Study on the Effect of Varying Mixing and Compaction Temperature of BC Mix using Polymer Modified Bitumen

M Shivakumar[1], Y Gemechu[2]

[1]Department of Civil Engineering, University Visvesvaraya College of Engineering, Bangalore 560056, India
shivakumarmathur[at]gmail.com

[2]Department of Civil Engineering, Mizan Tepi University, Tepi College of engineering, Ethiopia-5160
gemechuyilikal[at]gmail.com

Abstract: ***The bituminous concrete mix design aims to govern the percentage of bitumen, filler, fine aggregates, and coarse aggregates to produce a mix which is workable, sturdy, long-lasting and economical. Bituminous ingredients are widely used for roadway construction, primarily because of their excellent binding characteristics and water proofing properties and relatively low cost. Bituminous concrete mix is strong enough to handle vehicle traffic, and is relatively easy to overhaul. Present study focuses on the design of Bituminous Concrete mix (Grade-II) prepared using Polymer modified binder [PMB-70 (SBS)]. The Marshall method of mix design was adopted to prepare mix and at optimum bitumen content, Marshall Properties and Indirect Tensile Strength (ITS) test were conducted on Bituminous Concrete Mix by varying mixing and compaction temperatures. The Indirect Tensile Strength value has been considerably increased from mixing temperature 140°C to 160°C and as further increase in mixing temperature to 170°C there is a hasty reduction. The Fatigue test result shows the maximum number of fatigue cycles and higher resilient modulus value at optimum mixing temperature 160°C and compaction temperature 140°C.***

Keywords: Bituminous concrete, Polymer Modified Bitumen, Mixing and compaction temperature, Indirect Tensile Strength.

1. Introduction

1.1 General

Bituminous materials are extensively used for roadway construction, primarily because of their excellent binding characteristics and water proofing properties relatively at low cost. The bituminous mix design aims to determine the proportion of bitumen, filler, fine aggregates and coarse aggregates to produce a mix which is workable, strong, durable and economical. Significant variation in daily and seasonal temperature of pavement induces early development of distress conditions (raveling, undulation, rutting, cracking, bleeding, and potholing) of bituminous pavement. Another major concern for distress of road surface is overloading of commercial vehicles and increased traffic density.

Bituminous concrete (BC) mix is a combination of aggregate and bitumen binder. The aggregate acts as the structural skeleton of the pavement and the bitumen binder as the glue of the mixture. As a construction material bituminous concrete is much more complicated than it appears. It is a composite material consisting of aggregate of different sizes; a bitumen binder that is much softer than the aggregate, and more percentage of air voids. It should also provide a smoother and comfortable ride than cement surfaces, which helps to reduce noise pollution around highways and other busy roads.

1.2 Polymer Modified Bitumen (SBS)

SBS is a styrene-butadiene-styrene made by the co-polymerization of butadiene and styrene. Butadiene and styrene block copolymer, to form a styrene (S) - butadiene (B) - benzene Ethylene (S) of the structure, as thermoplastic elastomeric. SBS has the advantages of rubber and plastic, at room temperature with a rubber elastic, like rubber, as high temperatures can melt flow, a plastic material. SBS formed within the bitumen, greatly improving the performance of bitumen. Polymer modified bitumen can increase more rapidly than unmodified bitumen on cooling and consequently, influence the required compactive effort and time available for compaction. . Polymer-modification has been reported to reduce pavement cracking caused by thermal stresses and repetitive loads and decrease rutting due to plastic or inelastic deformations.

1.3 Temperature Characteristics of Binders in Bituminous Pavement

Binder viscosity varies with temperature and different binders require different temperatures to achieve the same handling properties. Polymer modified binders, in particular, increase in viscosity at a much faster rate on cooling than normal paving grade bitumen. The binder is heated to enable it to flow so as to achieve proper coating and "wetting" of aggregates. It must not be so fluid as to cause binder drain-down or lead to segregation or inadequate cohesion of the mix. Overheating or extended mixing times can also cause hardening of the binder due to oxidation or breakdown of polymers

The performance of bituminous concrete pavement depends on the bitumen properties, bituminous concrete mixtures volumetric properties and external factors such as traffic volume and environment. Bitumen is a visco-elastic material where temperature and rate of load application have a great influence on its behaviour. Bitumen is exposed to a wide range of loading and weather conditions; it is soft in a hot environment and brittle in cold weather. Higher traffic volume produces high stress within pavement layer, these distresses reduce the service life of the pavement and increase the maintenance cost.

