Laboratory Characterization of Flexible Pavement Design

Krushna Chandra Sethi
Guest faculty in Civil Engineering Department, Gautam Buddha University, U. P, India.

E-Mail: krushnacivil25@gmail.com

Abstract

An efficient road transport system provides a good level of service for its users. Roadways are considered to be the most common and important way for inland transport**.** Asphalt road infrastructure development is one of the major sectors contributing to the National economy**.** Modification of asphalt generally involves the use of modifiers that appears in solid forms. The limitation of using such materials lies in the high softening and melting temperatures, blending of polymers/rubbers/latex with asphalt at high temperature for a long duration, phase separation of the polymer from Asphalt apart from the availability of materials indigenously. This results in a high cost of PMBs. Liquid polymers are easy to blend with asphalt at relatively low temperature and for a short blending time. The road development programmes envisaged for the country involving a large amount of money, manpower, and materials will concern not only in the construction of new roads but also the improvements of existing roads and their durability for design life. Liquid polymers have also been used for soil stabilization. This paper depicts the use of a new modifier**-Vinyl Acrylic Copolymer** (liquid form) for development of cost-effective and high performance modified binder and its mixes applicable for construction and maintenance of asphalt roads. The goal of improving bitumen properties is achieved using 0.5 percent of a copolymer of Vinyl and Acrylic Acetate functional groups in liquid polymer-1(LP1). Advantages of liquid polymer with bitumen binder are ease of mixing with bitumen at relatively low temperature. Improved compatibility of polymer with bitumen was obtained as there is no phase separation. Polymer modified asphalt composition was characterized as per IRC: SP: 53-2010 to assess the effect of modification on the properties of VG-30. LP-1 modified binder is used for the preparation of asphalt mixes for BC grade-1 as per MoRTH 5th revision 2013. Job mix was prepared using VG-30 as per Marshall method and optimum binder content was obtained as 5.3(w/w mix). For comparative study, Marshall Samples were also prepared with modified binder at the same optimum binder content (i.e. 5.3%). To study the behavior of conventional and modified bituminous mixes various engineering and volumetric properties e. g Retained Stability, Tensile Strength, Tensile Strength Ratio (TSR), Marshall Stability, flow value, unit weight, air voids are determined.

The study indicated that the binder properties were improved marginally & accordingly the mechanical properties bituminous mixes were also found improved w.r.t Retained Stability and Indirect Tensile Strength and TSR. Bituminous concrete (BC) mixes developed with liquid polymer modified binders satisfied the requirement of IRC SP-53, 2010. The performance of modified mixes improved further with an admixture of liquid polymer and fly ash to satisfy the requirements of high-performance parameters such as rutting, thermal cracking, and fatigue.

Keywords: Asphalt Road, Liquid Polymer, Blending, PMBs.

Introduction

Polymer modification of bitumen is the incorporation of polymers in bitumen by mechanical mixing or chemical reaction. The various polymers investigated included plastomers (e.g. polyethylene (PE), polypropylene (PP), ethylene-vinyl acetate (EVA), ethylene-butyl acrylate (EBA)) and thermoplastic elastomers (e.g. styrene-butadiene-styrene (SBS), styrene-isoprene-styrene (SIS), and styrene/ethylene/butylene-styrene (SEBS)), although none of these were initially designed for bitumen modification. These polymers were reported to lead to some improved properties of bitumen, such as higher stiffness at high temperatures, higher cracking resistance at low temperatures, better moisture resistance or longer fatigue life **(1-7)**. PMB usually shows better overall performance concerning mechanical properties and cost-effectiveness. However, some of the polymers when added in their solid-state into hot bitumen melts and mix in the hot stage but phase separate at ambient temperature during storage and application of modified binders. Additives are needed to achieve adequate storage stability. Liquid polymers are easily mixed with bitumen at its molten stage and show negligent phase separation thereafter.

