, asphalt binder, and filler were all employed in this study. The asphalt mixture utilised in the current study is bituminous concrete (BC), which is produced in accordance with Indian standards. Mid-point grading is employed during the BC samples' processing. The performance of five different fillers—brick dust, fly ash, lime dust, recycled concrete waste aggregates dust, and traditional stone dust—used in asphalt mix is thoroughly analysed in this paper. The asphalt concentration was kept at 5.66% of the weight of the aggregates, excluding the filler. In the current work, a volume proportioning technique was employed in place of the stone dust fillers due to the various densities of the fillers[11].
- A**. Bashar Tarawneh** The MR should be determined by repeated load triaxial (RTL) laboratory studies. However, this test calls for expensive lab equipment and highly qualified personnel. Additionally, it is believed to take some time. As a result, MR is calculated using correlations with various in-situ test findings and material index attributes. How precisely the resilient modulus is determined depends on the prediction model's precision. Additionally, the accuracy of Mr. Prediction was significantly increased by the application of ANN-based models. Only models that used back calculated FWD moduli and other software programmes to account for soil physical properties showed the ANN improvement[12].
- **Jorge B. Sousa, Etal** Permanent deformation (rutting) has a substantial negative impact on the effectiveness of asphalt pavements. By altering how vehicles handle, rusting reduces the pavement's useful service life and poses a serious risk to other road users. Highway materials experts have struggled to develop rutting resistant materials because the methods currently utilised for testing and evaluating asphalt-aggregate mixes are empirical and do not offer a trustworthy indicator of in-service performance. Rutting is mostly caused by recurrent shear deformations under traffic stress, while mixture densification (volume change) also plays a role[13].

- **Jean-Pascal Bilodeau, et al** Although testing for the resilient modulus is expensive and laborious, it is routinely extrapolated from faulty, indirect tests or assumed using preset values. The robust modulus is an essential component of flexible pavement construction. A library of dependable resilient modulus laboratory tests conducted at the Quebec Ministry of Transportation was used to construct an estimating model for typical Canadian granular materials typically used in pavement bases and subbases[14].

III. MATERIALS AND METHODOLOGY

- **Materials**

➢ Bituminous modified binder (Polymer Modified Bitumen – PMB) has been obtained from HINCOL, Chennai of Grade namely PMB – 40 & 70 grade bitumen.

➢ Aggregates are obtained from Bangalore where in the stone quarry situated in Bidadi for the analysis.

- **Methodology**:

➢ Evaluate the physical &engineering properties of modified binders as per IS standard tests.

➢ Conduction of Marshal Stability test for PMB 40 & PMB 70 grade to estimate the Optimum Bitumen Content (OBC) of grade-I aggregates.

➢ Conduction of Indirect tensile strength (ITS) &moisture susceptibility tests of grade –I aggregate specimens.

➢ Evaluation of fatigue test of specimens casted with grade – I aggregates with PMB – 40 & PMB – 70 grade as a modified binders.

EVALUATION PHYSICAL PROPERTIES OF POLYMER MODIFIED BITUMEN & AGGREGATES

Table – 1: Tests on Aggregates -

Si no	Name of the test / Characteristics	Value obtained	Permissible Limits *	Test Method
1	Aggregate Crushing test	24%	< 30%	IS – 2386-IV
2	Aggregate Impact test	16.9%	< 24%	IS – 2386-IV
3	Specific Gravity	2.56	2.5 to 3.2	IS – 2386-III
4	Water absorption	0.3%	< 2%	IS – 2386-III
5	Aggregate shape test	26%	< 35%	IS – 2386-I
6	Abrasion test	20%	< 30%	IS – 2386-IV

***As per MORTH specifications 5th Revision**

Table – 2: Tests on Modified Bitumen (PMB – 40 & 70 Grades) –

Elastomeric **T**hermoplastic **B**ased - **ETB**

Si no	Name of the test / Characteristics	PMB – 40 Grade	PMB – 70 Grade	Permissible Limits – (PMB 40 Grade)	Permissible Limits – (PMB 70 Grade)	Test Method
1	Penetration test	42	63	30 to 50	50 to 90	IS 1203 - 1978
2	Softening point	63 degrees	57 degrees	Min 60	Min 55	IS 1205 - 1978
3	Specific Gravity	1.09	1.05	> 0.99	> 0.99	IS 1202 - 1978
4	Ductility test	58 cms	67 cms	Min 50 cms	Min 60 cms	IS 1208 - 1978
5	Elastic recovery	80%	77%	> 75%	> 75%	IS 15462 – 2004
6	Loss in mass	0.5%	0.7%	Max 1%	Max 1%	1206 (part 2) – 9382