The key objective is to analyse the experimental test results obtained from Marshall Stability Test, Indirect Tensile Strength Test and Indirect Tensile Fatigue Test on Polymer Modified Bituminous Concrete Mix. For this study the aggregate gradation (Grading-2) for Bituminous Concrete Mix as recommended by MoRT&H specifications and Polymer Modified Bitumen PMB-70(SBS) is selected. Bituminous Concrete Mix design was carried out as per Marshall Method of mix design to satisfy the requirements as per IRC SP: 53-2002 specifications. Cylindrical specimens of Bituminous Concrete Mix prepared using Polymer Modified Bitumen by varying mixing and compaction temperatures. These specimens were subjected to Marshall Stability Test and Indirect Tensile Strength Test and the test results were analysed. Indirect Tensile Fatigue Test was conducted at 25^{o}C keeping constant mixing temperature, varying compaction temperature and stress level.

1.4 Need for the study

The fatigue cracking caused by traffic on the bituminous layer is a very common occurrence and must be given a careful consideration in pavement design and selection of materials to prevent premature cracking of bituminous pavements. In this regard different types of additives are added to bitumen to improve its thermo mechanical properties which can offer high resistance to fatigue cracking and permanent deformation in bituminous layers. Therefore there is a need to carryout studies to evaluate the performance of the bituminous mixes with modified binders and to obtain information on the long term benefits over conventional binders.

1.5 Objectives

- To assess the physical properties of aggregate and bitumen as per the MoRT&H and IRC SP: 52-2002 requirements.
- To determine the optimum bitumen content of the bituminous mix and Marshall Properties of Bituminous concrete Mix by varying mixing and compaction temperatures
- To evaluate Indirect Tensile Strength Test on Bituminous Concrete Mix prepared using Polymer Modified Bitumen at optimum bitumen content by varying mixing and compaction temperatures.
- To conduct Indirect Tensile Fatigue Test on Bituminous Concrete Mix prepared using Polymer Modified Bitumen at 25^{o}C keeping constant compaction temperature and varying mixing temperature and stress level

1.6 Methodology

- Selection of the aggregate and bitumen
- Selection of aggregate gradation
- Determination of Optimum bitumen content
- Evaluation of Marshall properties by varying mixing and compaction temperatures
- Indirect tensile strength test on mix at different mixing and compaction temperature
- Fatigue test on optimum mixing temperature attained by varying compaction temperature and stress level
- Analysis and Results
- Conclusions.
- Recommendations.

2. Experimental Investigation

In the present study the aggregate gradation Grading-2 adopted for Bituminous Concrete as per Table 500-18 recommended by MORT&H (IVth Revision) specifications. Basic Engineering tests on aggregates and binder were conducted in the laboratory to assess their properties.

Marshall Method of mix design was adopted to carryout mix design for Bituminous Concrete Mix prepared using Polymer Modified Bitumen. Marshall Stability and Indirect Tensile Strength tests were conducted on Bituminous Concrete Mix prepared using Polymer Modified Bitumen by varying mixing and compaction temperatures. For the selected mixing and compaction temperatures Indirect Tensile Fatigue test was conducted at 25^{o}C by varying stress level.

2.1 Constituents of a Mix

2.1.1 Aggregates:

Aggregates offer good compressive and shear strength; along with this they provide good interlocking facility with sufficient permeability. Aggregate mainly consisting of both coarse and fine aggregates. Coarse aggregate of 19 mm to 2.36 mm and fine aggregates of 2.36 mm to 75 µ were used. The test results are presented in table 1.

Table 1: Physical Properties of Aggregates

Description of Aggregate Tests	Test Results	Requirements as per Table 500-17 of MoRT&H Specifications
Aggregate Impact value (%)	18.94	Max 24%
Flakiness and Elongation Index (Combined) (%)	28.97	Max 30%
Los Angeles Abrasion value (%)	19.44	Max 30%
Water Absorption (%)	0.5	Max 2%

2.1.2 Binder:

Bitumen is a binding agent. At normal temperature they are in the form of semi-solid, it is heated until liquefied before blending it with the aggregates. In this study Polymer Modified Bitumen PMB-70(SBS) is used as binder. All the basic fundamental test and also the thin film oven test were carried out at specified temperature (153^{o}C) on the bitumen sample as per the requirement. The test results were satisfying the requirements as per IRC-SP 53 2002. The results are presented in table 2.

