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

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Abstract

In order to determine the ideal binder content (OBC) for Grade-II aggregates with nominal sizes of 13.2 mm, this 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%. OBC was utilised as the bitumen component, and stress levels were increased from 10% to 40%, in order to cast the specimens for indirect tensile strength (ITS) with moisture susceptibility.

When evaluated for ITS and fatigue values, specimens constructed of PMB-40 grade with grade-II aggregates differ progressively from those made of PMB-70 grade with grade-II aggregates in terms of their engineering features.

I. INTRODUCTION

Resilient modulus

The resilient modulus, or MR, which typically measures a material's capacity to recover from external stress or disturbance, is a crucial design factor for flexible pavements. Applied deviator stress to recoverable or resilient strain is the basic definition of it.

This feature of the material genuinely serves to determine its modulus of elasticity, or E, even though 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. One can predict the structural behaviour of the pavement under traffic loading by understanding the robust modulus of the pavement substance. Finding MR is a very challenging task, as demonstrated by testing the bituminous pavement materials in a lab and on the ground. More so than the effects of traffic, temperature had an impact on the pavement. This is an extremely significant discovery that might significantly alter how things are made. For many various forms of pavement, a link between single-axle and tandem-axle loads has been established. Both of these types of loads are used to evaluate deflections. Deflections can occasionally be inversely related to load. The development of a resiliometer to evaluate the resilience of flexible pavements and the design of a fatigue testing device to determine the relative flexibility of pavements are two laboratory techniques that are discussed.

When stress conditions do not completely destroy a pavement system, the resilient modulus is utilised to define the pavement materials. Pavements can be made to handle specific wheel loads over the duration of their intended lifespan by altering layer thickness, employing the appropriate materials, and increasing the stiffness of the bituminous material. With an increase in confining pressure and slight increases in axial stress, the impact of aggregate density, aggregate gradation, and degree of saturation on the resilient modulus is substantially amplified. When confining pressure decreases and repetitive stresses rise, Poisson's ratio also rises.

Aggregates:

The robust modulus of asphalt mixes is influenced by the coarse aggregate morphology, which is dictated by angularity and surface texture features. Although the relationship between the coarse aggregate morphology and the resilient modulus was not significantly impacted by changes in aggregate gradation, 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. Up until a certain size, aggregates respond linearly elastically, generating valuable robust characteristics. Despite the average laboratory-determined maximum dry density being a little bit higher than the average field-measured in situ dry density, the laboratory optimum moisture content was equivalent to the field-measured in situ moisture content.

Modified binders:

Improved resistance to rutting at high temperatures and increased resistance to cracking at intermediate and low temperatures are two advantages of modified binders. Modified asphalt binders have been utilised in intersections with stop-and-go traffic, high volume truck routes, and high volume interstates because they are more workable than neat bitumen or binder in high stress applications. In tough settings, such as desert regions and places with extremely low temperatures like -34 degrees and -40 degrees, modifiers have also been used to reduce bitumen ageing. When utilised properly and in the right locations, modified bitumen can be a very cost-effective solution to reduce climatically related pavement distresses and failures. Asphalt mix is a composite material made of asphalt binder, stone aggregates, and air voids; it is often referred to as "binder mix" since it is believed that the combination of the asphalt binder, small stone pebbles, and air holes will function as a single unit. The aggregates make up around 85% of the mix's total volume, the asphalt binder makes up 10%, and the remaining 5% is made up of air spaces.

Analysis of elastic modulus characteristics:

Resilient modulus is used to describe the pavement materials under various loading circumstances without causing the pavement system to fail. However, by modifying layer thickness & stiffness, pavement systems can be built to resist design axle load applications throughout the entirety of their design life. A variety of design axle magnitudes and associated load applications are accommodated by pavement construction. Asphalts are very similar to many polymers in this aspect since the thermoplastic characteristic of the asphalt binder strongly determines the resilience modulus of asphaltic mixes.

The mixture is overly stiff and may cause fatigue and/or thermal cracking if the modulus is higher than the upper limit of this band. Additionally, the mixture is too soft and possibly prone to deformation because the robust modulus versus temperature relationship maps below the lowest limit. Resilient modulus at low temperatures has been discovered to be somewhat correlated with cracking because stiffer mixtures at low temperatures (higher MR) have a tendency to crack early than more flexible mixtures (lower MR).

II. LITERATURE REVIEW

- **D.N. Little and E. Tal** Due to the development of several approaches for determining the modulus of asphalt concrete in this study, the Department is now able to conduct this test in support of both design activities and the validation of non-destructive field testing. A production testing method was investigated along with procedures focusing on mechanistic design methodologies and techniques that are easily adaptable to new research discoveries. Due to the development of two test sets, the uniaxial compression test with sinusoidal loading may be applied to a wide range of materials and stresses(1).
- **Amir Modarres and E. Tal** One of the stress-strain measurements used to assess the elastic properties of these mixes is the robust modulus, which is calculated using the ASTM D4123-04 method. The bulk of pavement materials, which are frequently known to be non-elastic, permanently deform under pressure. However, the deformation caused by each repetition of the load is almost entirely recoverable, proportionate to the load, and can be classified as elastic as long as the load is modest in comparison to the material's strength and is applied repeatedly over a significant number of times.

