DETERMINING THE RHEOLOGICAL PROPERTIES OF ASPHALT BINDER USING DYNAMIC SHEAR RHEOMETER (DSR) FOR SELECTED PAVEMENT STRETCHES

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Abstract

This paper aims to study the rheological properties of the binder taken from four years old flexible pavement stretch. The stretch was divided into six different sections based on the thickness of the surface course. Originally, 60/70 grade asphalt binder was used throughout the pavement stretch. The binder was obtained from the process of extraction and recovery. Dynamic shear rheometer (DSR) test was conducted on the recovered asphalt binder to determine the various parameters viz., Complex modulus G^*, Elastic and viscous modulus, Complex viscosity and the phase angle δ. The major pavement distress modes namely, rutting and fatigue cracking were addressed by these output parameters of DSR. Rutting is caused by permanent deformation of paving mix while fatigue is related to the energy absorbed during repeated load application to pavement. The test results indicated that the 60/70 binder extracted from the selected stretches were stiff enough to resist rutting and fatigue failure.

Keywords: *Rheology, Dynamic shear rheometer, Complex modulus, phase angle, Rutting, fatigue*.

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1. INTRODUCTION

Rheology is a very powerful tool for characterizing and quantifying material properties. It has been well established that the rheological properties of asphalt binder affects the pavement performance. Since the rheological properties of asphalt change during production and continue to change subsequently in service, there is necessity to study the phenomenon of ageing. The first significant hardening of asphalt takes place in pug mill or drum mix plant where heated aggregate is mixed with hot asphalt cement. Substantial rheological changes such as decrease in penetration and increase in viscosity of asphalt binder takes place during short mixing period from both air oxidation and loss of more volatile components. Age hardening of asphalt continues, although at much slower rate, while the HMA is processed through a surge or storage silo, transported to the paving site, laid, and compacted. After the HMA pavement has cooled and been opened to traffic, age hardening continues at a significantly slower rate for first two to three years until the pavement approaches its limiting density under traffic. Thereafter the rate of age hardening is further reduced at longer time periods are needed to decide to changes in the rheological properties of asphalt cement.

Rutting resistance depends mainly on aggregate properties and mix design although binder characteristics are a secondary factor. The behavior is characterized in the SUPERPAVE specification by the complex shear modulus measured using dynamic shear rheometer (DSR). $G^*/\sin\delta$ is the rutting resistance parameter, while $G^* \sin\delta$ is the fatigue resistance parameter, according to SUPERPAVE specifications.

1.1 Objectives of Present Paper

1) To select the flexible pavement stretches for asphalt binder extraction.
2) To evaluate the change in basic binder property like softening point.
3) To evaluate the visco-elastic behavior of extracted neat bitumen of grade 60/70 by direct shear rheometer test.
4) To determine the rutting and fatigue resistance of binder under existing pavement conditions.

2. LITERATURE REVIEW

Conventional Bituminous materials have tended to perform satisfactorily in most highway pavement and airfield runway applications. With conventional methods such as penetration, viscosity, ductility and ring and ball softening point may still adequately describe the rheological characteristics of conventional bitumen, they have limited ability to accurately predict the relative performance of modified materials. Currently, dynamic shear rheometer is identified as a powerful tool to study the rheological characteristics.

Cho proposed a new experimental method called dynamic shear rheometer. This method was used to measure asphalt-aggregate interfacial properties. A degree of moisture damage relating to the interfacial properties was then quantified using linear viscoelastic concepts to propose a meaningful parameter, called wet to dry yield shear stress ratio. [1]

Apeagyei et al., adopted the use of higher recycled asphalt pavement (RAP) percentages with locally available binders. The results indicated that measured binder stiffness of high-RAP mixtures were not significantly affected by RAP amount. The correlation between binder stiffness and flow number for the selected high-RAP mixtures considered was good. The study concluded that the addition of higher amounts of RAP to asphalt concrete mixtures did not result in excessively stiffened mixture. [2]