Table 2: Test Results of Polymer Modified Bitumen PMB-70(SBS) and Requirements

Test	Test Results	Requirements as per IRC SP:53-2002

Penetration at 25°C, 100gm, 5 Seconds, 0.1mm	68.67	50-90
Softening Point (Ring & Ball), °C	58.5	Minimum 55
Ductility at 27°C	100+	Minimum 60
Flash point, COC, °C	252	Minimum 220
Elastic Recovery of Half Thread in Ductilometer at 15°C, %	78	Minimum 75
Separation, Difference in Softening point (Ring & Ball), °C	2	Maximum 3
Viscosity at 150°C, Poise	3.59	2-6
Thin Film Oven Test (TFOT) on Residue		
Loss in mass, %	0.64	Maximum 1
Increase in Softening point (Ring & Ball), °C	4	Maximum 6
Reduction in Penetration of Residue at 25°C, %	23.29	Maximum 35
Elastic Recovery of Half Thread in Ductilometer at 25°C, %	60	Minimum 50

2.1.3 Specific Gravity

The specific gravity values of coarse and fine aggregate, mineral filler, Polymer Modified bitumen PMB-70(SBS) are presented in the table 3.

Table 3: Specific Gravity of Materials

Description of materials	Specific Gravity
Coarse aggregate	2.67
Fine aggregate	2.72
Mineral filler (cement)	3.12
Polymer Modified Bitumen PMB-70(SBS)	1.02

2.1.4 Aggregate Gradation

The aggregate gradation (Grading-2) was adopted for bituminous concrete mix as per MoRT&H (IV revision) specifications presented in table 4.

Table 4: Aggregate Gradation for Bituminous Concrete Mix (Grading-2) as per MoRT&H Specification

IS Sieve Size, mm	% Passing (Specified)	% Passing (Mid Limit)
19	100	100
13.2	79-100	89.5
9.5	70-88	79
4.75	53-71	62
2.36	42-58	50
1.18	34-48	41
0.6	26-38	32
0.3	18-28	23
0.15	20-12	16
0.075	10-4	7

2.2 Procedure for Mix Design

- Select aggregate grading.
- Determine the proportion of each aggregate size required to produce the design grading.
- Determine the specific gravity of the aggregate, mineral filler and bitumen.
- Prepare the trial specimens with varying bitumen contents.
- Determine the specific gravity of each compacted specimen.
- Perform stability tests on the specimens.
- Calculate the percentage of voids, and percent voids filled with Bitumen in each specimen.
- Select the optimum binder content from the data obtained.
- Evaluate the design with the design requirements.

2.2.1 Marshall Method of Mix Design

Marshall Stability test of a mix is defined as maximum load carried by a compacted specimen at a standard test temperature of 60 degree Celsius. The flow value is the deformation of specimen that under goes during the loading up to the maximum load in 0.25 mm units. The Marshall Stability test is applicable for hot mix design using bitumen and aggregates with maximum size of 25mm. Marshall Stability test setup is shown in figure 1. In this method, the resistance to plastic deformation of cylindrical specimen of bituminous mixture is measurement when the same is loaded.

There are two major features of Marshall Stability method of designing mixes are:

➢Density Voids Analysis
➢Stability Flow Test.

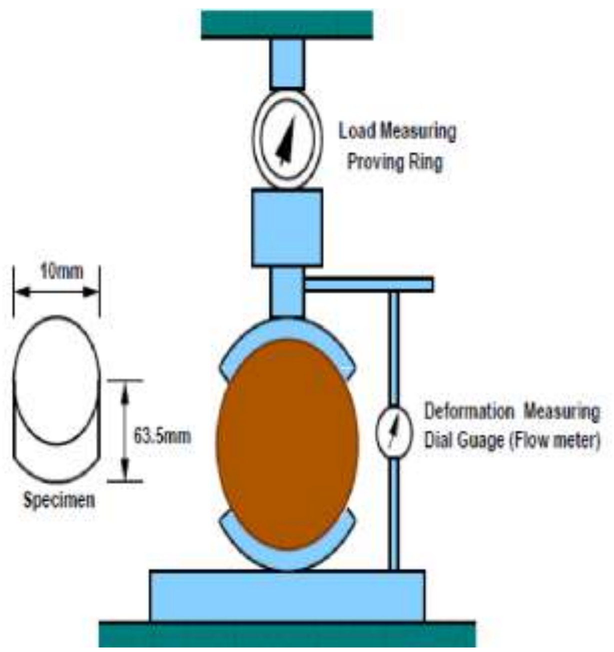


Figure 1: Marshall Test Apparatus

2.3 Indirect Tensile Strength Test

The Indirect Tensile Test is performed by loading a cylindrical specimen with a single or repeated compressive load, which acts parallel to and along the vertical diametric plane. This loading configuration develops a relatively uniform tensile stress perpendicular to the direction of the applied load and along the vertical diametric plane, which ultimately causes the specimen to fail by splitting along the vertical diameter. The Indirect Tensile Test is one of the most popular tests used for hot bituminous mixture characterization in evaluating pavement structures. Indirect Tensile test setup is shown in figure 2.