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

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 0.5 sec loading and 0.5 sec 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** The resilience characteristics of the areas where thick and semi-dense asphalt concrete experimental studies have been conducted have been studied by obtaining core samples from the pavements. In the suggested method for estimating MR, these cores were thoroughly characterised. The wearing and binder courses of the pavements at these airports had their cores removed. According to ASTM D6927, these cores were tested for flow value, Marshall Stability, and density-void analysis [14]. The outcomes are shown.

Marshall Stability values were determined to be 765 kg and 725 kg, respectively, for the DAC and SDAC specimens at 60 °C. When compared to DAC samples, it was discovered that the flow value of the SDAC specimens was a little greater. The DAC and SDAC specimens were found to have bulk densities of 2.36 and 2.33 g/cc, respectively[(3)].

- **Kalhan Mitra Etal** The indirect tensile test setup involves applying the load at a constant rate of deformation to the samples of the binder mix. The suggested numerical model of the binder mix is calibrated using the experimental data of the binder mix. The numerical model of the asphalt mixture uses the attributes of the aggregate and binder blend as input. At a predefined deformation date, the asphalt blend sample is also put through the indirect tensile test setup. Typically, "5% asphalt mix" refers to an asphalt mixture that contains 5% (by weight) or less asphalt binder than the total weight of the combination. On an Instron device, samples of asphalt and binder mix are placed through an indirect tension test. The measured force-versus-time curves are seen to vary significantly from sample to sample for all binder contents between 5.5% and 6.5% [(4)].
- **H. Di Benedetto E. tal** • These qualities can only be added when the behaviour of the material can be seen as linear. An assessment of the bituminous mixtures' linear viscoelastic domain taking into account the relationship between the base-10 logarithm of the tension's amplitude and the number of cycles applied. conclusions regarding test facilities, specimen preparation, testing, and stiffness calibration methodologies The results of inter-laboratory tests performed by 15 laboratories were utilised to design tests of bituminous mixes under cyclic (and not dynamic, as mentioned further) loading in order to increase the repeatability and reproducibility of this type of testing [(5)].
- **David H. Timm** explains the different pavement layers' composition and material properties. The results of laboratory tests on the triaxial resilient and dynamic moduli are discussed. Models were created to explain relationships between pertinent pavement measurements and mechanistic material properties after statistical analysis of the data from the laboratory and field. Air voids, binder quality, gradation, and asphalt content were found to be insignificant after analysis, and the HMA layer showed the greatest effects of cracking on moduli[(6)]**.**
- **Ramprasad, D.S., and E. Tal** The performance criteria specified in India's specifications for bituminous binders are based on a number of empirical studies that hardly seem to matter. The bituminous binders that are frequently used in India are discussed in this article in terms of their physical and rheological characteristics as well as their performance characteristics at high and moderate field temperatures. The effects of temperature variations, loading rates, and loading volumes are taken into account, along with other elements that influence how bituminous binders behave. It is well known what the properties of both their unaltered and changed forms of the widely used grades of (60-70) bitumen are. The bituminous concrete (BC) grading-2 specimens produced at the optimum binder content (OBC) are evaluated for the Marshall properties and the indirect tensile strength ratio [(7)].
- **Moe Aung Lwin E. Tal** A number of empirical studies with almost any significance serve as the foundation for the performance parameters specified in India's specifications for bituminous binders. In terms of their capabilities at both high and low field temperatures, this article explains the physical and rheological characteristics of bituminous binders, which are commonly used in India. The effects of temperature variations, loading volumes, loading rates, and other parameters are taken into account when analysing how bituminous binders behave. There is plenty of information available about the properties of regularly used grades of (60–70) bitumen, both in its original and modified forms. For the specimens made at the optimum binder content (OBC) for bituminous concrete (BC) grading-2, the Marshall properties and the indirect tensile strength ratio are examined [(8)].
- **Nabiin Rana Magar** The number, sort, size, source, and composition of the crumb rubber, as well as the duration, temperature, and method of mixing, have an effect on CRMB's rheology. (Using a dry or a wet approach). Examining the experimental results of bitumen modified with 15% by weight of various-sized crumb rubber is the goal of the current study. Coarse (1 mm - 600 m), medium (600 - 300 m), fine (300 - 150 m), and superfine (150 - 75 m) types of crumb rubber will be employed. Using different sizes of crumb rubber, standard laboratory tests will be run on the modified bitumen, and the results will be examined. For mix design, the Marshall Stability approach is used [(9)].
- **Ambika Kuity and E. Tal** CRMB's rheology is influenced by both internal and external elements, including the amount, sort, size, source, and composition of the crumb rubber as well as the duration, temperature, and method of mixing. (either a wet or dry approach). The goal of the current study is to review experimental results of bitumen modified with 15% by weight of different-sized crumb rubber. Crumb rubber will be utilised in four different sizes: coarse (1 mm - 600 m), medium (600 - 300 m), fine (300 - 150 m), and superfine (150 - 75 m). The modified bitumen will be subjected to typical laboratory tests using different sizes

of crumb rubber, and the outcomes will be examined. Mix design is done using the Marshall Stability approach [10].