Methodology:

1. Materials

1.1 Aggregates: met the requirements of MoRTH-2013

1.2 Binders: Bitumen VG-30 satisfied the requirement of IS-73, 2013. The liquid polymer was procured from Innovative Marketing Solutions (IMS) and already tried used for soil stabilization in CRRI.

1.3 Preparation of Liquid Polymer Modified Binder (LPMB): 0.5% and 1.0 percent (w/w of bitumen) liquid polymer was added to hot VG-30 bitumen & the mixture was stirred at 115+-5°Cfor 30 to 40 minutes. Liquid polymer modified binder (LPMB) satisfied the requirement of PMB as per IRC-SP- 53, 2010 except elastic recovery property. However, LPMB satisfied the requirement of the rheological parameter (an alternate to Elastic recovery test) i.e. minimum temperature to achieve 1 kPa complex modulus at 10 radian /sec. G*/sinδ for LPMB is found to be 2 °Chigher than VG-30. Phase separation is also found to be within limits as defined in the code of practice. A comparative data for VG-30 & LPMB is shown in table-1.

Table1. Comparative properties of Base binder and Modified binder

Property test	Test value obtained	
	VG-30	PMB Containing 0.5% Liquid Polymer
Penetration at 25°Ç0.1 mm, 100g, 5 s.	64	69
Softening point, (R&B), °ÇMin	48	53
Elastic Recovery of half thread in ductilometer at 15°Çpercent,min	NA	50
Complex Modulus (G/sin£) as Min 1.0 kPa at 10 rad/s, at a temperature, °C	76	78
Separation difference between in softening point(R&B), °ÇMax	NA	2
Viscosity at 150°ÇPoise	3.2	3.75

1.4 Mix Design by Marshall Method:

The design requirement for Bituminous Concrete (BC) mix as per the MoRT&H specifications (5th Revision, 2013) is given in Table 2.

Table 2.Design Requirements for BC Mixes Grade -1as per MORT&H, 2013, Specification

Property	Specified Value
Marshall Stability values,(KN) at 60°C	9.0
Marshall flow values, mm	2-4
Voids in total mix, Vv%	3-5
Voids in mineral aggregates filled with bitumen, VFB,%	65-75

The aggregate gradation and proportion of aggregates in a dry aggregate blend are given figure -1

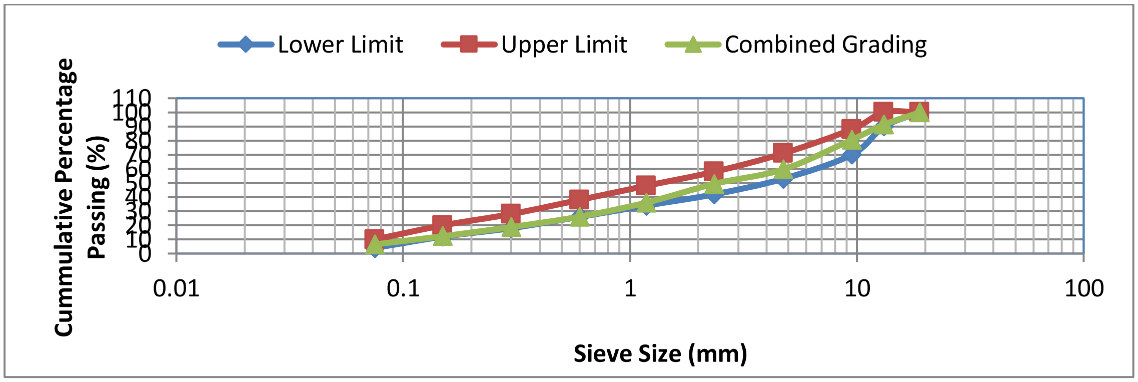

Figure.1 Gradation curves for combined grading and specified limits

Proportions of aggregates are as follows:

A: B: C: D: E=20mm: 10mm: 6mm: Stone Dust: Lime

12:22:24:40:2=20mm: 10mm: 6mm: Stone Dust: Lime

1.5 Determination of Optimum Binder Content (OBC) for VG-30:

To determine the optimum binder content (OBC), Marshall Samples were prepared at varying percentage of VG-30 bitumen. Bulk density, Marshall Stability, Flow, and other volumetric properties were then determined and are given in Table 3. Optimum Binder Content (OBC) was found to be 5.1 percent by weight of aggregates.

