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Laboratory Performance Characterization of Asphalt Binders Blended with Rap

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***Abstract* – The use of recycled asphalt pavement (RAP) in construction of a pavement helps in economic savings and conservation of natural resources as well as solves problem of disposal of large amount of pavement waste materials produced every year. Considering significant benefits of RAP, the highway agencies around the world are encouraged to use RAP in construction of pavements. However, use of RAP is not popular in India due to the lack of specific guidelines and design procedure. Furthermore, measurement and interpretation of rheological performance of RAP blended binders require advance laboratory instruments. A flexible pavement experiences different weather, extreme solar radiation, temperature, oxidation, and traffic loading and unloading conditions, which results in a stiffer and aged binder over time. Therefore, a binder extracted from RAP can have different chemical and rheological property compared to a virgin binder. Though a stiffer binder may be beneficial for better rut resistance, however, it may have a tendency to fail in fatigue. A softer grade binder is required for utilization of higher percentage of RAP. Superpave criteria suggested that that no grade change is required up to 14% addition of RAP, one softer grade binder is required for addition of RAP in range of 14% to 24%, and blending charts should be prepared for RAP amount > 24%. However, at present, no viscosity blend charts are available for Indian conditions. The blending charts can be helpful in selection of a proper grade of a binder. The current literature has limited studies evaluate effects of RAP on rutting and fatigue performance of polymer and crumb rubber modified binders. Further, relationship between change in chemical properties with addition of RAP and rheological properties have not been established yet for conventional or modified binders.**

Therefore, the present study is undertaken to evaluate rutting, fatigue, rheological performances of different types of modified and unmodified binder with and without addition of RAP. Two different types of viscosity grade virgin binders (VG10, VG30) and one polymer modified binder (PMB 40), and one crumb rubber modified binder (CRMB 60) were selected in this study. The RAP was collected from Mumbai - Nashik NH 3. The RAP was milled from top 25mm layer from 8 years old road. The original binder used during construction was penetration grade 50/60. The binder was recovered from RAP using a rotary evaporator (ASTM D 5404) method. The different proportions of RAP binder (i.e., 0%, 14%, 24% and 40%) were blended with modified and unmodified binders using a high shear mixer. The preliminary tests: softening point, penetration, ductility, and elastic recovery were conducted on blended binders. The absolute viscosity of RAP blended VG grade binder was measured at 59 oC using vacuum capillary viscometer and was used to develop viscosity blending charts. The kinematic viscosity was measured at different temperatures 115°C, 130°C, 155°C, 160°C, 175°C using Brookfield viscometer.

Results show that addition of RAP increases penetration and viscosity and decreases softening point, indicating a stiffer nature of a binder containing RAP. Further, mixing and compaction temperatures of modified and unmodified binders increase with addition of RAP. The Superpave rutting parameter and MSCR test shows that addition of RAP enhances rutting performance of VG 10 and VG 30 binders. However, addition of RAP decreases rutting resistance of PMB 40 binder due to replacement of polymer content. The fatigue resistance of VG 30 and PMB 40 binders increases with addition of RAP at low strain, while performance decreases at high strain.

Key Words: RAP, Rotary Evaporator, Viscosity, Rheological Performance, Chemical Composition

1. INTRODUCTION

Reclaimed Asphalt Pavement (RAP) is the bituminous mix collected from old and deteriorated pavements containing asphalt and aggregates (Transportation Research Thesaurus, 2014). The construction of pavements utilizing RAP helps in significant cost savings and conservation of natural resources. In addition, utilization of RAP solves the problem of disposal of large amount of pavement waste materials produced every year. Considering significant benefits of RAP, the regional transportation departments and agencies in the United States are encouraged to use RAP in construction of pavements (Kennedy et. al., 1998). A recent study showed that more than 90% (i.e. 68.3 million tonnes) of the asphalt pavements were reclaimed and used for construction of new pavement in United States of America in year 2012 (Asphalt - The Green Paving Choice, 2014). However, RAP is not a popular option in India for construction of pavements due to the lack of specific guidelines and design procedure for mixes with RAP. Furthermore measurement and interpretation of the rheological properties of virgin binder blended with RAP requires skill, manpower and tools. Though US has specific guidelines for use of RAP (McDaniel and Anderson [NCHRP Report-452], 2001). However they may not be directly applicable to Indian conditions. The reasons can be the difference in test methods to characterize asphalt binders. For example, US utilizes Superpave criteria for all grades of binders, however, in India, a viscosity grade, penetration, softening point are still being utilized to characterize modified and unmodified binders. In addition, properties of RAP change with source which may influence its use in mixes.

A flexible pavement experiences different weather, extreme solar radiation, temperature, oxidation, and traffic loading and unloading conditions, which results in stiff and aged binder over time. Therefore, a binder extracted from RAP can have different property compared to a virgin binder (Al-Qadi et. al., 2007). Thus, rheological and chemical properties of a virgin binder change with addition of RAP. A softer grade binder is required for utilization of higher percentage of RAP. The following are the concerns on utilization of RAP blended binders (1) selection of base binder (2) mixing and compaction temperatures (3) temperature susceptibility (4) performance frequency, strain, and temperature sweep (5) rutting performance (6) fatigue performances (7) chemical changes. A study conducted by McDaniel and Anderson (2001) reported that the required grade of a virgin binder depends upon quality of RAP binder. They suggested that no grade change is required up to 15% addition of RAP, one softer grade binder is required for addition of RAP in range of 15% to 25%, and blending charts should be prepared for RAP amount more than 25%. ASTM D4887 suggests to develop a blending chart based on absolute viscosity measured at 60°C, using vacuum capillary viscometer. At present, no viscosity blend charts are available for Indian conditions. Therefore, the present study aims to develop blending charts for different types of viscosity grade binders used in India. The blending charts will be helpful in selection of a proper grade of a base binder. Similarly grade of polymer and crumb rubber modified binder are estimated based on penetration and softening point values of binders.

With rapidly increasing Indian roads transportation and infrastructure, road network is undergoing a challenging development under National highways development programs (NHDP), Bharat Nirman, Pradhan Mantri Gram Sadak Yojna (PMGSY), and State Highways Improvement Programs, etc. where a huge money is being invested by the Government of India in order to reach excellent pavement performance & low maintenance.

The present study was undertaken to characterize RAP blended binders using different rheological tests. Four different types of asphalt binders, polymer modified asphalt (PMB 40), crumb rubber modified asphalt (CRMB 60), and viscosity grade virgin binder (VG 10 and VG 30) were selected. VG10 is a softer grade binder which is used to produce modified and unmodified binders. Each of the selected asphalt binders was blended with four different percentages of extracted RAP binder (i.e., 15%, 25%, and 40%), except VG10 with additional 50% RAP. The absolute viscosity of blended binders was measured at 60°C using vacuum capillary viscometer. The kinematic viscosity at high temperatures were measured using Brookfield Viscometer. The high temperature grade of different blends was estimated using dynamic shear remoter. In addition, MSCR and LAS tests were conducted to evaluate rutting and fatigue performances of RAP blended asphalt binders. The temperature - frequency and strain sweep tests were conducted to further evaluate performance. The chemical and functional group of RAP blended binders were determined using FTIR.