- **Georges A.J. Mturi and E. Tal** the aggregates, asphalt binder, and filler used in this study were all locally supplied. In the present investigation, bituminous concrete (BC), which is made in compliance with Indian specifications, was used as the asphalt mixture. The BC samples are processed using mid-point grading. This study provides a thorough analysis of the performance of five distinct fillers used in asphalt mix: brick dust, fly ash, lime dust, recycled concrete waste aggregates dust, and typical stone dust[11].
- A**. Bashar Tarawneh** laboratory experiments using repeated load triaxial (RTL) should be used to estimate the MR. However, this test necessitates high-end lab hardware and skilled workers. Furthermore, it is anticipated to take some time. As a result, correlations between various in-situ test results and material index features are used to determine MR. The precision of the prediction model determines how exactly the robust modulus is computed. Additionally, the use of ANN-based models considerably improved Mr. Prediction's accuracy [12].
- **Jorge B. Sousa, Etal** Asphalt pavements lose a significant amount of their effectiveness due to permanent deformation (rutting). Rust diminishes the pavement's useful service life and poses a major risk to other road users by changing how cars handle. Because the methods currently used for testing and assessing asphalt-aggregate mixes are empirical and do not provide a reliable predictor of in-service performance, highway materials experts have struggled to produce rutting resistant materials. While mixture densification (volume change) also contributes to rusting, recurring shear deformations under traffic stress are the primary culprit. The volume of traffic, the temperature, the size and pressure of the tyre loads, as well as different mixing qualities, are some of the variables that affect the amount of rutting [13].
- **Jean-Pascal Bilodeau, et al** Despite being costly and time-consuming to test for, the robust modulus is frequently estimated from unreliable, indirect tests or assumed using predetermined values. The resilient modulus is a crucial element in the development of flexible pavement. An estimation model for typical Canadian granular materials commonly used in pavement bases and subbases was built using a library of reliable resilient modulus laboratory experiments performed at the Quebec Ministry of Transportation[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-II aggregates.
  - Conduction of Indirect tensile strength (ITS) &moisture susceptibility tests of grade –II aggregate specimens.
  - Evaluation of fatigue test of specimens casted with grade – II aggregates with PMB – 40 & PMB – 70 grade as a modified binders.

EVALUATION OF 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 Thermoplastic Based - 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-**

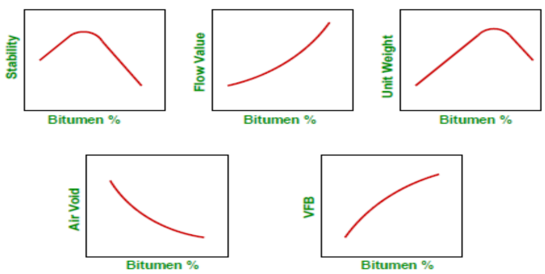
The objective of the mix design is to produce a bituminous mix by proportionating various components so as to have:

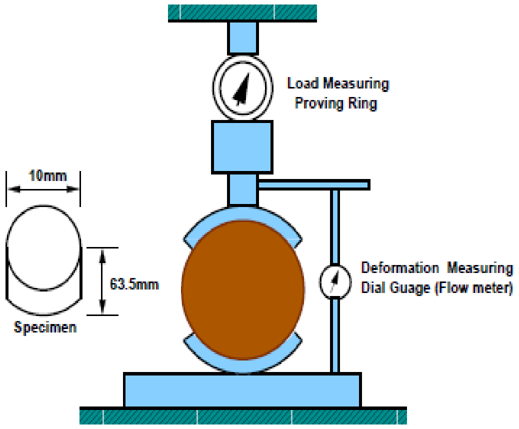
1. Sufficient bitumen to ensure a durable pavement.
2. Sufficient strength to resist shear deformation under traffic at higher temperature.
3. Sufficient air voids in the compacted bitumen to allow for additional compaction by traffic.
4. Sufficient workability to permit easy placement without segregation.
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%)