Table3. Volumetric and Mechanical Parameters Obtained for mix prepared with VG-30 and Lime

Binder content, % by weight of Aggregate	Bulk Density, gm/cc	Stability (KN)	Flow Value (mm)	Air Voids,%	Voids in Mineral Aggregates, VMA	Voids Filled with Bitumen, VFB, %
4.5	2.377	10.81	2.38	4.50	14.50	65.76
5.0	2.380	11.98	2.99	4.06	14.90	70.31
5.5	2.378	12.34	3.27	3.69	16.55	70.69
6.0	2.362	11.02	3.62	3.62	16.94	76.22

1.6 Properties of Conventional and Modified Mixes at Optimum binder content: The Marshall Stability & Retained Marshall Stability of two different mixes were evaluated Table 4 .To assess the durability and performance of bituminous mixes, several laboratory tests are used worldwide.

Table4. Test Results of Marshall stability and Retained Marshall Stability for BC Mixes

Bituminous mix	Marshall stability of controlled sample at 60°C (KN)	Retained Marshall stability (%)
A) Mix with VG-30 &Lime	12	88.5
B)Mix with LPMB & lime	14	90.3

Tensile Strength Ratio (TSR): The degree of susceptibility to moisture damage is determined by preparing a set of laboratory-compacted specimens conforming to the job mix formula. The specimens are compacted to avoid content corresponding to void levels expected in the field, usually in the 6 to 8% range. The samples were compacted using gyratory compactor at target air voids of 7%. TSR was then determined as per AASHTO T-283. Test results are shown in Table-5.

Table5. Test results of tensile strength ratio (TSR) for BC Mixes at OBC

Bituminous Mix	Average Tensile strength of unconditioned Samples (kg/cm^2)	Average Tensile strength of Conditioned Samples (kg/cm^2)	Tensile Strength Ratio (TSR)%
A) Mix with VG-30 &Lime	5.61	5.37	86.0
B)Mix with LPMB & lime	7.52	6.48	91.2

1.7 Resilient modulus properties of conventional & modified mixes: A material's resilient modulus is an estimate of its modulus of elasticity. The value of resilient modulus is used to evaluate the relative quality of material, designing the pavement as well as to generate input for pavement evaluation and analysis.

The resilient modulus of bituminous mixes with VG-30 &lime and bituminous mixes with liquid polymer & lime was studied at different temperatures. The test was done on Universal Testing Machine (UTM-16) according to ASTM D 4123, "Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixture". The Test was conducted by applying the compressive load with a haversine waveform at 25°C,35°C The test results are shown in Table 6.

Table6. Resilient Modulus at Optimum Binder Content for BC Mix

Bituminous Mix	Resilient Modulus(MR.) at 25°C	Specified indicative values as per IRC 37-2012	Resilient Modulus(MR.) at 35°C	Specified indicative values as per IRC 37-2012
A) Mix with VG-30 &Lime	3689	3000-4500	1963	1700-2500
B) Mix with LPMB & lime	4213	3000-4500	2356	1700-2500

1.8 Effect of Fly ash on BC mixes Properties:

The properties of BC mix prepared with VG-30 were further improved by replacing VG-30 with LPMB and 2 % lime with 2 % fly ash .These results are summarized in Table .7

Table7. Properties of BC Mixes at Optimum Binder Content

Bituminous Mix	Marshall stability at 60°C (KN)	Retained Marshall stability (%)	Average Tensile strength of unconditioned Samples (kg/cm²)	Tensile Strength Ratio (TSR)%
Mix with VG-30 &Lime	12.0	88.0	6.21	86.51
Mix with LPMB & fly ash	13.8	87.9	6.93	90.62