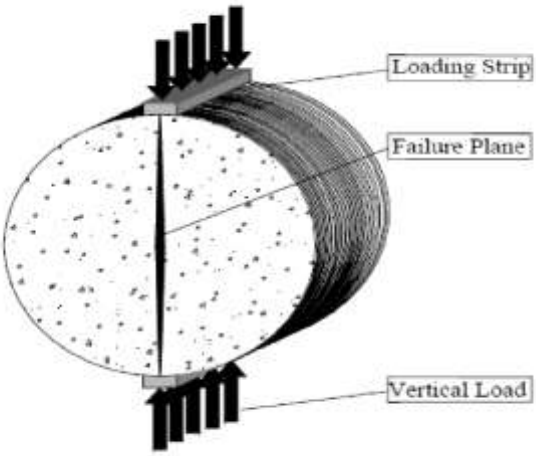
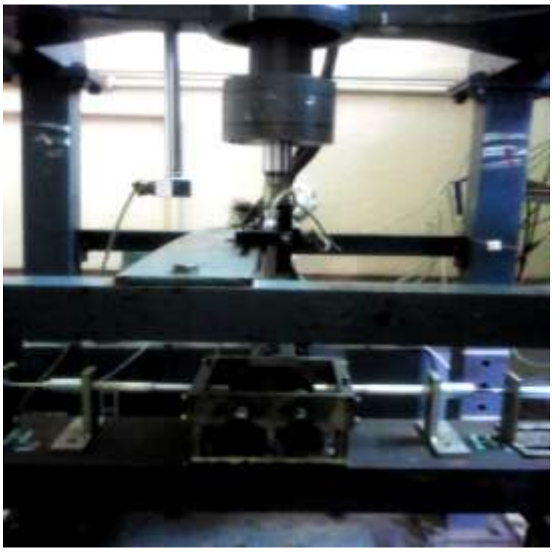


Figure 2: Indirect Tensile Strength Test

2.4 Indirect Tensile Fatigue Test

Indirect Tensile Fatigue Test was conducted at 25^{0}C temperature to study the effect of mixing and compaction temperature on the fatigue behaviour of Bituminous Concrete Mix prepared using Polymer Modified Bitumen, by varying stress levels at 10%, 20%, 30% and 40%. The stress levels were fixed based on the Indirect Tensile Strength Tests conducted on cylindrical specimens of Bituminous Concrete Mix. Indirect Tensile Fatigue test setup is shown in figure 3.



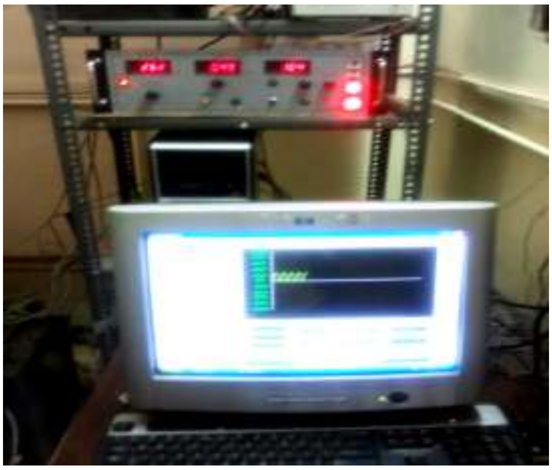


Figure 3: Indirect Tensile Fatigue Test

The equipment was designed and developed at Centre for Transportation Engineering; Bangalore University was used to carry out the Indirect Tensile Fatigue Tests. A thermostatically controlled unit was used to regulate the temperature during the test. A load cell is provided for applying the required magnitude of load applied parallel to and along the vertical diametrical plane of the Marshall specimen controlled by a servo valve operated by a computer. The samples were mixed and prepared at optimum mixing and compaction temperature i.e. the higher Indirect tensile strength obtained among all the variation of temperatures and subjected to fatigue life cycles The data provided by the software in an excel format was analysed to determine Resilient Modulus, Applied Stress, and Initial Tensile Strain,

3. Analysis of Data

3.1 Determination of Optimum Bitumen Content

The optimum bitumen content for mix is determined by taking the average values of three bitumen content corresponding to Maximum Stability, Maximum Bulk Density and 4% Air Voids in Total Mix. The Optimum Bitumen Content (OBC) for mix obtained was **5.63 %.** The various Marshall Properties of Bituminous Concrete Mix prepared using Polymer Modified Bitumen at Optimum Bitumen Content was evaluated and the result has been tabulated in table 5 below.