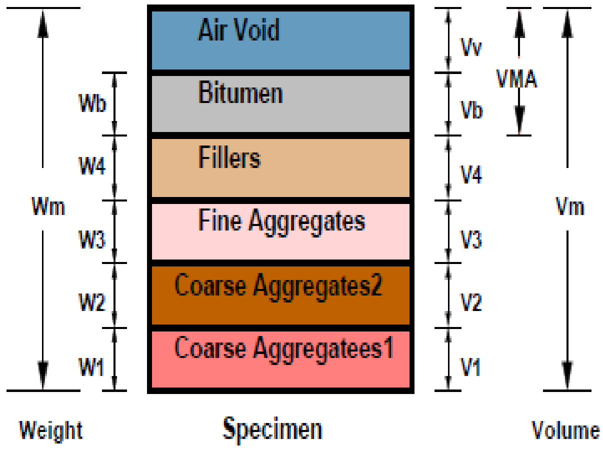


TABLE – 3 SPECIFICATIONS FOR BITUMINOUS CONCRETE AS PER MORTH SPECIFICATIONS 5th REVISION-

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

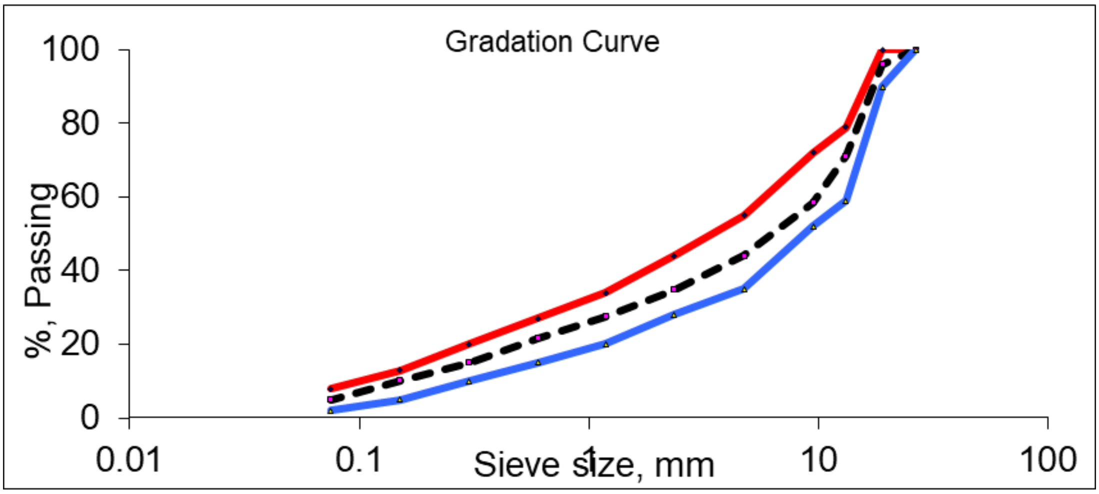


FIG 1 – OBTAINED GRADATION CURVE

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 -
   $G_t = [\{(W_1+W_2+W_3+W_b) / \{(W_1/G_1) +(W_2/G_2) +(W_3/G_3) +(W_b/G_b)\}]$
2. Bulk specific gravity, $G_m = W_m / (W_m – W_w)$
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 – II MIX -

Bitumen content in %	Stability in KN	Flow in mm units	V_V in %	VFB in %	VMA in %	G_m
4	8.1	2.6	4.66	67.3	13.4	2.375
4.5	8.9	2.8	4.23	67.8	13.8	2.381
5	10.3	3.1	3.92	69.3	14.2	2.386
5.7	14.6	3.4	3.56	70.3	15.9	2.411
6	12.5	3.6	3.41	71.5	16.6	2.365
6.5	10.5	3.8	3.33	72.6	17.3	2.344