EXPERIMENTAL PROCEDURES OF POLYMER MODIFIED BITUMEN – 40 & 70 GRADES FOR OPTIMUM BITUMEN CONTENT (OBC) IN THE LABORATORY-

• MARSHAL MIX DESIGN-

The objective of the mix design is to produce a bituminous mix by proportionating various components so as to have:

1. Sufficient bitumen to ensure a durable pavement.
2. Sufficient strength to resist shear deformation under traffic at higher temperature.
3. Sufficient air voids in the compacted bitumen to allow for additional compaction by traffic.
4. Sufficient workability to permit easy placement without segregation.
5. Sufficient flexibility to avoid premature cracking due to repeated bending by traffic.
6. Sufficient flexibility at low temperature to prevent shrinkage cracks.

Determination of Optimum Bitumen Content-

Determine the optimum binder content for the mix design by taking average value of the following three bitumen contents found form the graphs obtained in the previous step.

1. Binder content corresponding to maximum stability
2. Binder content corresponding to maximum bulk specific gravity (Gm)
3. Binder content corresponding to the median of designed limits of percent air voids (Vv) in the total mix (i.e. 4%)

TABLE – 3 SPECIFICATIONS FOR BITUMINOUS CONCRETE AS PER MORTH SPECIFICATIONS 5th REVISION-

Grading	1	2
Nominal aggregate size	**19 mm**	**13.2 mm**
Layer thickness	**50 mm**	**30 – 40 mm**
IS sieve in mm	**Cumulative % by weight of total aggregate passing**	
19	**90 - 100**	**100**

13.2	**59 – 79**	**90 – 100**
9.5	**52 – 72**	**70 – 88**
4.75	**35 – 55**	**53 – 71**
2.36	**28 - 44**	**42 – 58**
1.18	**20 – 34**	**34 – 48**
0.6	**15 – 27**	**26 – 38**
0.3	**10 – 20**	**18 – 28**
0.15	**5 – 13**	**12 – 20**
0.075	**2 – 8**	**4- 10**
Bitumen content % by mass of total mix	**Min 5.4**	**Min 5.6**

TABLE – 4 – GRADATION BLEND OF AGGREGATES

Sieve Size mm	**Cumulative Percent by Weight of Total Aggregate Passing**				**Blend Proportions And Obtained Gradation**	**Gradation Requirement as per Table 500-18 of MORTH Specifications (Grading – 1)**
	19.0 mm Down Size	**13.2 mm Down Size**	**6.0 mm down size**	**Cement as filler**		
26.5	100.00	100.00	100.00	100.00	**100.00**	**100**
19	87.83	100.00	100.00	100.00	**95.98**	**90-100**
13.2	15.00	94.40	100.00	100.00	**71.28**	**59-79**
9.5	0.17	28.40	100.00	100.00	**58.46**	**52-72**
4.75	0.00	0.60	39.00	98.30	**44.06**	**35-55**
2.36	0.00	0.00	14.00	85.60	**34.91**	**28-44**
1.18	0.00	0.00	7.00	69.40	**27.56**	**20-34**
0.6	0.00	0.00	3.70	55.25	**21.62**	**15-27**
0.3	0.00	0.00	2.50	38.40	**15.02**	**10-20**
0.15	0.00	0.00	0.75	26.60	**10.24**	**5-13**
0.075	0.00	0.00	0.00	13.20	**5.02**	**2-8**

TABLE – 5- PROPORTION OF AGGREGATES FOR THE MIX

Sl. No.	Materials	Proportion	Remark
1	19.0 mm down size aggregates, %	**46**	% by Weight of aggregate Mix
2	13.2mm down size aggregates, %	**12**	
3	6 mm aggregate, %	**39**	
4	Cement as filler, %	**3**	