1.1 Objective of Purposed work

- Evaluate effects of RAP on preliminary properties (i.e., softening point, penetration, ductility, elastic recovery, viscosity) of modified and unmodified binders absolute viscosity blending charts for unmodified (VG grade) binder containing different percentages of RAP
- Determine the mixing and compaction temperatures of RAP blending asphalt binders
- Estimation temperature susceptibility of RAP blended modified and unmodified binders using A-VTS approach.
- Evaluate effects of RAP binders on high temperature grade of modified and unmodified binder based on Superpave rutting parameter.
- Compare performance of RAP blended binder under temperature, frequency, and strain sweep tests.
- Evaluate rutting performance of modified and unmodified binders blended with different percentages of RAP binder using MSCR test.
- Evaluate fatigue damage potential of modified and unmodified binders blended with different percentages of RAP binder using LAS test.
- Determine change in chemical composition of a binder with addition of RAP binder using FTIR spectroscopy.

2. LITERATURE REVIEW

This section summarizes introduction to recycled asphalt pavement (RAP), characterization and methods to extract binder from RAP. In addition test methods to characterize rheological and chemical properties of RAP and blended binders are discussed. Finally, a detailed literature review is presented on studies conducted on performance of binder with and without RAP.

Table 2.1 : Summary of tests for binder characterization

Test Name	**Purpose**	**Instrument**	**Standard**
Penetration	Measure consistency	Penetrometer	ASTM D5
Softening Point	Measure	Ring and Ball apparatus	ASTM D36
Ductility	temperature	Ductilometer	ASTM D113
Elastic Recovery	Ductile	Ductilometer	ASTM D6084
Brookfield Viscosity	binder	Brookfield Viscometer	ASTM D4402
Absolute Viscosity	Elastic	Vacuum	ASTM D4887

Table 2.2: Literature review summary for studies on rheological analysis

Test Name	**Purpose**	**Instrument**	**Standard**
Linear Range	Viscoelastic	Linearity limit of binder	DSR
Multiple Recovery	Stress Creep	Rutting resistance	DSR
Linear Amplitude Sweep	Fatigue resistance	DSR	AASHTO TP 101
High Grading	Temperature	Maximum allowable temperature	DSR
Time Temperature Superposition (Master Curve)	G* and 6 extended range	DSR	ASTM Manual E1921
Zero Shear Viscosity	Useful for rutting measurement	DSR	-
FTIR	Chemical composition	Bruker 3000 Hyperion Microscope with Vertex 80 FTIR System	BRRC ME 83

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2.1 Literature Review on Performance of RAP Blended Binders

Liu et al., (2015) studied the influence of soft virgin binder on the rheological properties of three reclaimed polymer modified binders obtained from old surface layer of roads in Europe. The three RAP PMB from different sites were used in this study while two base binders and two PMB were used as soft virgin binder to be blended with the RAP binders. The blends were prepared with 15% and 40% RAP content. The rheological analysis for the blends was carried out by means of DSR in terms of the LVE range and master curve. It was reported that residual rheological properties of the polymer modification in the RAP binder were evident from the phase angle master curve as compared to the base binder. Addition of softer virgin bitumen helped in improving the properties of the RAP binders in terms of lower G* and reduced phase angle. Overall the author concluded that it is possible to restore the rheological properties of reclaimed PMB by addition of virgin PMB.

Jamshidi et. al. (2015) studied the rheological properties and the activation energy of virgin binder-RAP binder blends. A PG 64 binder was used as the base binder while the RAP binder was collected from three different sources and was blended in 15% and 30% proportions by mass of the asphalt binder. The ageing of the blend was done conforming to RTFO and PAV ageing standards. The rheological analysis was conducted by means of rotational viscometer, Superpave rutting and fatigue parameter i.e. G*/sin6 and G*sin6 respectively. The increase in viscosity per 1% recovered binder was evaluated using non-dimensional viscosity index while increase in G*/sin6 and G*sin6 per 1% recovered binder was evaluated by Superpave rutting gradient (RSRG) and fatigue gradient (RG) respectively.

Zhou et. al. (2014) analyzed the rheological properties of virgin binders blended with reclaimed asphalt shingles (RAS). Two virgin binders (PG 64-22A and PG 64-22B) and three RAS binders were used in the study. The blends were prepared with RAS content of 5%, 10%, 15%, 20%, 30%, 45%, 60% and 80%. The rheological properties were studied in terms of the performance grade (PG) of the blends and frequency sweep. The virgin binder-RAS blend showed a non-linear relationship for PG as opposed to a linear relationship observed in RAP blends. Also increase in the RAS content significantly increased the stiffness of the blend as was evident from the complex shear modulus master curves plotted using the Christensen-Anderson equation.

Mogawer et. al. (2012) conducted a study to analyse the effect of mixture production parameters and varying RAP content on the performance characteristics of virgin and RAP binder blend. Plant produced mixtures containing four different virgin base binders and RAP content varying from 0% to 40% were obtained. Further the blends were RTFO aged and PAV aged. The performance of the blending was evaluated in terms of rutting, cracking resistance and stiffness by means of Superpave parameters. The testing showed that addition of RAP increased the stiffness of the blend. The cracking resistance reduced while the rutting performance increased with an increase in the RAP content.

Colbert and You (2012) tested the PG 58-28 binder rheological properties by blending it with varying amount of RAP binder at three different ageing states i.e. unaged, RTFO Aged and PAV Aged. The RAP binder percentage in the blend was kept at 30%, 50%, 70% and 100%. The rotational viscosity test, temperature and frequency sweep were conducted to study the variation in the flow and rheological properties of the blends. It was observed that with the increase in the RAP binder proportion and with ageing, the blend goes on becoming stiffer, thus resulting in higher mixing and compaction temperatures. But in their case, increase in the RAP content from 50 % to 70% did not reflect much in the stiffness values over similar temperature and frequency ranges based on the G* value.

Wasage et. al., (2011) studied the newly developed MSCR test on a number of conventional, polymer modified and crumb rubber modified binders and check the suitability of the Jnr parameter for the prediction of rutting. For testing 4 different binders were used, one base binder (PG 64-25), 2 SBS PMB (PG 64-34 and PG 64-37) and1 CRMB (PG 64-37). The test was conducted from 30°C to 70°C using 25 mm plate geometry. The test was done for shear stress from 25 Pa to 25,600 Pa at 11 different levels with 10 cycles of 1 second creep and 9 second recovery at each level. Wheel tracking test was also performed on the mixes prepared using these binders to validate the test results. It was reported that ability of Jnr to predict rutting was largely dependent on the temperature and stress. The best relation between Jnr and rut depth was found at high stress levels, but was not useful as at higher stresses the material was beyond its linear viscoelastic range.

2.2 Literature Gaps

Limited study has been conducted to combine the rheological performance with chemical analysis in order to show the change in the rheology in relation to the presence of certain functional groups. Very few studies have been conducted to study the temperature susceptibility of the RAP blended binders using Brookfield viscosity. Another area which has limited studies is the effect of RAP binder addition on viscosity grading of VG binders. It is of particular importance from the point of view of India due to the grading system followed.

Furthermore, the rheological tests done till now in the above studies involve basic tests like G* and 6 determination, with not much emphasis laid on analysis based on performance parameters like rutting susceptibility or fatigue cracking potential using advanced tests like MSCR and LAS.

In addition, all the studies were conducted with focus on use of neat binder or PMB for studying the effect of RAP binder, but none of them has used CRMB which is widely used now-a-days.

3. METHODOLOGY

The detailed methodology followed in the course of this project is explained along with the experimental plan. It includes the details about the RAP collected and the base binders that were used in this study. It also includes the details of the tests that were conducted on the blends for their characterization.