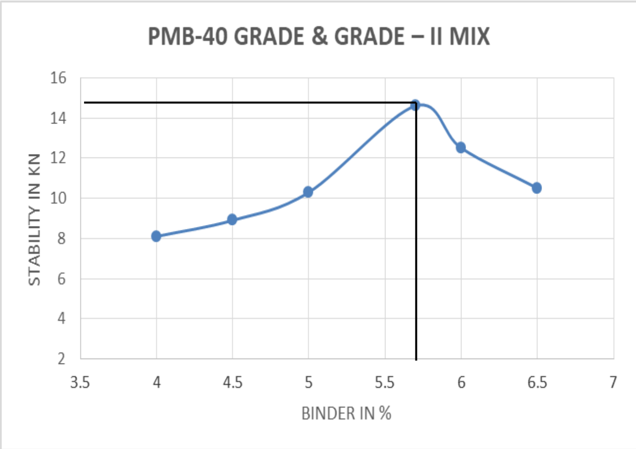


FIG – 2 PMB 40 GRADE Vs STABILITY ANALYSIS

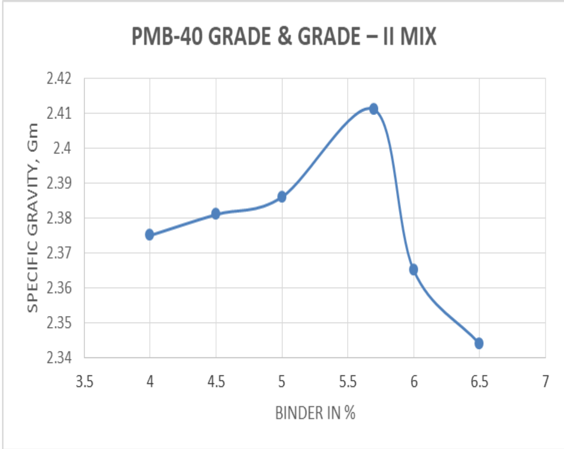


FIG – 3 PMB 40 GRADE Vs SPECIFIC GRAVITY G_M

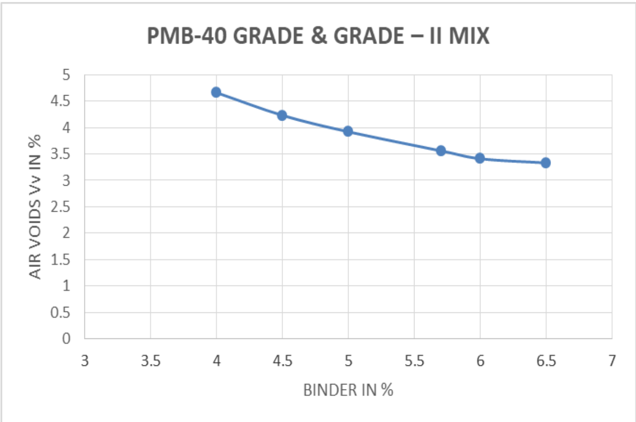


FIG – 4 PMB 40 GRADE Vs PERCENTAGE OF VOIDS

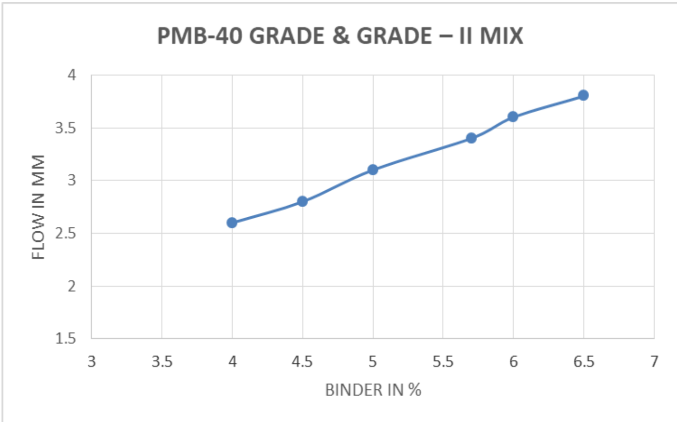


FIG – 5 PMB 40GRADE Vs FLOW VALUE

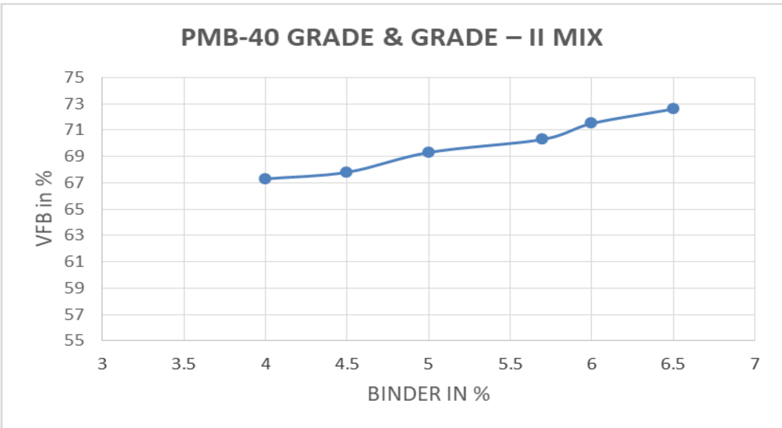


FIG – 6 PMB 40 GRADE Vs VOIDS FILLED BY BITUMEN

Conclusion:

It has been found from the analysis that the Optimum Binder Content for Polymer Modified Bitumen – 40 Grade & Grade-II (13.2 mm nominal size) aggregates is 5.7% with the flow value of 3.4 mm where in the minimum Binder content specified by MORTH specifications 5th Revision is 5.6%.

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 = (5.70+5.70+4.8)/3

= **5.50 %.** (By weight of aggregates)

= **5.60%.** (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).	**5.60**	Min 5.60
2	Bulk density G_m, gm/cc.	**2.408**	2.34 to 2.42 g/cc
3	Voids in Compacted Mix, %.	**4.01**	3.0 – 5.0
4	Marshall Stability (75 blows) (At 60°C), kgs.	**1450**	Min 1200
5	Marshall Flow at 60°C, mm.	**3.57**	2.5 - 4.0
6	Percentage void filled with bitumen, %	**71.10**	65 - 75
7	Voids in Mineral Aggregates, %.	**15.70**	Min 13.00
8	Marshal Quotient, stability/ flow, kg/mm	**406**	250-500

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

Bitumen content in %	Stability in KN	Flow in mm units	V_V in %	VFB in %	VMA in %	G_m
4	6.3	2.71	4.16	66.3	14.1	2.353
4.5	7.8	2.93	3.87	67.2	14.7	2.367
5	9.3	3.17	3.61	67.9	15.2	2.392
5.6	12.9	3.45	3.43	68.7	16.1	2.41
6	11.2	3.59	3.21	69.2	16.9	2.397
6.5	8.8	3.77	3.14	70.2	17.4	2.381

Conclusion:

It has been found from the analysis that the Optimum Binder Content for Polymer Modified Bitumen – 70 Grade & Grade-II (13.2 mm nominal size) aggregates is 5.6% with the flow value of 3.45 mm where in the minimum Binder content specified by MORTH specifications 5th Revision is 5.6%.

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 = (5.6+5.6+4.2)/3

= **5.20 %.** (By weight of aggregates)

= **5.60%.** (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 **2.410 gm/cc.**