TABLE – 6 MIX DESIGN SPECIFICATIONS FOR BITUMINOUS CONCRETE BY MORTH 5th REVISION-

Minimum Marshal stability value in Kgs	1200
Marshal flow value in mm	2.5 to 4
Air voids in total mix, V_v in %	3 to 5
Voids filled with bitumen VFB in %	65 to 75

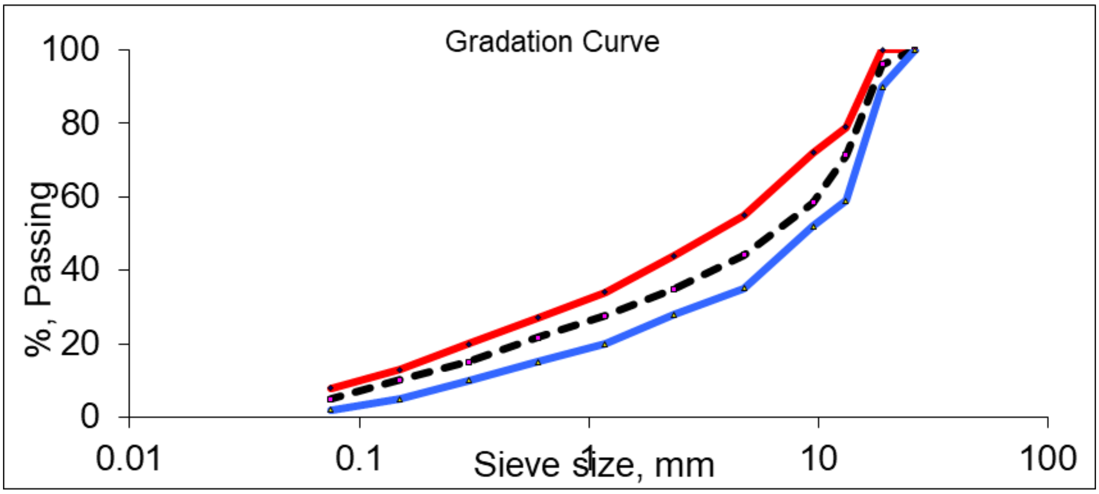

FIG 1 – OBTAINED GRADATION CURVE

TABLE – 7 GRADING REQUIREMENT OF MINERAL FILLER

Is sieve (mm)	Cumulative % passing by weight of total aggregate	% Passing of filler material
0.6	100	100
0.3	95-100	100
0.075	85-100	99.0

Marshal stability Formulaes for estimation of OBC-

1. Theoretical specific gravity for 4 % bitumen -

   $\mathbf{G_t} = [\{(W_1+W_2+W_3+W_b) / \{(W_1/G_1) +(W_2/G_2) +(W_3/G_3) +(W_b/G_b)\}]$

2. Bulk specific gravity, $\mathbf{G_m} = W_m / (W_m – W_w)$
3. Air voids percent $V_v = \{(G_t – G_m) /G_t\} * 100$

4. Percent volume of bitumen $V_b = [\{(W_b / G_b)\} / \{(W_1 + W_2 + W_3 + W_b) / G_m\}]$
5. Voids in mineral aggregate VMA

   $VMA = V_v + V_b$
6. Voids filled with bitumen VFB

   $VFB = (V_b * 100) / VMA$

TABLE – 8 STABILITY & FLOW ANALYSIS OF PMB - 40 GRADE & GRADE – 1 MIX -

Bitumen content in %	Stability in KN	Flow in mm units	V_V in %	VFB in %	VMA in %	G_m
4	7.3	2.2	4.86	66.1	12.4	2.365
4.5	8.2	2.5	4.32	67.2	13.3	2.372
5	10.3	2.7	4.11	68.5	14.4	2.389
5.6	13.7	3.1	3.76	70.1	15.9	2.411
6	11.5	3.3	3.44	71.4	16.3	2.387
6.5	9.5	3.5	3.11	72.4	17.1	2.356

Conclusion:

It has been found from the analysis that the Optimum Binder Content for Polymer Modified Bitumen – 40 Grade & Grade-I (19 mm nominal size) aggregates is 5.6% with the flow value of 3.1 mm where in the minimum Binder content specified by MORTH specifications 5th Revision is 5.4%.

1) **Optimum binder content:** The optimum bitumen content is computed as the average bitumen content selected corresponding to:

a) Maximum Marshall Stability.
b) Maximum Bulk Density.
c) 4% Air voids.