3.1 Material Collections

In this study, two viscosity grade binder (VG10 and VG30), and two modified: polymer modified (PMB 40) and crumb rubber modified binder (CRMB 60) were collected. The VG 30 was obtained from Supreme Infrastructure Ltd., while VG 10, PMB 40 and CRMB 60 were obtained from Hindustan Colas Ltd. The RAP used in this study was collected from Mumbai-Nashik NH 3 from a site near Diva Village, 25 kms from Mumbai. The RAP, shown in Figure 3-1 was from the surface layer of 25 mm being removed and milled. The bitumen originally used in the surface layer was of penetration grade 50/60.

Figure 3-1: Reclaimed Asphalt Pavement

3.2 Extraction of RAP Binder

Extraction of RAP binder from the RAP was done in two stages, first, separation of aggregates from RAP using centrifuge extractor and then extraction of binder from solution using rotary evaporator.

3.2.1 Separation of Aggregates from RAP

This stage is carried out as per ASTM D2172. The procedure is as follows.

- Initially, 600 gm of RAP sample was taken and submerged in solvent until the RAP is completely submerged and then kept for minimum 30 minutes but not more than 55 minutes. The solvent used in this study is Tri-Chloro Ethylene (TCE).
- The sample was then transferred to the rotating container in the Centrifuge Extractor and the lid of the extractor was closed.
- Then, the sample was rotated at the gradually increasing speed of 0 rpm to 3500 rpm for at least 30 minutes or when the solvent stopped coming out of the drain pipe.
- After this wash is completed, the remaining aggregates were again submerged in TCE and similar process was done for separating solvent.
- Minimum of 3 washes were done to separate the aggregates from the RAP. The weight of the aggregates at the end of 3 washes was noted from which gave the weight of binder in 600 gm of RAP. One set of washes was completed in one and half hour.
- This was repeated 15 times and the averaged out bitumen content was found to be 4.3%.
- Centrifuge Extractor and its container are shown in Figure 3-2.

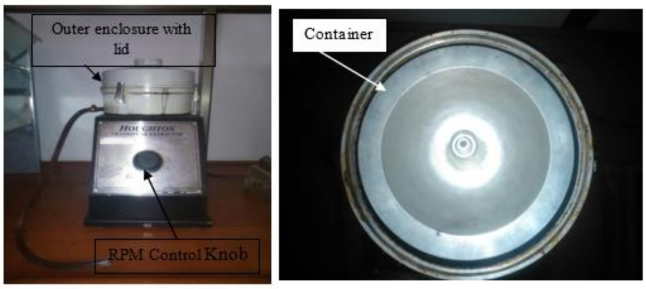

Figure 3-2: Centrifuge Extractor

3.2.2 Extraction of Binder from Solvent

In this second stage of RAP binder separation, the solvent obtained from centrifuge extractor was used. The binder separation was done by means of Rotary Evaporator in accordance with ASTM D 5404. A Rotary Evaporator and its components are shown in Figure 3-3.

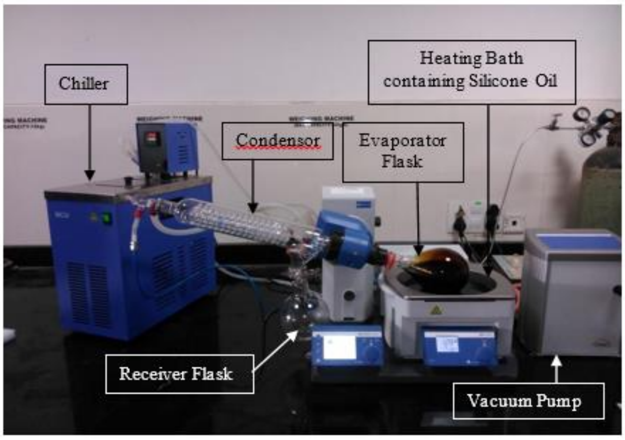

Figure 3-3: Rotary Evaporator

A stepwise procedure is given below.

- The apparatus was switched on and oil bath capable of heating upto 180°C was started. In this case, the oil bath was filled with Silicone 210 H oil having a boiling point of 210°C.
- Temperature of the oil bath was set to 135°C to 140°C.
- Chiller and water pump were switched on and temperature set to 20°C allowing the water to flow through the condensor for effective cooling.
- Evaporator flask was filled with the solution obtained from centrifuge extractor and attached the flask to the condensor tube as shown in the figure above.
- Receiver flask was attached to the condensor tube as shown in the figure.
- Setup was lowered using the control panel so that the evaporator flask touched the oil bath.
- Vacuum pump was switched on.
- Vacuum pressure was set at 700 mbar and rotation speed to 50 rpm to start with.
- Note that the clamp on the top of the condensor tube is at the lock position so that the pressure does not escape out.
- Once all the above steps were followed, test started using the control panel.
- As the solution got heated and started evaporating, vapours started condensing and TCE got collected in the condensor flask.

- Pressure was reduced by 50 mbar every 10 minutes and repeated upto a minimum pressure value of 75 mbar.
- Instrument was switched off when the collection rate at 75 mbar fell below 3 drops per 30 seconds.
- Evaporator flask was removed and inverted on a stand in the oven to collect the RAP binder.
- TCE collected from condensor flask for reuse.
- One run of rotary evaporator took about 1 hour 30 minutes for completion.

3.2.3 Selection of RAP Percentage

The percentage of RAP binder was added in different proportions. For VG grade binder, four different percentages of RAP binder, i.e., 15%, 25%, 40%, and 50% were utilized. Likewise, for polymer and crumb rubber modified binders, three different percentage of RAP binder, i.e., 15%, 25%, and 40% were used. The RAP percentage was higher for VG grade binder to develop the viscosity blending chart using absolute viscosity, and to compare the viscosity of RAP blended VG10 binder with VG30 binder. This analysis helped to understand the percentage of RAP require to result in the viscosity equivalent to VG30 binder. Similarly, the percentage of RAP used for modified binder helped to evaluate the change in their chemical and rheological performance. The blending proportions were decided based on Superpave criteria given by McDaniel and Anderson (2001). The criteria specified no Grade bump upto 15% RAP content, a drop of one grade for RAP content between 15% to 25% and above 25% the use has to be based on the preparation of blending charts with 30 % being the upper limit for addition of RAP. 40% RAP binder content was done to study the effect of high RAP content on the binder properties.

3.2.4 Mixing of RAP with Binders

The RAP binder was mixed with virgin binder using Ross Mixer available in Advanced Pavement Laboratory at IIT Bombay at a speed of 500 rpm for 30 mins at temperature of 140°C. The mixer is shown in Figure 3-4.

For VG 10 binder, the RAP binder content was set at 15%, 25%, 40% and 50% while for VG 30, PMB 40 and CRMB 60 it was set at 15%, 25% and 40%. The blending percentages were set based on the proportions by weight i.e. for 10% VG 10 blend, every 100 gm contains 90 gm of VG 10 and 10 gm of RAP binder. The blade of mixer was moved along the depth of the container to ensure uniform mixing.