A study was conducted to estimate E values of two commonly used hot mix asphalt (HMA) mixes. They observed that rotational viscometer (RV) test data overestimate the E values in the case of stiff binders. Conversely, dynamic shear rheometer (DSR) test data predict significantly lower E values of asphalt mixes. The study provided transportation professionals with a better understanding of material input parameters that influence E values of asphalt mixes [3]

Badawy et al., investigated two models for Levels 2 and 3 hot-mix asphalt (HMA) dynamic modulus (E) predictions using dynamic shear rheometer. The two models were NCHRP 1-37A and NCHRP 1-40D. The primary difference between the two is the binder stiffness parameter; viscosity or shear modulus. The influence of the binder characterization input level on the performance of the predictive models was evaluated. [4]

The viscoelastic behavior of asphalt mixtures can be conveniently presented in the form of a stiffness master curve in various engineering applications. Kalapi G. Biswas(2007) described and compared the methods for constructing asphalt mixture master curves utilizing stiffness predictive equations for asphalt binders and mixtures, in addition to using laboratory measurements, as an alternative to FWD back calculation analysis. [5]

An effort to characterize asphalt emulsions that are typically used in cold in-place recycling applications for asphalt binders was done. Four asphalt emulsions were investigated: CRS-2P, CSS-1, EE, and HFMS-2P. The air-cured samples were aged in the pressure aging vessel. The residues were tested using the bending beam rheometer at low temperatures and the dynamic shear rheometer at high and intermediate temperatures. The methods described in AASHTO M320 and MP1a specifications were used to determine critical temperatures for four asphalt emulsions and master curves of absolute value of the complex modulus G* were obtained to investigate rheological behavior of the residues. [6]

With increasing use of modified asphalt binders, the correct compaction temperature range for asphalt mixtures containing these binders needs to be determined. However, the current procedure often provides unacceptably high temperatures for modified binders. In one of the studies, the shear properties of the mixture compacted at four temperatures was evaluated. These properties improved to some extent with an increase in temperature, except for strain-controlled fatigue damage. Finally, it was concluded that the changes in the shear stiffness of the asphalt binder was one of the responsible factors for the changes in mixture shear properties. [7]

Tan Yi-Qiu et al., investigated the interactions between granites and asphalts based on rheology. The rheological properties of asphalt mastics using different granite powders and different filler-asphalt ratios were measured using a dynamic shear rheometer. Statistically significant relations between the rheological properties of the granite-asphalt mastics and the moisture stability of granite-asphalt mixtures were found. For practical application, the selection criteria for selecting granite aggregates for use in roads were developed. [8]

3. METHODOLOGY

The study stretch selected was From Sirsi circle to RV college of Engineering along Bangalore – Mysore State Highway 17. The stretch is a four lane divided highway scheduled for up gradation to six lanes. The pavement composition along the arterial road stretch included of surface, base and sub-base course upon sub grade. The existing flexible pavement crust thickness and compositions were noted along the roadway at shoulder level. Based on the composition and thickness of the individual layers, the stretch was divided into six sections and the details are as given in Table 1. As per BBMP records the age of pavement varied between 3 to 4 years.

Table 1: Section number and composition for the study sections

Section	Section number	Details
R.V. College of Engineering to Bangalore University	C1	BC+DBM=200mm, Base=200mm, Sub-Base=200mm
Bangalore University to Gopalan	C2	BC+DBM=150mm, Base=200mm, Sub-Base=200mm

Arcade		
Gopalan Arcade to Pipeline Road	C3	BC+DBM=100mm, Base=200mm, Sub-Base=200mm
Deepanjali Nagar to Satellite Bus Station	C4	BC+DBM=150mm, Base=200mm, Sub-Base=100mm
Satellite Bus Station to Gopalan Mall	C5	BC+DBM=80mm, Base=200mm, Sub-Base=100mm
Gopalan Mall to Sirsi Circle	C6	BC+DBM=80mm, Base=200mm, Sub-Base=120mm

The original asphalt binder used for construction was 60/70 grade. The details of the basic properties of this asphalt binder are as shown in Table 2.