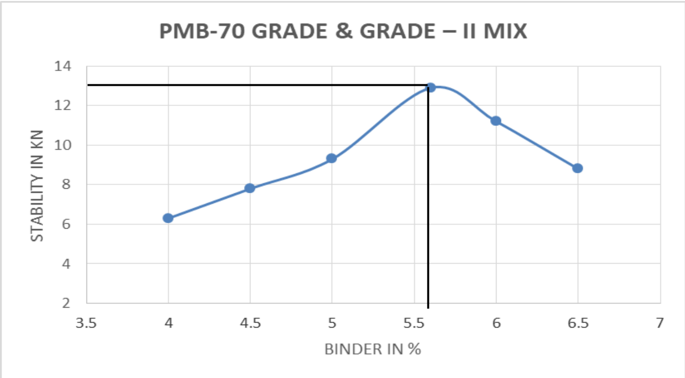


FIG – 7 PMB 70 GRADE Vs STABILITY ANALYSIS

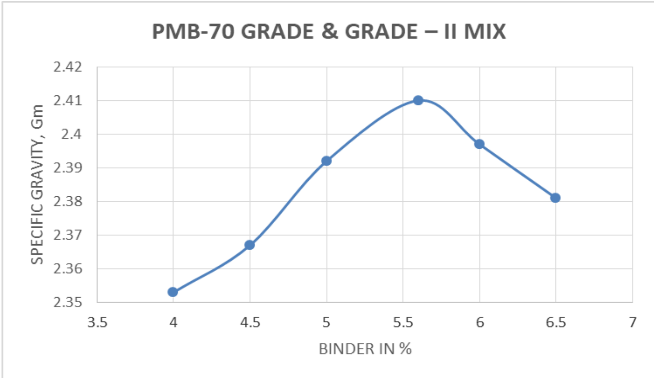


FIG – 8 PMB 70 GRADE Vs SPECIFIC GRAVITY G_M

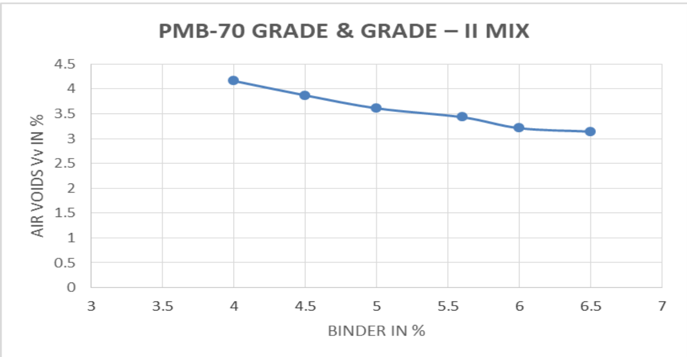


FIG – 9 PMB 70 GRADE Vs PERCENTAGE OF VOIDS

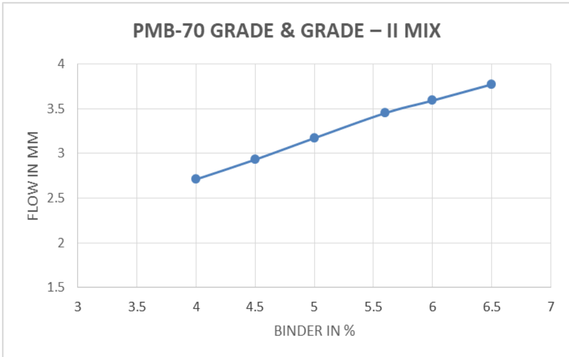


FIG – 10 PMB 70 GRADE Vs FLOW VALUE

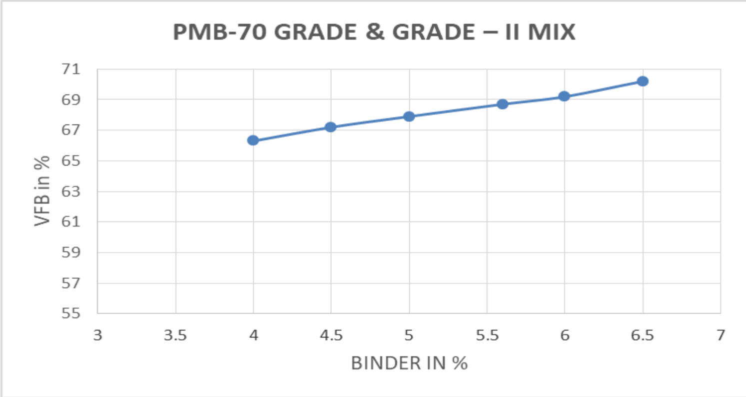


FIG – 11 PMB 70 GRADE Vs VOIDS FILLED BY BITUMEN

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).	**5.60**	Min 5.60
2	Bulk density G_m, gm/cc.	**2.410**	2.34 to 2.42 g/cc
3	Voids in Compacted Mix, %.	**3.43**	3.0 – 5.0
4	Marshall Stability (75 blows) (At 60°C), kgs.	**1290**	Min 1200
5	Marshall Flow at 60°C, mm.	**3.45**	2.5 - 4.0
6	Percentage void filled with bitumen, %	**68.7**	65 – 75
7	Voids in Mineral Aggregates, %.	**16.10**	Min 13.00
8	Marshal Quotient, stability/ flow, kg/mm	**374**	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:

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

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 Bitumen content on PMB-40 Grade With Grade – II aggregates –

Table 13 Results of ITS test of various bitumen content on PMB- 70 Grade with Grade – II aggregates –

Unsoaked condition	
Bitumen content in %	ITS, N/mm^2
4	1.58
4.5	1.62
5	1.66
5.6 (OBC)	1.68
6	1.53

Unsoaked condition	
Bitumen content in %	ITS, N/mm^2
4.0	1.53
4.5	1.58
5.0	1.62
5.6 (OBC)	1.65
6.0	1.49

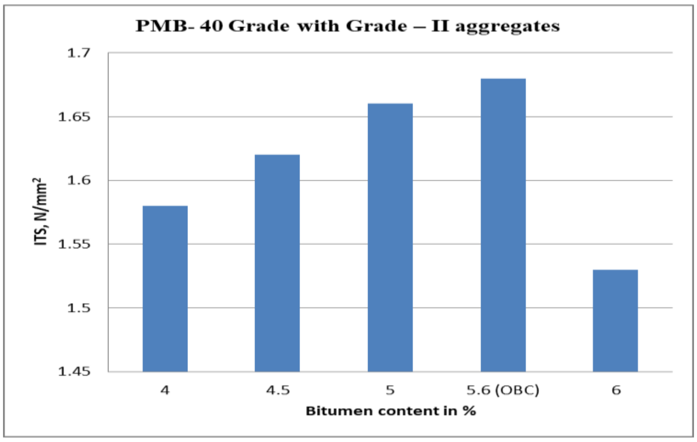


Fig 12 Variation in ITS value with different bitumen content of PMB-40 & Grade-II aggregates at 25°C