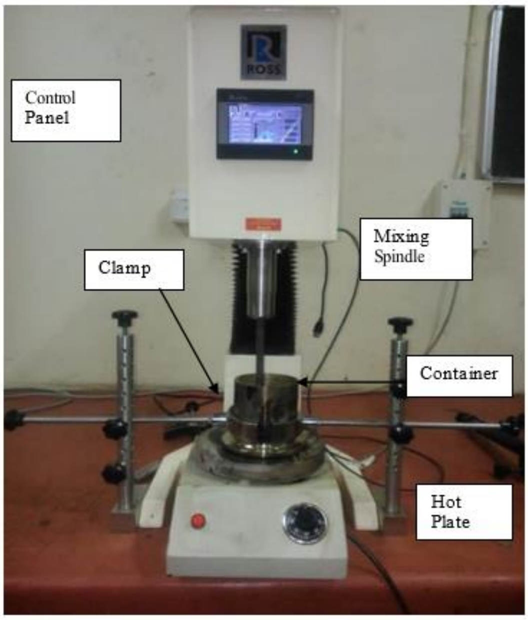

Figure 3-4: Ross Mixer

3.2.5 Experimental Plan

The testing of the virgin binder, RAP binder and the RAP blended binder was done in four parts (1) preliminary tests: penetration, softening point, ductility and elastic recovery; (2) Viscosity analysis using Brookfield viscometer and vacuum capillary viscometer; (3) rheological characterization tests: linear viscoelastic range, high temperature grading, multiple stress creep and recovery test, linear amplitude sweep test and test for master curve estimation; (3) chemical characterization using FTIR analysis. Each of the test was performed using 3 samples at each blending proportion. The overall experimental plan is as shown in Figure 3-5. The test parameters of each test have been explained in detail later.

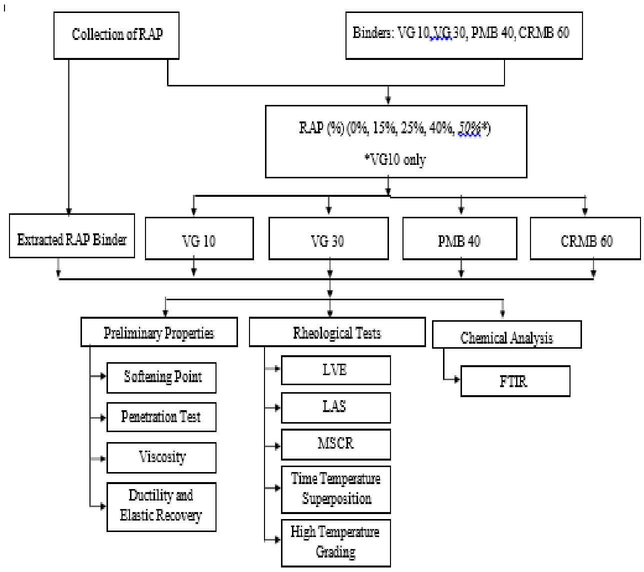

Figure 3-5: Experimental Plan

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4. RESULTS

In this section the results of the different tests conducted for the characterization of basic, rheological and chemical analysis of virgin binders, RAP binder and RAP blended binders are prescribed.

4.1 Preliminary tests

The preliminary tests were conducted in three stages (a) tests on collected samples of binders to verify the grade (b) tests on extracted RAP binder to evaluate its characteristics, and (c) tests on RAP blended binders.

4.1.1 Characterization of collected binders

In this section, the results of the preliminary tests conducted on the collected binders (VG 10, VG 30, PMB 40 and CRMB 60) are discussed. The results obtained were compared with the criteria provided in the IS codes for grading of the binder in order to verify the grade.

4.1.1.1 Softening point test

The softening point test was conducted on CRMB 60 binder in order to verify its grade. The softening point value of 62°C was obtained for the sample. As per IS 15462 : 2004, CRMB 60 should have a minimum softening point value of 60°C, thus satisfying the codal provisions.

4.1.1.2 Penetration test

The penetration test was conducted on the PMB 40 sample. A penetration value of 45 units (4.5 mm) was reported for the sample. As per IS 15462: 2004, PMB 40 should have a penetration values between 30 to 50 units, thus satisfying the requirements of the code.

4.1.1.3 Ductility test

Ductility test was conducted on all the collected binders. The results though were obtained for modified binders (CRMB 60 and PMB 40) only, since conventional binders (VG 10 and VG 30) were subjected to a sagging problem while testing at 25°C while at 15°C premature breaking was observed. The PMB 40 gave a ductility value of 137 cm while it was 15.1 cm at 15°C for CRMB 60 sample.

4.1.1.4 Elastic recovery test

The elastic recovery was found to be 5%, 87% and 30% for VG 30, PMB 40 and CRMB 60 binder, respectively. As expected it was negligible in case of VG 10 binders. IS codes do not specify elastic recovery values for VG 10 and VG 30 binders As per IS 15462 : 2004, PMB 40 should have a minimum elastic recovery value of 70% while that for CRMB 60 should be 30%. Thus the collected samples satisfied the code requirements.

4.1.1.5 Absolute viscosity test

Though this test is not a part of the preliminary tests, the gradation of VG 10 and VG 30 binders is based on absolute viscosity values and hence it was conducted on the 2 binders. VG 10 binder gave absolute viscosity 1037 Poise at 60°C while that of VG 30 was found to be 2949 Poise. As per IS 73 : 2013, minimum absolute viscosity for VG 10 is 800 Poise while that for VG 30 is 2400 Poise, thus satisfying the criteria.

4.1.2 Characterization of RAP blended binders

In this section, test results of the preliminary tests conducted on different RAP blended binders are reported.

4.1.2.1 Softening point test on CRMB 60 blends

The Figure 4-1 shows softening point value of CRMB 60 binder blended with 0, 15%, 25%, and 40% RAP binder. It can be seen that initially with addition of RAP (15% and 25% RAP), the softening point decreased from 62°C to 53°C which may be attributed to the replacement of the solid crumb rubber particles with RAP binder. The softening point of 15% and 25% RAP blended binder shows similar value. However, further addition of higher percentage of RAP (i.e. 40%) increased the softening point to 61°C, which may be due to RAP binder having a higher softening point as compared to the CRMB 60 binder. The results are in consistent with Hamzah and Shahadan (2011), who reported increase in softening point with RAP addition.

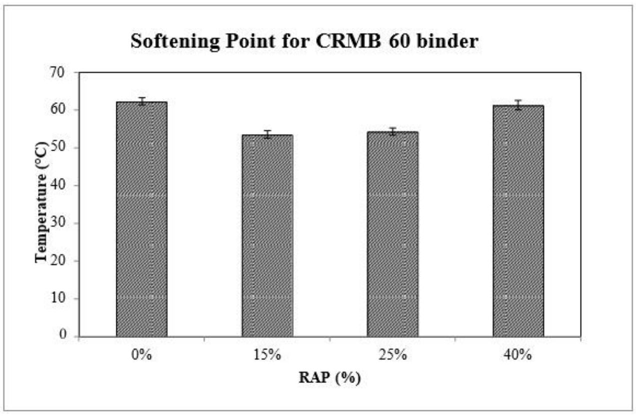

Figure 4-1: Results for softening point test on CRMB 60 binder

4.1.2.2 Penetration test on PMB 40 blends

The Figure 4-2 shows penetration value of PMB 40 binder blended with 0, 15%, 25%, and 40% RAP binder. It can be seen that with the addition of RAP, initially (0% and 15% RAP) the penetration value of the blend (remained constant at about 45-47 units. After that it progressively decreased from 47, 37 and 33 units for 15%, 25% and 40% blend, respectively. The reduction in penetration value can be attributed to the addition of stiffer RAP binder to PMB 40. Hamzah and Shahadan (2011) also reported reduction in penetration value with RAP addition.