The Optimum bitumen content = (5.60+5.60+5.2)/3
= 5.50 %. (By weight of aggregates)
= 5.40%. (By weight of total Mix)

2) **Bulk Density:** *Bulk density* of the mix determined for the above aggregate proportion and at optimum binder content is found to be **2.411 gm/cc.**

TABLE – 9 TABULATION OF VALUES -

Sl. No.	Test Property	*Test results obtained by Marshall method	Requirements of Bituminous Concrete mix as per MoRTH –V revision & IRC-SP-53-2010
1	Optimum binder content, % (by weight of total mix).	**5.40**	Min 5.40
2	Bulk density G_m, gm/cc.	**2.406**	2.34 to 2.42 g/cc
3	Voids in Compacted Mix, %.	**3.86**	3.0 – 5.0
4	Marshall Stability (75 blows) (At 60°C), kgs.	**1350**	Min 1200

5	Marshall Flow at 60ºC, mm.	**2.86**	2.5 - 4.0
6	Percentage void filled with bitumen, %	**71.20**	65 - 75
7	Voids in Mineral Aggregates, %.	**14.90**	Min 13.00
8	Marshal Quotient, stability/ flow, kg/mm	**472**	250-500

TABLE – 10 STABILITY & FLOW ANALYSIS OF PMB 70 GRADE & GRADE – 1 MIX -

Bitumen content in %	**Stability in KN**	**Flow in mm units**	**V_V in %**	**VFB in %**	**VMA in %**	**G_m**
4	6.1	2.61	3.95	65.9	13.9	2.351
4.5	7.2	2.89	3.68	67.8	14.5	2.362
5	9.3	3.11	3.25	68.3	15.1	2.379
5.5	12.9	3.38	3.1	70.1	16.2	2.412
6	11.6	3.56	2.9	72.3	16.9	2.386
6.5	9.1	3.78	2.87	73.6	17.1	2.352

Conclusion:

It has been found from the analysis that the Optimum Binder Content for Polymer Modified Bitumen – 70 Grade & Grade-I (19 mm nominal size) aggregates is 5.5% with the flow value of 3.38 mm where in the minimum Binder content specified by MORTH specifications 5th Revision is 5.4%.

Optimum binder content: The optimum bitumen content is computed as the average bitumen content selected corresponding to:

a) Maximum Marshall Stability.

b) Maximum Bulk Density.

c) 4% Air voids.

The Optimum bitumen content = (5.5+5.5+4.0)/3

= **5.0 %.** (By weight of aggregates)

= **5.40%.** (By weight of total Mix)

3) **Bulk Density:** *Bulk density* of the mix determined for the above aggregate proportion and at optimum binder content is found to be **2.412 gm/cc.**

TABLE – 11-TABULATION OF VALUES -

Sl. No.	Test Property	*Test results obtained by Marshall method	Requirements of Bituminous Concrete mix as per MoRTH –V revision & IRC-SP-53-2010
1	Optimum binder content, % (by weight of total mix).	**5.40**	Min 5.40
2	Bulk density G_m, gm/cc.	**2.412**	2.34 to 2.42 g/cc
3	Voids in Compacted Mix, %.	**3.20**	3.0 – 5.0
4	Marshall Stability (75 blows) (At 60°C), kgs.	**1360**	Min 1200
5	Marshall Flow at 60°C, mm.	**3.32**	2.5 - 4.0
6	Percentage void filled with bitumen, %	**70.1**	65 – 75
7	Voids in Mineral Aggregates, %.	**15.60**	Min 13.00
8	Marshal Quotient, stability/ flow, kg/mm	**410**	250-500

Indirect Tensile Strength (ITS)

Test Procedure for Indirect Tensile Strength test

- The indirect tensile strength test is carried out as per ASTM D-4123-1995 to study the behaviour of paving mixes.