Table 5: Marshall Properties of BC Mix at OBC

SL. No.	Marshall Properties	Test Results	Requirements as per IRC SP 53 2002
1	Optimum Bitumen Content, %	5.63	-----
2	Marshall Stability, kgs	1776.83	1200
3	Marshall Flow, mm	3.60	2.5 - 4.0%
4	Marshall Quotient, kg/mm	493.56	250-500
5	Air voids(Vv), %	4.43	3.0 - 5.0%
6	Bulk density, g/cc	2.38	-----
7	Voids in Mineral Aggregates (VMA), %	17.59	-----
8	Voids filled with Bitumen (VFB), %	74.82	-----

3.2 Marshall Properties of BC Mix Prepared by Varying Mixing and Compaction Temperatures

Marshall Stability test were conducted on specimens prepared using Polymer Modified Bitumen by varying mixing temperature (140°C, 150°C, 160°C, 170°C and 180°C) and compaction temperature (90°C, 100°C, 110°C, 120°C, 130°C and 140°C).The comparison of Marshall Properties V/S Compaction Temperature of Bituminous Concrete Mix prepared using Polymer Modified Bitumen for Mixing Temperature 140°C, 150°C, 160°C, 170°C and 180°C are shown in figures below.

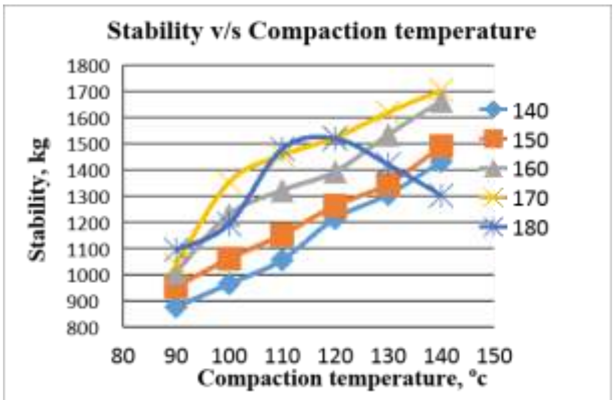


Figure 4: Comparison of Marshall Stability V/S Compaction Temperature

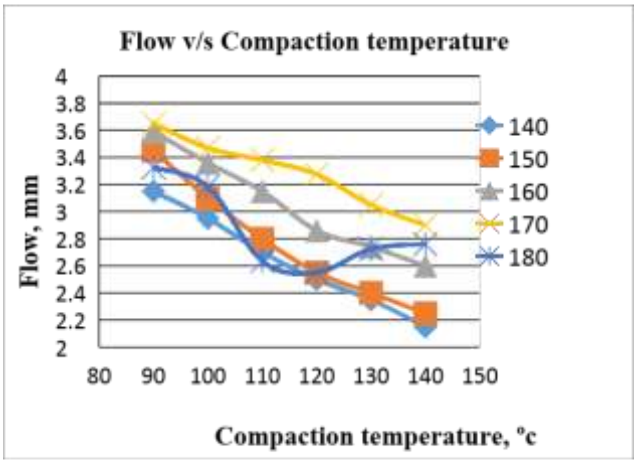


Figure 5: Comparison of Flow V/S Compaction Temperature

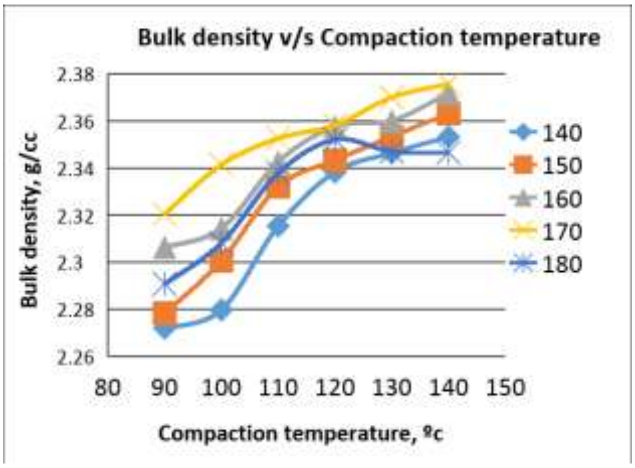


Figure 6: Comparison of Bulk Density V/S Compaction Temperature