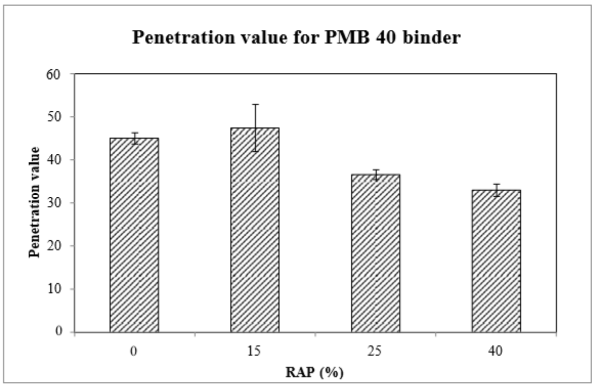

Figure 4-2: Results for penetration test on PMB 40 binder

4.1.2.3 Ductility and elastic recovery tests on different binder blends

The Figure 4-3 compares the results of ductility tests conducted at 15°C. The test results are reported for PMB 40 and CRMB

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60 binders as the tests conducted on VG 10 and VG 30 binders had sagging problem and no satisfactory results were obtained. It can be seen that ductility decreased with addition of RAP binder. For example, ductility of PMB 40 binder decreased from 1370 mm (0 %RAP), 1180 mm (15% RAP), 828 mm (25% RAP) to 754 mm (40% RAP). Similarly, ductility of CRMB 60 decreased from 151 mm (0% RAP) to 59 mm with addition of 40% RAP. The rate of change in ductility was significant for PMB 40 binder than that of CRMB 60 binder, indicating that addition of RAP decreased ductile behaviour of polymer modified binder significantly. The decrease in ductility can be due to replacement of modifier in the binders.

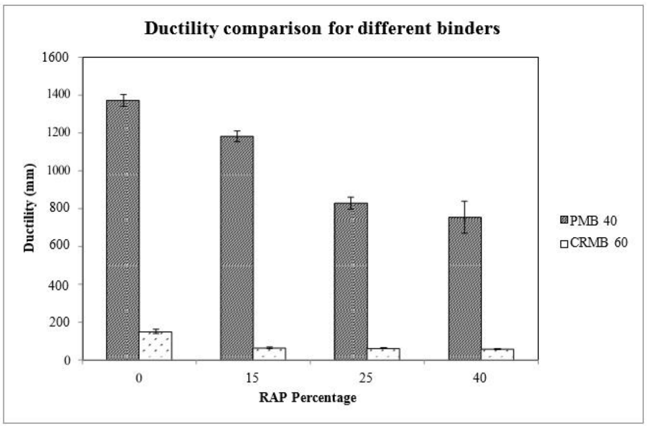

Figure 4-3: Results for ductility test on all binders

The Figure 4-4 compares the results of elastic recovery tests. The test was conducted on all the binders. From the results it can be seen that the purpose of the modifier was served in both PMB 40 and CRMB 60 binders as they showed a high value of elastic recovery (ER).

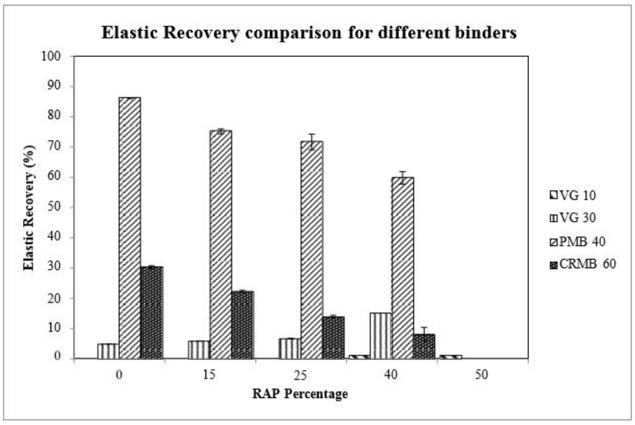

Figure 4-4: Results for elastic recovery test on all binders

4.2 Viscosity analysis

In this section the results obtained for the viscosity testing conducted on different binder blends have been presented. The results were divided based on test i.e. Brookfield test and absolute viscosity test.

4.2.1 Brookfield Viscometer Test

The kinematic viscosity was measured using the Brookfield viscometer test. The kinematic viscosity values were used to measure the mixing and compaction temperature of the different binder blends. Further, viscosity values were used to determine temperature susceptibility of the binder using the A-VTS relationship.

4.2.1.1 Brookfield viscosity for extracted RAP binder

Figure 4-5 shows the plot for Brookfield viscosity test conducted on the extracted RAP binder sample at varying temperatures. The viscosity goes on decreasing with increase in the temperature.

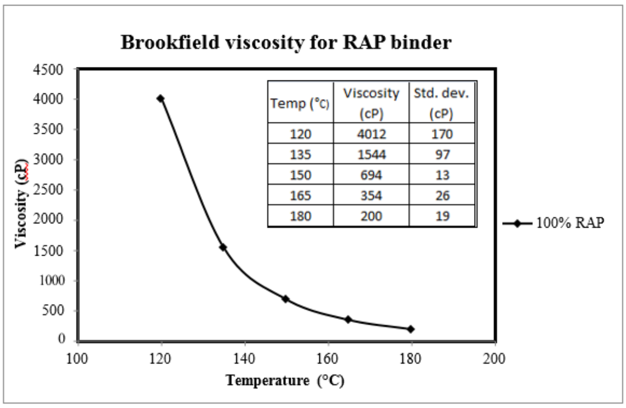

Figure 4-5: Brookfield viscosity for RAP binder

4.2.1.2 Brookfield viscosity for different binder blends

Figure 4-6 to Figure 4-9 show the viscosity plots obtained for the different RAP blends for the conventional as well as modified binders at varying temperatures i.e. 120°C, 135°C, 150°C, 165°C and 180°C. It can been seen that viscosity increased with addition of RAP binder. It can be noted that conventional binders showed comparatively significant difference with RAP addition as compared to the modified binders. The difference in the modified binders may be less due to the presence of the modifiers, which impart viscosity.

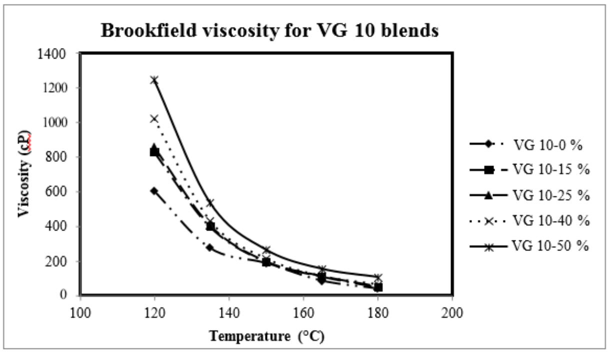

Figure 4-6: Results of Brookfield viscosity on VG 10 blends

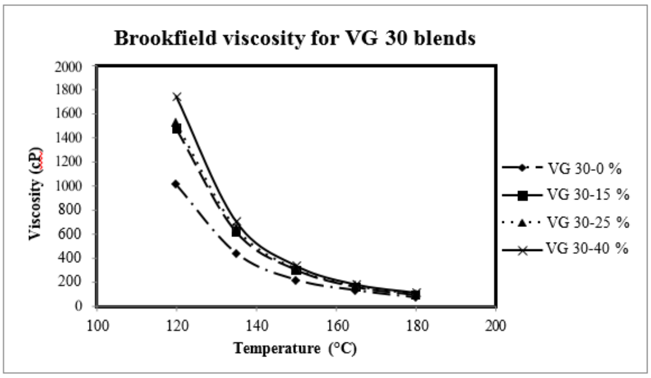

Figure 4-7: Results of Brookfield viscosity on VG 30 blends

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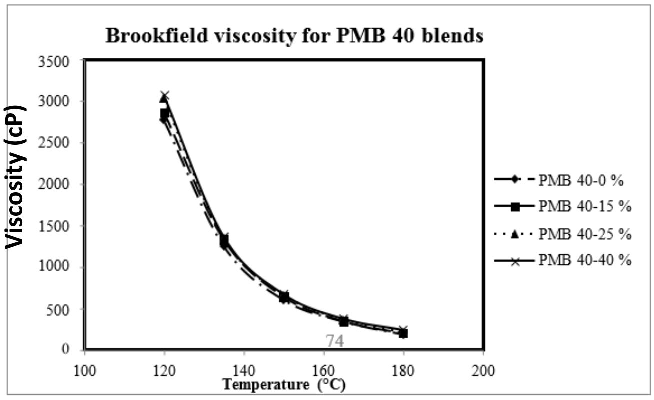