Table 2: Basic properties of original asphalt binder

Basic tests	Result	Limit as per IS-73-1961 & 2006
Penetration test @ 25°C, 0.1 mm, 100 g, 5 secs	65	60-70
Specific gravity @ 25°C, mm	0.982	0.99
Water % by mass (max)	0.207	0.20
Softening point	44	40-55
Solubility in tri-chloroethylene %, mm	98.30	99

RAP samples were obtained from these sections. Samples were taken from the test pits dug to a depth equal to thickness of the surface layer. Samples were then subjected to extraction process using Centrifugal extractor to separate binder from aggregates.

3.1 Extraction Process

Extraction of asphalt cement for rheological testing was done as per IRC SP 11-1998. The paving mixture was repeatedly washed and filtered with solvents in the centrifugal extractor apparatus. A known weight of sample was weighed and placed in the bowl of extractor apparatus and covered with commercial grade of benzene. Sufficient time was allowed for the solvent to disintegrate the sample before running the centrifuge. The cover of the bowl was clamped tightly. A beaker was placed under to collect the extract. The machine was revolved slowly and then gradually at a speed of 3600 revolutions per minute. The speed was maintained till the solvent ceases to flow from the drain. The machine was allowed to stop and 200ml of benzene was added and the above procedure was repeated.

3.2 Recovery Process

Recovery of asphalt cement was done by Abson method of distillation as per ASTM D1856. This method covers the recovery by the Abson method of asphalt from a solution from a previously conducted extraction. The asphalt was recovered with properties substantially the same as those it possessed in the bituminous mixture and in quantities sufficient for further testing. In this process the solvent of benzene and bitumen was heated at 135°C until all the benzene vaporizes and gets collected in a beaker passing through the condenser. Asphalt cement was left out as a residue in the round bottom flask placed in a heating mantle. Similarly asphalt cement samples of all the six sections were obtained.

Softening point test was conducted on reclaimed binder and the results are as presented in Table 3.

Table 3: Softening point test results

Section	Softening point on(°C) :		
	Reclaimed binder	Original binder	Specification
C1	48	44	40-55
C2	47		
C3	47		
C4	48		
C5	46		
C6	47		

The average value of softening point was found to be 47°C.

3.3 Dynamic Shear Rheometer

To study the rheological properties of these asphalt cement samples, dynamic shear rheometer test was conducted at pavement service temperature as per IRC 53-2010.

Preparing Test Specimens:- The surfaces of the test plates were carefully cleaned and dried so that the specimen adheres to both plates uniformly and strongly. The chamber is brought to approximately 45°C so that the plates are preheated prior to the mounting of the test specimen. This will provide sufficient heat so that the asphalt binder may be squeezed between the plates for trimming and to ensure that the asphalt binder adheres to the plates. The test procedure is as follows:

1. Bring the specimen to the test temperature + 0.1°C.
2. Set the temperature controller to the desired test temperature, including any difference as required. Allow the temperature to come to the desired temperature.
3. The test shall be started only after the temperature has remained at the desired temperature + 0.1 °C for at least 10 minutes.
4. After temperature equilibration, anneal the specimen for 5 minutes.
5. *Strain Control Mode*--When operating in a strain controlled mode, determine the strain value according to the value of the complex modulus. Control the strain within 20 % of the target value calculated by equation given below:

$$\gamma = 12.0/(G^*)^{0.29} \quad (1)$$

Where:
γ = shear strain in percent
G^* = complex modulus in kPa

6. *Stress-Controlled Mode*: When operating in a stress-controlled mode, determine the stress level according to the value of the complex modulus. Control the stress within 20% of the target value calculated by equation below:

$$\tau = 0.12(G^*)^{0.71} \quad (2)$$

Where:
τ = shear stress in kPa

7. Software is available with the dynamic shear rheometer that will control the stress level automatically without control by the operator.
8. When the temperature has equilibrated, condition the specimen by applying the required strain for 10 cycles at a frequency of 10 rad/s.
9. Obtain test measurements by recording data for an additional 10 cycles.
10. The data acquisition system automatically acquires and reduces the data when properly activated.