1.9 Dynamic Creep Test

In the Dynamic creep test, an axial load is applied dynamically to the test specimen throughout the duration of the test. The Dynamic creep test was performed of Universal Testing Facility (UTM-16) .The test was conducted as NCHRP 9-19(Unconfined).During the test, a cycle stress of 69kPa was applied with a seating stress of 11kPa and haversine pulse is applied with loading width of 0.1s followed by a rest period of 0.9s.A maximum of 10000 load cycles were applied and accumulated permanent strain (%) were obtained as average of two samples and reported.

Figure 2.1 Window of Dynamic Creep Test

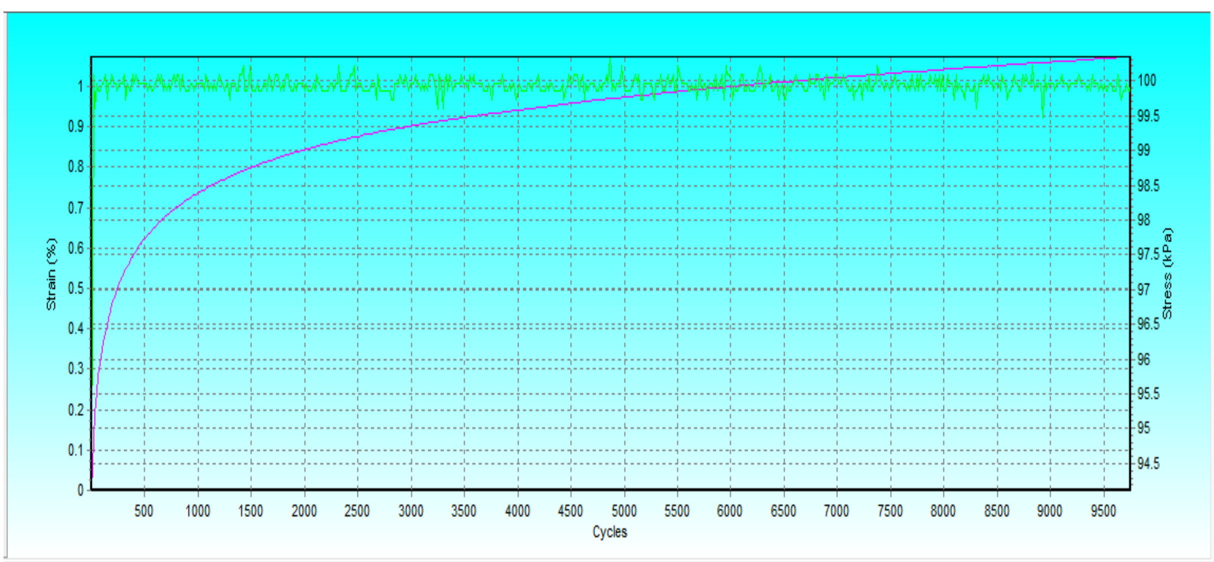

Figure 2.2 Dynamic creep test in progress

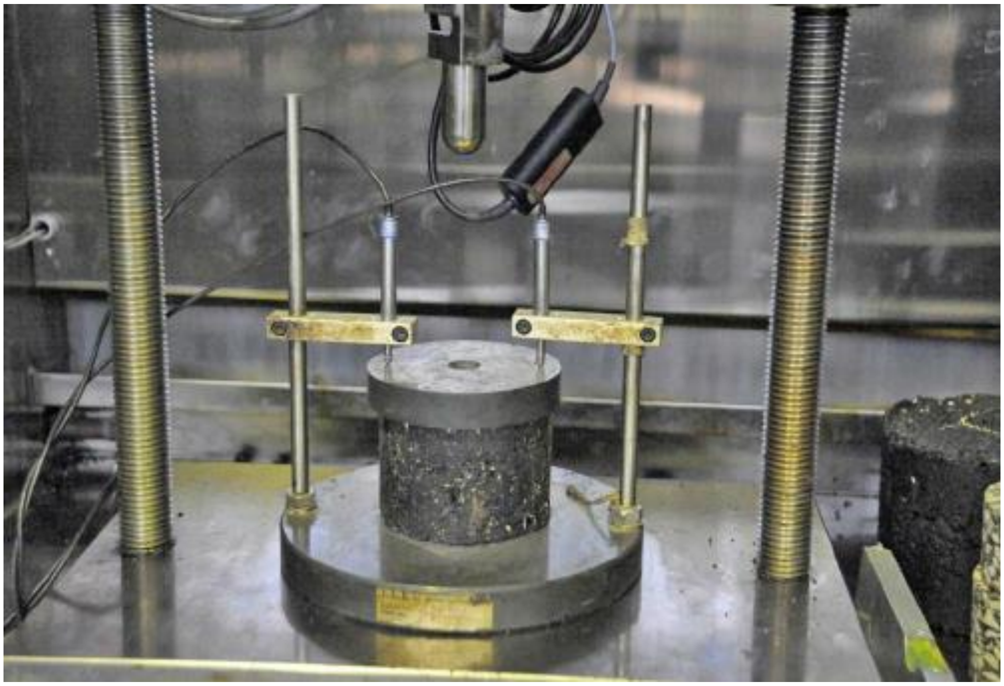

Table.8 Dynamic creep results

Bituminous Mix	Total permanent Strain(%) at 35°C	Total permanent Strain(%) at 45°C
VG-30 with Lime	0.655	0.801
VG-30 with Fly ash	0.683	0.735
Polymer Modified BC mix Fly ash with 0.5% Polymer	0.742	0.831
Polymer Modified BC mix Lime with 0.5% Polymer	0.856	1.003

Results & Discussions:

The results obtained through various tests, are discussed in the following text

1. The physical properties of aggregate used lies within the limit as specified in MoRT&H for Marshall Mix design ensuring its further use for the preparation of bituminous mixes. VG -30 bitumen met all the required properties as described in IS 73-2013. LPMB met most of the required properties as described in IRC SP- 53- 2010 except elastic recovery. Dynamic Shear Rheometer (DSR) test on