Figure 4-8: Results of Brookfield viscosity on PMB 40 blends

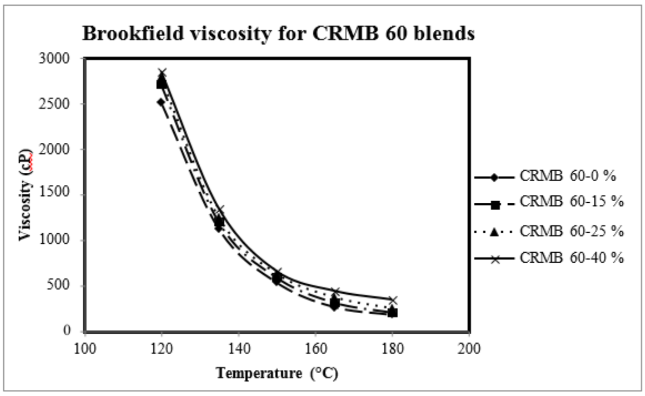

Figure 4-9: Results of Brookfield viscosity on CRMB 60 blends

4.2.1.3 Temperature susceptibility of different binder blends

The effect of RAP binder addition on the binder viscosity with change in temperature, called as temperature susceptibility was studied using A-VTS relationship explained in literature review section. The Brookfield viscosity values were used to determine the A-VTS relationship. Figure 4-10 to 4-13 show the log log viscosity vs. log temperature plots, the slope of which gives the value of temperature susceptibility. From the results it could be seen that addition of RAP binder helped in improving the temperature susceptibility in case of both conventional and modified binders. Kim et. al. (2011) reported similar results in their study i.e. improving temperature susceptibility.

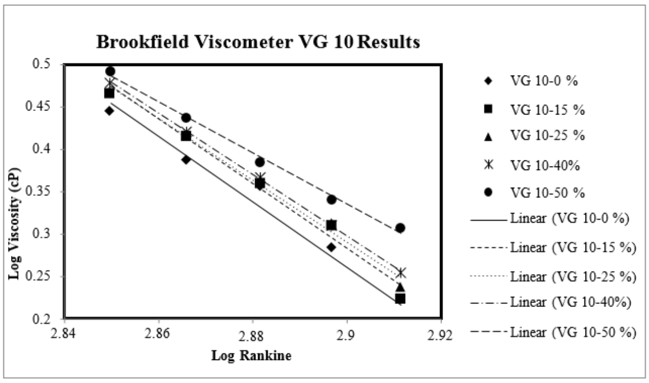

Figure 4-10: Temperature susceptibility plots for VG 10 blends

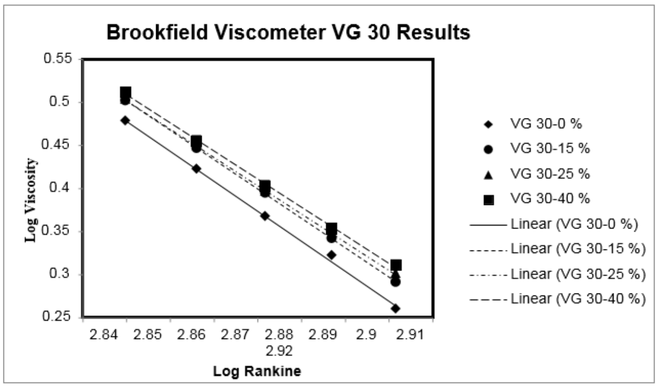

Figure 4-11: Temperature susceptibility plots for VG 30 blends

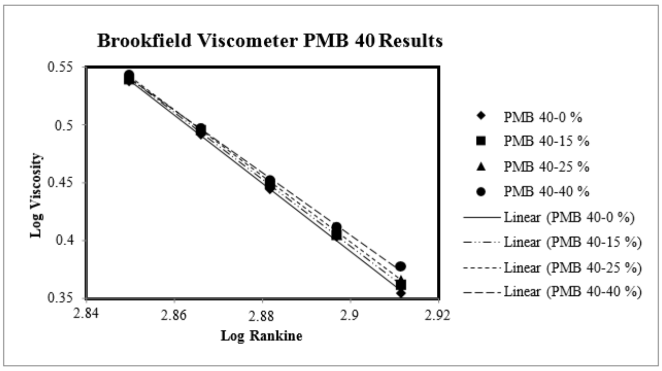

Figure 4-12: Temperature susceptibility plots for PMB 40 blends

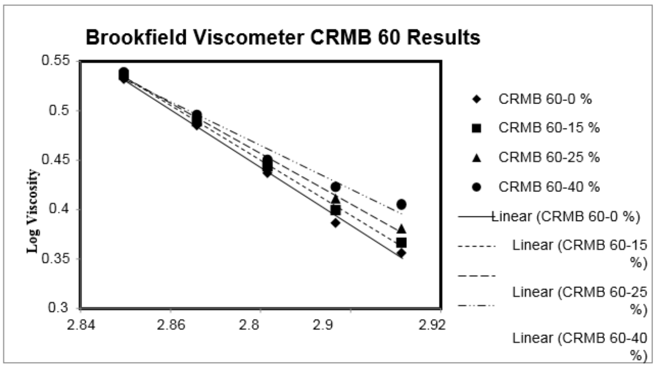

Figure 4-13: Temperature susceptibility plots for CRMB 60 blends

4.2.2 Absolute viscosity test

In this section the results of the absolute viscosity test conducted on conventional binder blends and the blending charts prepared based on the obtained data are provided.

4.2.2.1 Absolute viscosity values

The absolute viscosity test was performed using vacuum capillary viscometer. It was conducted to study the effect of RAP addition on the viscosity grade of VG 10 and VG 30 blends. Figure 4-14 shows the variation in the absolute viscosity of the binders due to RAP addition. It can be seen that though the viscosity increased with increase in the RAP content, no exact relationship or trend is visible for the variation. For VG 10 blends the absolute viscosity increased from 1037 Poise for virgin binder to 3051 Poise for 50% RAP content.