Load at failure is recorded and the indirect tensile strength is computed using the relation given below:

$\sigma_x = \{(2*P) / (\pi t D)\}$, MPA

Where: σ_x= Horizontal tensile stress/tensile strength, in MPa

P= Failure load, N

D= Diameter of the specimen, mm

t = Height of the specimen, mm

Table 12 Results of ITS test of various on PMB-40 Grade bitumen content on with Grade – I aggregates –

Unsoaked condition	
Bitumen content in %	**ITS, N/mm²**
4.0	1.63
4.5	1.68
5.0	1.73
5.4 (OBC)	1.79
6.0	1.68

Table 13 Results of ITS test of various Bitumen content PMB 70 Grade With Grade – I aggregates –

Unsoaked condition	
Bitumen content in %	**ITS, N/mm²**
4.0	1.58
4.5	1.65
5.0	1.69
5.4 (OBC)	1.73
6.0	1.61

Table 14

Results of ITS test of various bitumen content on PMB- 40 Grade with Grade – I aggregates at varied temperatures –

Soaked condition -						
Temperature in °C	**10°C**	**20°C**	**30°C**	**40°C**	**50°C**	**60°C**
Bitumen content in %	**4.0**	**4.5**	**5.0**	**5.4**	**6.0**	**5.4 (OBC value)**
ITS, N/mm^2	1.525	1.533	1.542	1.556	1.405	1.520

Table 15 Results of ITS test of various bitumen content on PMB- 70 Grade with Grade – I aggregates at varied temperatures –

Soaked condition -						
Temperature in °C	**10°C**	**20°C**	**30°C**	**40°C**	**50°C**	**60°C**
Bitumen content in %	**4.0**	**4.5**	**5.0**	**5.4**	**6.0**	**5.4 (OBC value)**
ITS, N/mm^2	1.441	1.475	1.474	1.482	1.438	1.455

Test Procedure for conducting Tensile Strength Ratio (TSR)

The indirect tensile strength ratio (TSR) can be determined using the following relation

$$TSR = \frac{Sn}{St}$$

Where, TSR: Indirect Tensile Strength Ratio

S_t: Average Indirect tensile strength of Group-1 (Unsoaked) specimens

S_n: Average Indirect tensile strength of Group-2 (Soaked) specimens

Table 16 Results of TSR value at varied test temperatures for Grade-I aggregates-

Test Temperature, ^{0}C	**TSR, %**	
	PMB-40 grade	**PMB-70 grade**
10°C	93.61	91.26
20°C	91.29	89.43
30°C	89.17	87.22
40°C	86.97	85.68
50°C	83.69	83.13
60°C (OBC value)	84.96	84.12

Fatigue Test

Test procedure for conducting Fatigue test

The data provided by the software in an excel format was analysed to determine Resilient Modulus, Tensile stress, and Initial Tensile Strain for all the specimens tested using the following equations.

1. Tensile stress, $\sigma_x = \frac{2 \times P}{(\pi \times d \times t)} Mpa$

Where,

P = applied repeated load in Newton.

d = diameter of the specimen in mm.

t = thickness of the specimen in mm.

2. Resilient Modulus, MR $= \dfrac{P(0.27+\mu)}{(HR \times t)} Mpa$

Where,

HR = Resilient Horizontal Deformation

μ = Resilient Poisson's Ratio (@ 25^0C μ = 0.35 as per TRL)

3. Initial tensile strain, $\varepsilon = \dfrac{\sigma_x (1+3\mu)}{MR}$

Table 17 Results of Indirect Tensile Fatigue Test with 25^0C temperature at 10%, 20%, 30%, and 40% stress level using PMB-40 grade with Grade-I aggregates

Specimen Name	Stress Level, %	Load, N	Height of specimen, mm	Tensile Stress, MPa	Resilient Horizontal Deformation, mm	Resilient Modulus, MPa	Initial Tensile strain, Micro strain	Fatigue Life, No. of cycles
PMB-40-1	10	1400	65.3	0.0963	0.0120	2219.21	240.656	15044
PMB-40-2	10	1400	66.3	0.0951	0.0125	2230.51	243.085	15042
PMB-40-3	10	1400	65.6	0.0969	0.0123	2229.11	245.514	15545
PMB-40-4	20	2800	66.3	0.1912	0.0133	1777.33	311.678	13783
PMB-40-5	20	2800	66.3	0.1901	0.0135	1778.66	313.823	13119
PMB-40-6	20	2800	66.6	0.1948	0.0134	1762.15	319.016	13765
PMB-40-7	30	4200	65.3	0.2983	0.0161	1317.72	332.802	11543
PMB-40-8	30	4200	65.6	0.2938	0.0165	1397.39	337.661	11411
PMB-40-9	30	4200	65.3	0.2954	0.0163	1363.03	333.517	11435
PMB-40-10	40	5600	66.3	0.4423	0.0182	990.86	366.812	9356
PMB-40-11	40	5600	66.6	0.4432	0.0181	999.33	362.986	9116
PMB-40-12	40	5600	66.2	0.4489	0.0186	959.33	361.248	9215