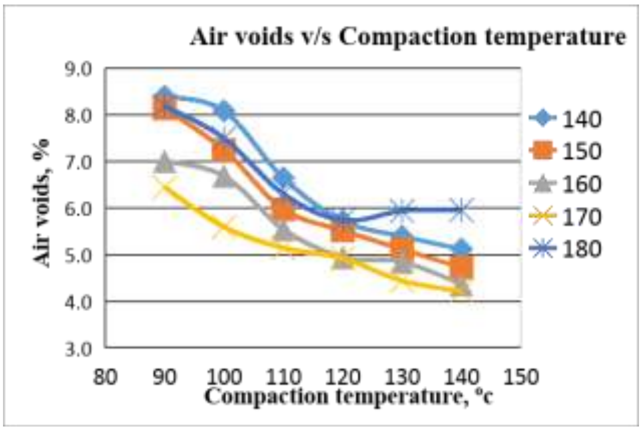


Figure 7: Comparison of Air voids V/S Compaction Temperature

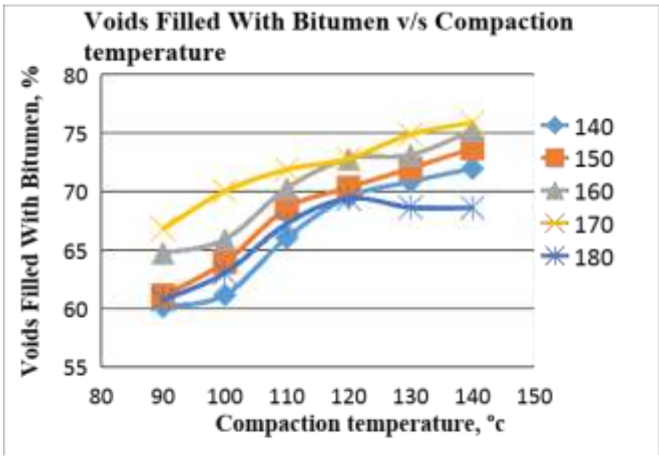


Figure 8: Comparison of Voids Filled With Bitumen (VFB) V/S Compaction Temperature

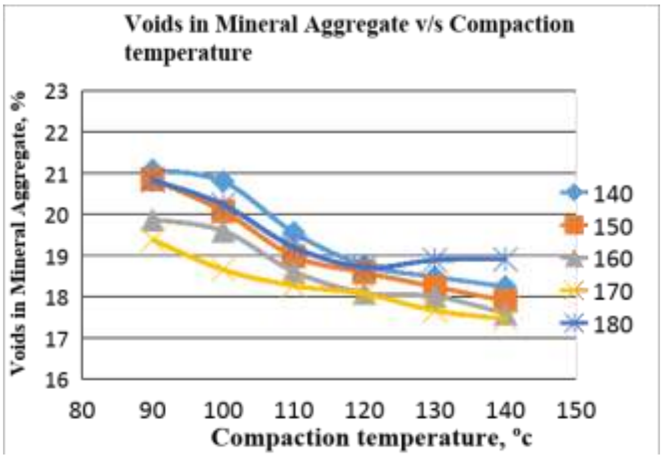


Figure 9: Comparison of Voids in Mineral Aggregate (Vma) V/S Compaction Temperature

3.3 Indirect Tensile Strength

Indirect Tensile Strength test was conducted on specimens prepared using Polymer Modified Bitumen by varying mixing temperature (140°C, 150°C, 160°C and 170°C) and compaction temperature (90°C, 100°C, 110°C, 120°C, 130°C and 140°C). The trends are presented in the figure 10.

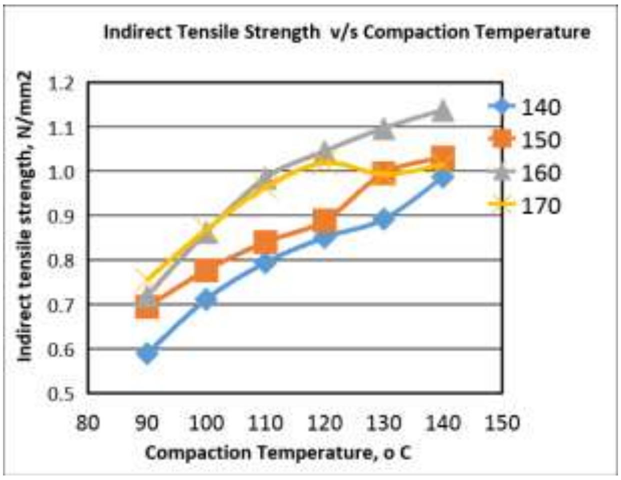


Figure 10: Comparison of Indirect Tensile Strength v/s Compaction Temperature of Bituminous Concrete Mix

3.4 Indirect Tensile Fatigue Tests

Indirect Tensile Fatigue Tests were conducted on cylindrical specimens of Bituminous Concrete Mix. Indirect Tensile Fatigue Test was conducted at 25°C test temperature on Bituminous Concrete Mix prepared using Polymer Modified Bitumen keeping constant mixing temperature (160°C), varying compaction temperature (110°C, 120°C, 130°C and 140°C) and stress levels (10%, 20%, 30% and 40%). The trends in the figures below shows the relation of various fatigue properties such as resilient modulus etc.