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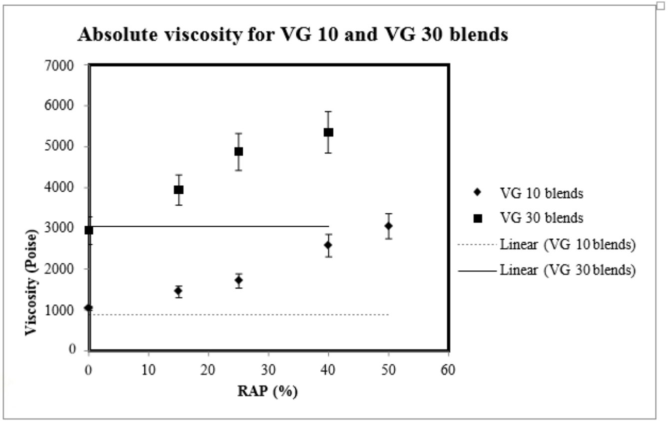

Figure 4-14: Results of absolute viscosity on VG 10 and VG 30 blends

4.2.2.2 Blending chart

ASTM D4887 provision was followed for plotting the blending charts. The method provided is based on the absolute viscosity at 60°C and high temperature grade of the virgin and RAP binder. Due to the limitation of the available instrument, the blending chart based only on the high temperature grade could be studied. For determining optimum RAP content, results absolute viscosity and high temperature grade for VG 10 blends was compared with that of the virgin VG 30 binder to get an approximate value. Figure 4-15 shows the blending chart as per ASTM D4887 based on the high temperature grade of the binder.

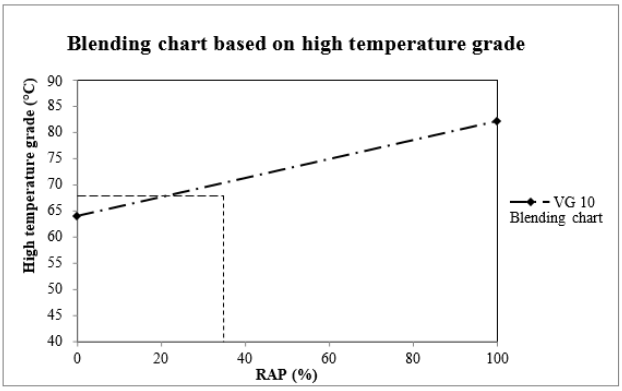

Figure 4-15: VG 10 blending chart based on high temperature grade

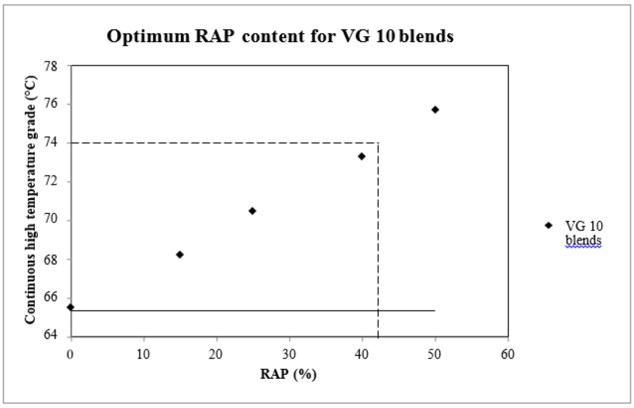

Figure 4-16: Approximate VG 10 blending chart based on high temperature

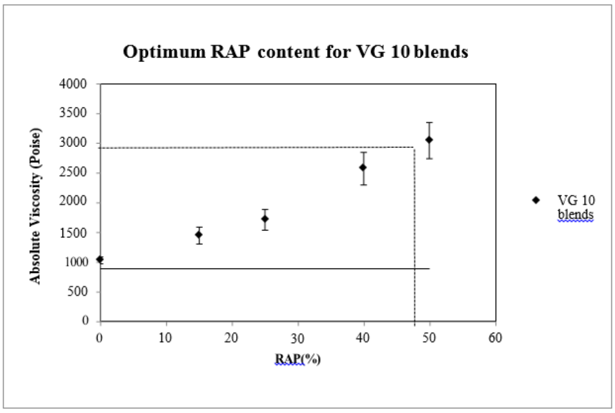

Figure 4-17: Approximate VG 10 blending chart based on absolute viscosity

4.3 Linear Viscoelastic Range

The LVE range was determined by testing the sample subjected to increasing strain and corresponding measurement of G* value. The strain corresponding to 5% reduction in G* value is noted as the LVE range. The rheological models developed for binders are applicable within this LVE range.

4.3.1 LVE range for extracted RAP binder

Figure 4-18 shows the LVE range plot for extracted RAP binder. LVE value for RAP binder was found to be 24%. The value meant that upto 24% strain, the reduction in the G* value for RAP binder was 5%.

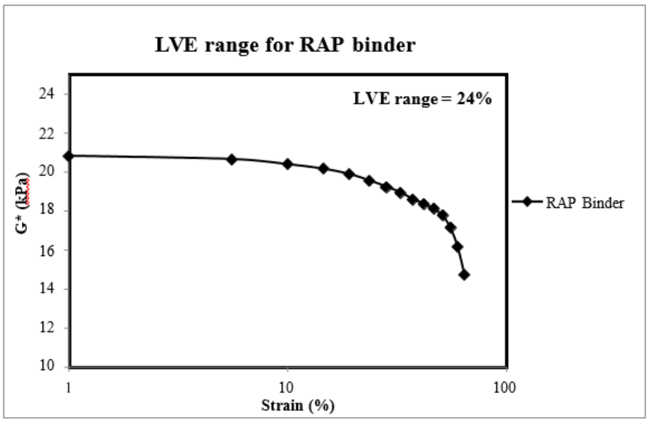

Figure 4-18: LVE range plot for RAP binder

4.3.2 LVE range for conventional binder blends

This section summarizes the results pertaining to the LVE range of conventional binders i.e. VG 10 and VG 30 blended with different percentages of RAP (i.e., 0%, 15%, 25%, 40%, and 50%).

The Figure 4-17 and Table 4-18 shows the plots and values for LVE range of VG 10 blends. It can be seen that the LVE range decreases with addition of RAP. For example, the LVE for VG 10 virgin binder was found to be 256%, which decreases to 197%, 173%, 137%, and 95% with addition of 15%, 25%, 40%, and 50% RAP, respectively.