Table 18 Results of Indirect Tensile Fatigue Test with 25^0C temperature at 10%, 20%, 30%, and 40% stress level using PMB-70 grade with Grade-I aggregates

Specimen Name	Stress Level, %	Load, N	Height of specimen, mm	Tensile Stress, MPa	Resilient Horizontal Deformation, mm	Resilient Modulus, MPa	Initial Tensile strain, Micro strain	Fatigue Life, No. of cycles
PMB-70-1	10	1350	65.3	0.0899	0.0151	2012.99	211.354	14765
PMB-70-2	10	1350	65.3	0.0884	0.0159	2017.88	214.384	14168
PMB-70-3	10	1350	63.5	0.0881	0.0154	2011.02	219.646	14987
PMB-70-4	20	2700	66.6	0.1529	0.0185	1963.12	246.037	12324
PMB-70-5	20	2700	66.3	0.1578	0.0184	1896.32	247.434	12765

PMB-70-6	20	2700	63.5	0.1523	0.0189	1887.42	243.814	12210
PMB-70-7	30	4050	66.6	0.2313	0.0196	1682.32	297.325	11222
PMB-70-8	30	4050	66.3	0.2378	0.0199	1687.21	294.187	11123
PMB-70-9	30	4050	65.3	0.2393	0.0193	1637.99	296.332	11976
PMB-70-10	40	5400	65.3	0.3285	0.0217	885.729	316.587	9454
PMB-70-11	40	5400	63.5	0.3222	0.0212	882.126	314.756	9687
PMB-70-12	40	5400	66.6	0.3225	0.0219	880.355	317.819	9823

IV. RESULTS AND DISCUSSION

Results of ITS Test-

Un Soaked Condition-

1. The ITS value for PMB- 40 grade & PMB- 70 grade bituminous concrete mix are prepared using Cement as filler of 2% are tested at 25°C for both grade-I aggregates.

2. ITS of bituminous concrete mix prepared using PMB-40 grade as binder with cement as filler material by 2% at 25^0C with grade – I with varied bitumen content are 1.63, 1.68, 1.73, 1.79, 1.68 N/mm^2 respectively.
3. ITS of bituminous concrete mix prepared using PMB-70 grade as binder with cement as filler material by 2% at 25^0C with grade – I with varied bitumen content are 1.58, 1.65, 1.69, 1.73, 1.61 N/mm^2 respectively.

Soaked Condition-

1. ITS of bituminous concrete mix prepared using PMB-40 grade as binder with cement as filler material by 2% at 25^0C with grade – I with varied bitumen content are 1.525, 1.533, 1.542, 1.556, 1.405, 1.520 N/mm^2 respectively.
2. ITS of bituminous concrete mix prepared using PMB-70 grade as binder with cement as filler material by 2% at 25^0C with grade – I with varied bitumen content are 1.441, 1.475, 1.474, 1.482, 1.438, 1.455 N/mm^2 respectively.

Results of TSR

1. TSR values of bituminous concrete mix prepared using PMB-40 grade as binder with cement as filler material by 2% for Grade-I aggregates for 10°C, 20°C, 30°C, 40°C, 50°C & 60°C is found to be 93.61%, 91.29%, 89.17%, 86.97%, 83.69%, 84.96% respectively.
2. TSR values of bituminous concrete mix prepared using PMB-70 grade as binder with cement as filler material by 2% for Grade-I aggregates for 10°C, 20°C, 30°C, 40°C, 50°C & 60°C is found to be 91.26%, 89.43%, 87.22%, 85.68%, 83.13%, 84.12% respectively.

Results of Fatigue test

1. The Resilient Modulus of PMB-40 grade with Grade-I aggregates are in the range of 2219.21 to 959.33N/mm^2.

2. The Resilient Modulus of PMB-70 grade with Grade-I aggregates are in the range of 2012.99 to 880.355 N/mm^2.

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