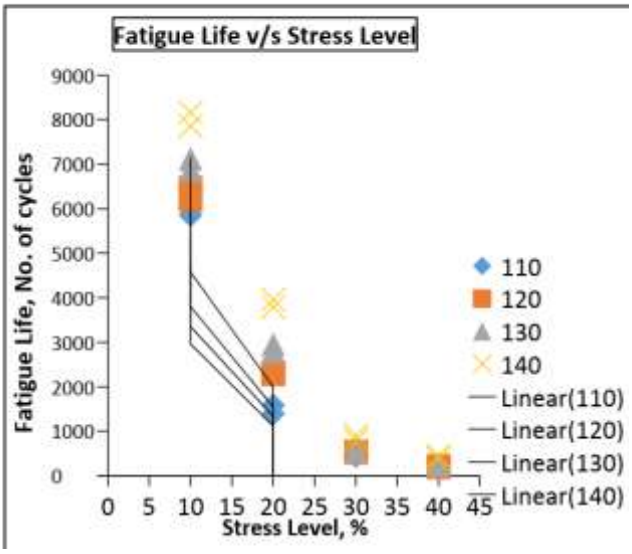


Figure 11: Fatigue Life v/s Stress Level of Bituminous Concrete Mix

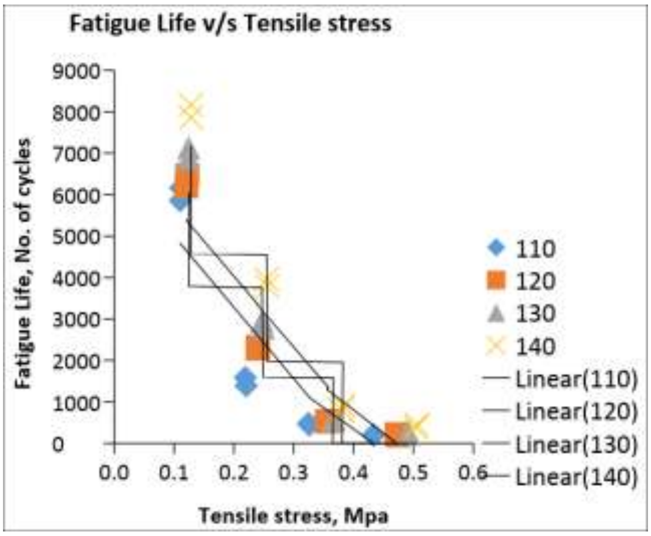


Figure 12: Fatigue Life v/s Tensile Stress of Bituminous Concrete Mix

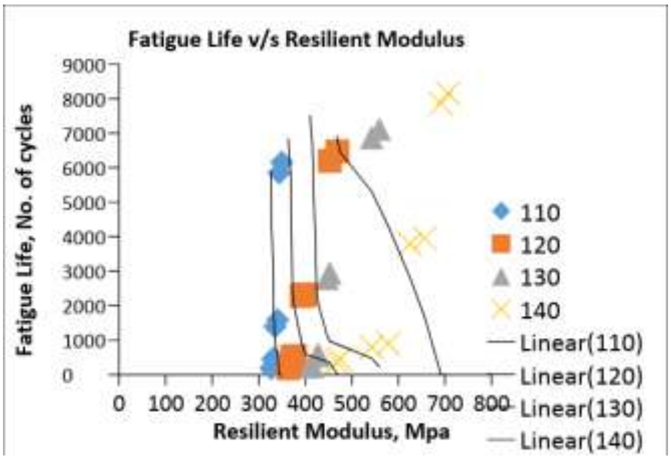


Figure 13: Fatigue Life v/s Resilient Modulus of Bituminous Concrete Mix

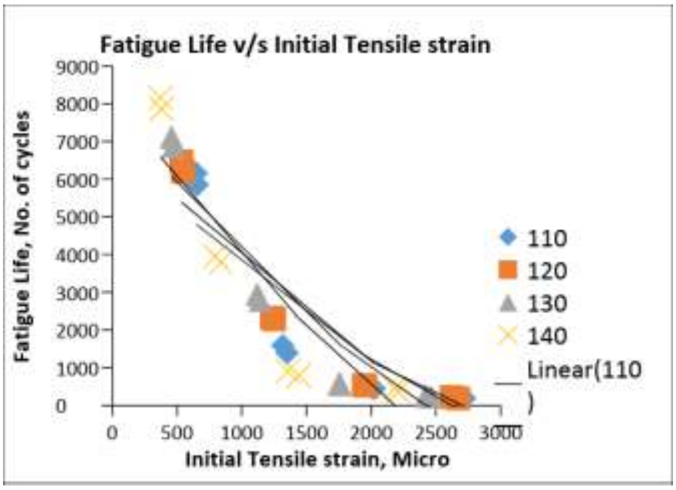


Figure 14: Fatigue Life v/s Initial Tensile Strain of Bituminous Concrete Mix

4. Conclusions

- The physical properties of aggregate and bitumen were satisfying the requirements and the Optimum Bitumen Content obtained for Polymer Modified Bituminous concrete mix is 5.63%.
- It was seen that there is a considerable increase in the Marshall Stability as the mixing and compaction temperature increases and substantial reduction in the Marshall Stability with further increase in the mixing temperature.
- There is considerable increase in the Indirect Tensile Strength as the mixing and compaction temperature increases and substantial reduction in the Indirect Tensile Strength with further increase in the mixing and compaction temperature
- Fatigue Life, Tensile stress and Resilient Modulus of Bituminous Concrete Mix prepared using Polymer Modified Bitumen increases from as the compaction temperature increases and whereas Initial Tensile Strain decreases as the compaction temperature increases

Based on the experimental work and analysis carried out in the present study, an ideal mixing temperature of 160^{o}C and compaction temperature of 140^{o}C is suggested for the preparation of Bituminous Concrete Mix prepared using Polymer Modified Bitumen.

References

[1] Farag Khodary Moalla, Hamed Fachgebiet Strabenwesen “Evaluation of Fatigue Resistance for Modified Asphalt Concrete Mixtures based on Dissipated Energy Concept”.2010
[2] James Dwyer, Matt Betts “Polymer-Modified Asphalt: Improving Our Nation’s Infrastructure”. 2011
[3] Jian-Shiuh Chen, Min-Chih Liao and Ming-Shen Shiah “Asphalt Modified by Styrene-Butadiene-Styrene Tri-Block Copolymer: Morphology and Model”.
[4] K.Kantha Kumar and A.Veeraragavan “Optimizing the Bituminous Concrete Mixes for Fatigue Performance”.
[5] Lamia A. Ahmed “Improvement of Marshall Properties of the Asphalt Concrete Mixtures using the Polyethylene as Additive”.