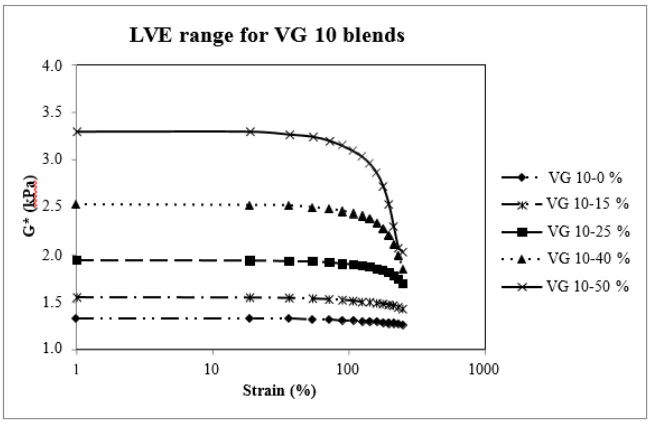

Figure 4-19: LVE range plot for VG 10 blends

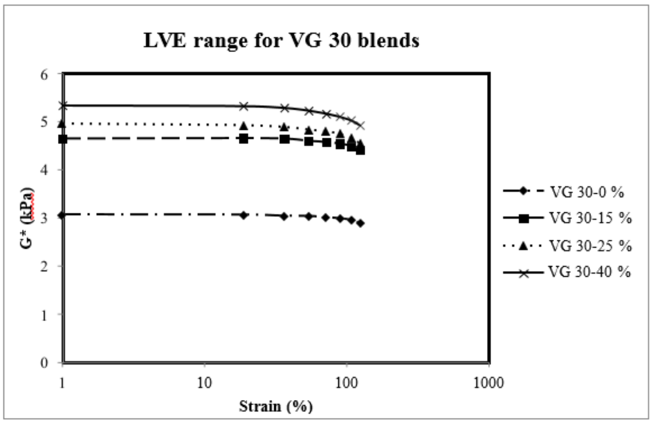

Figure 4-20: LVE range plot for VG 30 blends

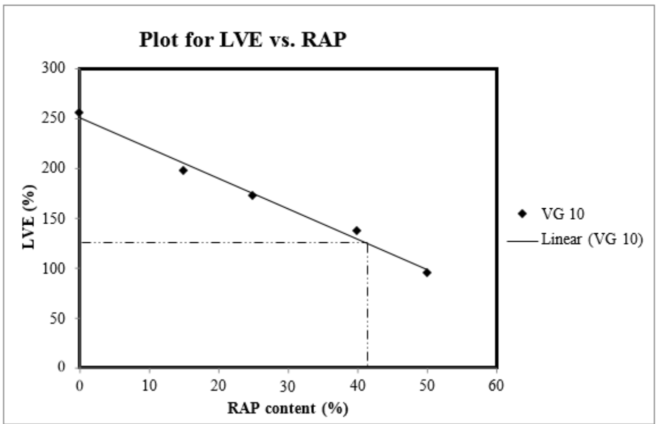

Figure 4-21: Plot for LVE vs RAP content

4.3.3 LVE range for modified binder blends

The Figure 4-22 show the plot and values of LVE range for PMB 40 binder blended with different percentages of RAP. From the results it can be seen that addition of the RAP binder causes a reduction in the LVE range of PMB 40 binder. For example, the LVE range reduces from 104% for virgin PMB 40 to 79% for 40% RAP content blend. This change may be a combined effect of both, stiffening of binder due to RAP addition as well as reduction in the proportion of polymer. The reduction in the polymer content was verified by means of FTIR testing performed on the samples. Thus it can be seen from the results that with RAP addition, the binder became stiffer along with reducing the polymer content, thus reducing the LVE range for PMB 40 blends.

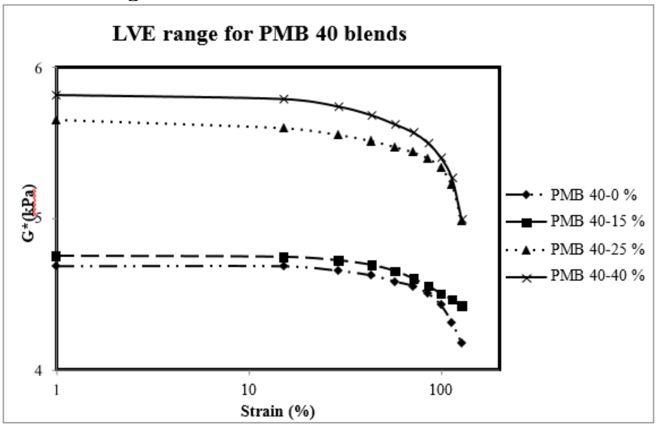

Figure 4-22: LVE range plot for PMB 40 blends

5. Conclusions

The present study was undertaken to evaluate rutting, fatigue, rheological performances of different types of modified (PMB 40, CRMB 60) and unmodified (VG 10, VG 30) binder with and without addition of reclaimed asphalt pavement (RAP). The RAP binder was extracted using Rotary Evaporator method. The four different percentages of RAP 0%, 15%, 25% and 40% was blended with modified and unmodified binders.
Preliminary characterisation of virgin binders, extracted RAP and RAP blended binders was conducted. Further, different tests were conducted to study the effects of RAP on the viscoelastic properties of binders. The Brookfield viscosity test was conducted to determine mixing and compaction temperature of the binders with and without addition of RAP. In addition, kinematic viscosity was used to estimate temperature susceptibility of the binders. The absolute viscosity was measured using vacuum capillary viscometer for purpose of grading VG 10 and VG 30 binders and for developing blending charts.
The LVE range test was conducted to study the region of linear behaviour for the binders. The rutting resistance of RAP containing binders was studied by means of different approaches, namely, MSCR test, Superpave high temperature grade, ZSV and non- recoverable compliance. The fatigue behaviour of binder blended with different percentages of RAP was studied by conducting recently developed LAS test. The frequency and temperature sweep tests were conducted to evaluate performance of the binders. Finally change in chemical composition of the binder's blends was measured using FTIR spectroscopy. Further, relationship between rheological and chemical property of binders with addition of RAP was established. An effort was made to determine the optimum RAP binder content for VG 10 binder so a binder with similar or better performance than VG30 can be achieved.

The following section summarizes conclusions drawn in this study. The effects of RAP on preliminary properties, viscosity, LVE range, high temperature grade, rutting, fatigue, and chemical property are discussed under a different heading.

Preliminary properties

• Penetration value for PMB 40 binder decreases from 45 units to 33 units with 0% to 40% increase in RAP content, improvement in stiffness with addition of RAP.

• Softening point for CRMB 60 binder initially reduces with addition of RAP upto 25%, and then increases for 40% RAP content.

• Ductility and elastic recovery of for both modified binder's decreases significantly with an increase in RAP content. Ductility reduced from 1370 mm to 754 mm for PMB 40 while for CRMB 60 reduced from 151mm to 59 mm. ER reduced from 87% to 60% and 30% to 8% for PMB 40 and CRMB 60 respectively. It can be to reduction in the modifier content.

• Elastic recovery for VG 10 remained almost zero with and without RAP, while elastic recovery of VG 30 binder increases from 5% to 15% with addition of RAP.

Viscosity and Blending Chart

• Kinematic viscosity increases with addition of RAP for modified and conventional binders. Likewise, absolute viscosity measured for conventional binder at 60°C increases with RAP content.

• Addition of RAP binder increases mixing and compaction temperature for both modified and conventional binder blends. Further, addition of 40% RAP in VG 10 binder gives similar mixing and compaction temperature values to those of virgin VG 30 binder. REWHDGC NB

• Temperature susceptibility improved with addition of RAP for modified and conventional binder blends, though the difference was less at higher RAP content

• Blending chart for VG10 binder with different percentage of RAP was plotted based on absolute viscosity at 60°C and based on high temperature grade using Superpave rutting parameter. QWERTYUI

• The optimum RAP binder content of VG10 which can result a similar viscosity at VG30 binder was found to be approximately 46 % and 38%, from absolute viscosity and high temperature grade, respectively.

LVE range

• LVE range reduces with addition of RAP for conventional binder blends, though the reduction in G* value was more drastic in a softer VG 10 blends than in VG 30 blends. For VG 10 it reduced from 256% to 95% while for VG 30 it reduced from 122% to 96% with RAP addition.

• Addition of 42% RAP content to VG 10 binder gave results similar to virgin VG 30 binder.

• Similarly, the LVE range of PMB 40 reduces with addition of RAP (104% to 79%), while no trend was observed for CRMB 60.

6. FUTURE WORK

• The effects of RAP obtained from different sources should be tried in future study. Further, the effects of long term aging on RAP blended binders should be studied in detail.

• The results obtained from LAS test on fatigue performance can be correlated with laboratory or field measured fatigue resistance of asphalt mixes. Similarly, validation of the rutting resistance of blends can be confirmed by means of wheel tracking in future.

• The CRMB 60 blends could not give satisfactory results in any of the advanced rheological tests conducted, hence further research needs to be conducted to determine the reason for the same.

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