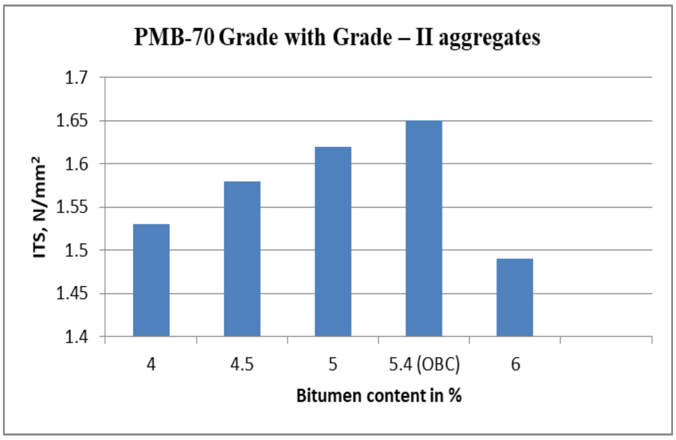


Fig 13 Variation in ITS value with different bitumen content of PMB-70 & Grade-II aggregates at 25°C

Table 14 Results of ITS test of various bitumen content on PMB- 40 Grade with Grade – II 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	5.6	6.0	5.6 (OBC value)
ITS, N/mm^2	1.441	1.444	1.465	1.466	1.257	1.398

Table 15 Results of ITS test of various bitumen content on PMB- 70 Grade with Grade – II 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	5.6	6.0	5.6 (OBC value)
ITS, N/mm^2	1.385	1.394	1.395	1.407	1.220	1.381

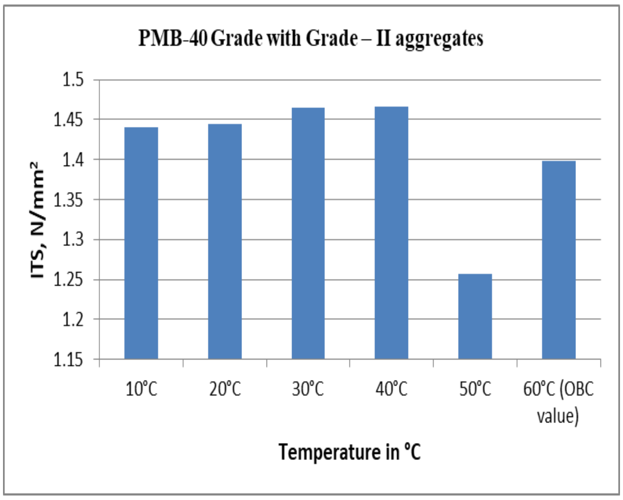


Fig 14 Variation in ITS value with different temperatures of Grade-II aggregates (soaked condition)

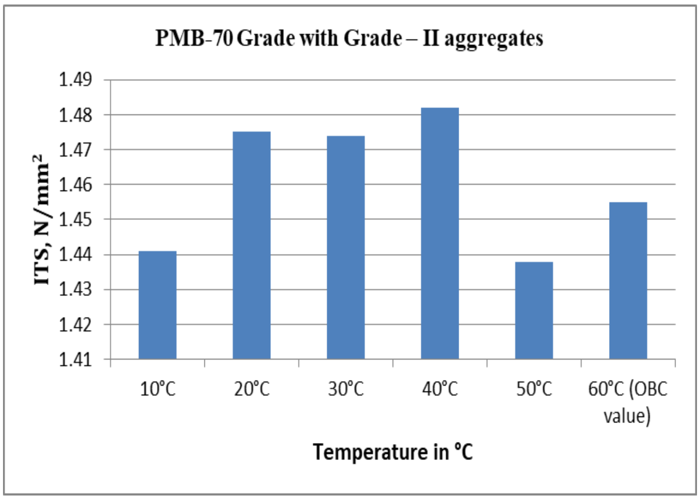


Fig 15 Variation in ITS value with different temperatures of Grade-II aggregates (soaked condition)

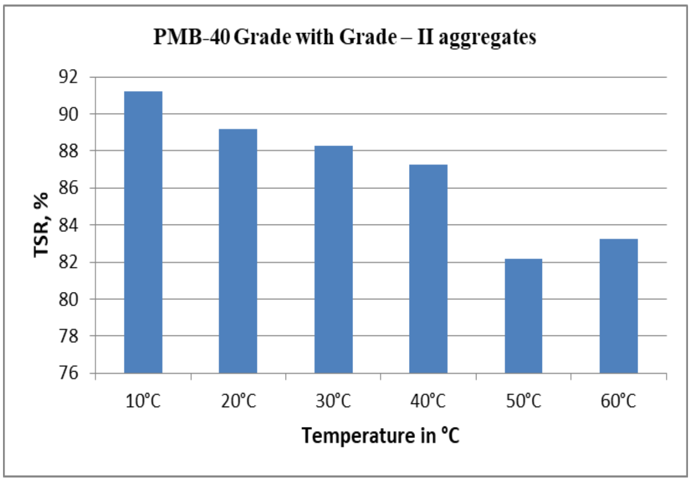


Fig 16 Variation in TSR value with different Test temperatures of PMB-40 grade with Grade-II aggregates