unaged VG-30 and LPMB indicated temperature for the failure of bitumen 76 ^{o}C and 78 ^{o}C respectively under the similar test condition as specified in IRC SP- 53- 2010.

2. Marshall Stability and indirect tensile strength value of mixes improved with the usage of a minor dose of liquid polymer in a modified binder. The retained stability was found to be 88.56% for samples containing VG-30 and lime whereas the retained stability of sample prepared with Liquid polymer was found to be 90.32%.
3. The tensile strength ratio for bituminous mix prepared with VG-30 and lime as a filler was found to be 86.51% and the same property for mix prepared by lime with liquid polymer modified binder was found to be higher i.e 91.12%. This indicated approx 5.61% improvement in TSR values.
4. Marshall stability , retained stability, indirect tensile strength and tensile strength ratio were found to be further improved by replacing lime with fly ash.

Conclusions:

Following conclusions are drawn based on the test data obtained in laboratory and analysis of data.

- The tensile strength ratios of BC mixture containing LPMB were more than the mix without polymer. This indicates that incorporation of liquid polymer modified mix improved resistance to moisture.
- Similarly the retained stability of the BC mixture containing liquid polymer modified bitumen showed higher resistance to moisture to BC mix prepared with liquid polymer as compared to BC mix prepared with VG-30 bitumen (Without Polymer).
- Elastic recovery of LPMB did not meet the requirements of IRC SP-53, 2010.However $G^*/\sin\delta$ for LPMB is found to be 2 °C higher than VG-30.

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