[6] Lutfi Raad, Steve Saboundjian, and George Minassian “Field Aging Effects on the Fatigue of Asphalt Concrete and Asphalt-Rubber Concrete”.
[7] Monica Romero Santos Fernandes, Maria Madalena Camargo Forte, Leni Figueiredo Mathias Leite “Rheological Evaluation of Polymer-Modified Asphalt Binders”.
[8] Noorafidah Binti Ithnin “Determination of Mixing and Compacting Temperatures for Hot Mix Asphalt”.
[9] Shivangi Gupta & A.Veeraragavan “Fatigue Behaviour of Polymer Modified Bituminous Concrete Mixtures”.
[10] Smith, Benjamin J, Hesp and Simon A.M “Crack Pinning in Asphalt Mastic and Concrete: Effect of Rest Periods and Polymer Modifiers on the Fatigue Life”.
[11] Soon-Jae Lee, Serji N.Amirkhanian, Khaldown Shantanawis and Carl Thodesen “Influence of Compaction Temperature on Rubberized Asphalt Mix and Binders”.
[12] Taher Baghaee Moghaddam, Mohamed Rehan Karim and Mahrez Abdelaziz “A Review on Fatigue and Rutting Performance of Asphalt Mixes”.
[13] Xiaohu Lu, Ulf Isacsson and Jonas Ekblad “Influence of Polymer Modification on Low Temperature Behaviour of Bituminous Binders and Mixtures”.
[14] Yetkin Yildirim “Mixing and Compacting Temperature for Modified Asphalt Binder”. Superpave Research Program 2006.
[15] NCHRP Report 648 “Mixing and Compaction Temperatures of Asphalt Binders in Hot-Mix Asphalt”.2012
[16] Pavement Work Tips-No13 November 2010 “Temperature Characteristics of Binders in Asphalt”.
[17] Chaiwat Na Chiangmai “Fatigue-Fracture Relation on Asphalt Concrete Mixtures”.2010
[18] Sixth Framework Programme of Spens Project, Transport Research Europe “Practical Mix Design Model for Asphalt Mixture”.
[19] Specification of Ministry of Road Transport and Highways (MoRT&H) Government of India 4th Revision.
[20] IRC SP 53-2002 specification for Modified bitumen.

Author Profile

Shivakumar Mahto received the B.E. degree in Civil Engineering from Visvesvaraya Technological University, Belgaum in 2011 and M.E. degree in the year 2013 from University Visvesvaraya College of Engineering, Bangalore respectively. During 2011-2013, he stayed in Highway Research Laboratory, and conducted all the relevant experiments required for the project work. He is now working in Mizan Tepi University as a lecturer post in the country Ethiopia.