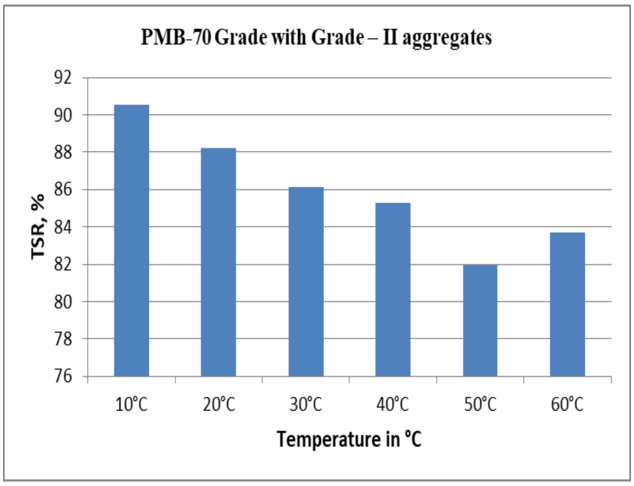


Fig 17 Variation in TSR value with different Test temperatures of PMB-70 grade with Grade-II aggregates

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-II aggregates-

Test Temperature, ^{0}C	TSR, %	
	PMB-40 grade	PMB-70 grade
10°C	91.21	90.56

20°C	89.19	88.23
30°C	88.27	86.12
40°C	87.27	85.28
50°C	82.19	81.93
60°C (OBC value)	83.26	83.72

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 $= \frac{P(0.27 + \mu)}{(HR \times t)} Mpa$

Where,

HR = Resilient Horizontal Deformation

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

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

Table 17 Results of Indirect Tensile Fatigue Test with 25^{0}C temperature at 10%, 20%, 30%, and 40% stress level using PMB-40 grade with Grade-II 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	1620	65.3	0.1063	0.0220	2519.21	230.656	16044
PMB-40-2	10	1620	66.3	0.1151	0.0225	2530.51	233.085	16042
PMB-40-3	10	1620	65.6	0.1069	0.0223	2529.11	235.514	16545
PMB-40-4	20	3240	66.3	0.2112	0.0253	1977.33	291.678	14783
PMB-40-5	20	3240	66.3	0.2001	0.0245	1978.66	293.823	14119
PMB-40-6	20	3240	66.6	0.2148	0.0254	1962.15	299.016	14765

PMB-40-7	30	4860	65.3	0.2933	0.0271	1617.72	312.802	13543
PMB-40-8	30	4860	65.6	0.2958	0.0275	1697.39	317.661	13411
PMB-40-9	30	4860	65.3	0.2974	0.0263	1663.03	313.517	13435
PMB-40-10	40	6480	66.3	0.4623	0.0282	1090.86	346.812	10356
PMB-40-11	40	6480	66.6	0.4632	0.0281	1099.33	342.986	10116
PMB-40-12	40	6480	66.2	0.4689	0.0286	1059.33	341.248	10215

Table 18 Results of Indirect Tensile Fatigue Test with 25^{0}C temperature at 10%, 20%, 30%, and 40% stress level using PMB-70 grade with Grade-II 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	1250	65.3	0.0799	0.0141	2212.99	201.354	13765
PMB-70-2	10	1250	65.3	0.0784	0.0149	2217.88	204.384	13168
PMB-70-3	10	1250	63.5	0.0781	0.0144	2211.02	209.646	13987
PMB-70-4	20	2500	66.6	0.1329	0.0175	1863.12	236.037	12124
PMB-70-5	20	2500	66.3	0.1378	0.0174	1896.32	237.434	12165
PMB-70-6	20	2500	63.5	0.1323	0.0179	1787.42	233.814	12110
PMB-70-7	30	3750	66.6	0.2213	0.0216	1482.32	287.325	10222
PMB-70-8	30	3750	66.3	0.2278	0.0219	1487.21	284.187	10123
PMB-70-9	30	3750	65.3	0.2293	0.0213	1437.99	286.332	10976
PMB-70-10	40	5000	65.3	0.2285	0.0237	1005.72	311.587	9754
PMB-70-11	40	5000	63.5	0.3222	0.0232	1002.12	311.756	9787
PMB-70-12	40	5000	66.6	0.3225	0.0239	1000.35	311.819	9523

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-II aggregates.

2. ITS of bituminous concrete mix prepared using PMB-40 grade as binder with cement as filler material by 2% at 25^{0}C with grade – II with varied bitumen content are 1.58, 1.62, 1.66, 1.68, 1.53 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^{0}C with grade – II with varied bitumen content are 1.53, 1.58, 1.62, 1.65, 1.49 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^{0}C with grade – II with varied bitumen content are 1.441, 1.444, 1.465, 1.466, 1.257, 1.398 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^{0}C with grade – II with varied bitumen content are 1.385, 1.394, 1.395, 1.407, 1.220, 1.381 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-II aggregates for 10°C, 20°C, 30°C, 40°C, 50°C & 60°C is found to be 91.21%, 89.19%, 88.27%, 87.27%, 82.19%, 83.26% respectively.
2. TSR values of bituminous concrete mix prepared using PMB-70 grade as binder with cement as filler material by 2% for Grade-II aggregates for 10°C, 20°C, 30°C, 40°C, 50°C & 60°C is found to be 90.56%, 88.23%, 86.12%, 85.28%, 81.93%, 83.72% respectively.

Results of Fatigue test

1. The Resilient Modulus of PMB-40 grade with Grade-II aggregates are in the range of 2519.21 to 1059.33N/mm^2.
2. The Resilient Modulus of PMB-70 grade with Grade-II aggregates are in the range of 2212.99 to 1000.35 N/mm^2.

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