4. ANALYSIS OF RESULTS

To determine the rheological parameters for selected stretch of flexible pavement, dynamic shear rheometer test was conducted on the reclaimed binder samples, test results are as presented in Table 4. The test was conducted under stress controlled mode (constant stress σ(Pa): 2.45e+03) at a frequency of 10 rad/s. and at a constant temperature of 46°C.

Table 4: Test results of dynamic shear rheometer

Section number	Phase angle δ(°)	Complex modulus G* (Pa)	Elastic modulus G′(Pa)	Viscous modulus G″(Pa)	Complex viscosity Ƞ* (Pas)	Strain γ	G*/sin δ (Rutting parameter) kPa	G* sin δ (Fatigue parameter) kPa
C1	52.54	31.98e+04	19.5e+04	25.4e+04	31.9e+03	76.45e-02	402.90	253.80
C2	58.51	9.767e+04	5.10e+04	8.33e+04	9.74e+03	2.5033e-02	114.53	83.22
C3	55.86	22.13e+04	12.4e+04	18.3e+04	22.1e+03	1.105e-02	267.32	182.91
C4	77.35	3.116e+04	6.83e+03	3.04e+04	3.11e+03	7.8469e-02	31.936	30.34
C5	62.91	20.79e+04	9.47e+04	18.52e+04	20.74e+03	1.176e-02	233.60	185.09
C6	70.59	8.276e+04	2.75e+04	7.81e+04	8.25e+03	2.954e-02	87.748	77.99

The Relation between G', G" and G* of all the six stretches with varying phase angles is as shown in Figure 1.

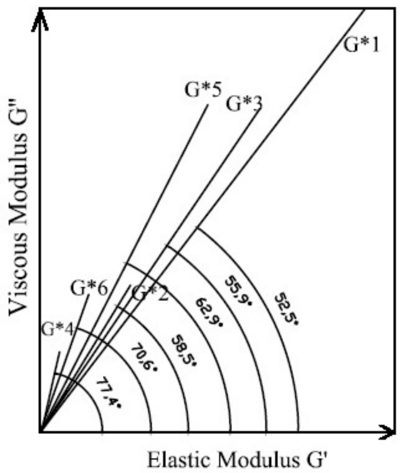

Fig1: Graph representing relation between Elastic modulus (G'), viscous modulus (G"), Complex modulus (G*) and phase angle δ

SUMMARY

The binder of grade 60/70, reclaimed from selected flexible pavement stretches was subjected to DSR test. The main findings have been summarized below.

1) From Table 3, the softening point test results indicated that the binder exhibited a small increase in the softening point temperature which indicated that the binder has become harder with its age, while it still remains within specification limits.
2) The dynamic shear rheometer (DSR) is used to characterize the viscous and elastic behavior of asphalt binders at medium to high temperatures. As with other Superpave binder tests, the actual temperatures anticipated in the area where the asphalt binder will be placed determine the test temperatures used. The typical values of complex modulus (G*) can range from about 0.07 to 0.87 psi (500 to 6000 Pa), while the phase angle (δ) can ranges from about 50 to 90°. A phase angle of 90° is essentially complete viscous behavior.
3) The phase angle (δ) is the lag between the applied shear stress and the resulting shear strain. From the results obtained it was observed that the phase angle ranges from 52.54° to 77.35° for the six sections of pavement. Larger the phase angle, more viscous the material. The test results indicated that binder from all the stretches were highly viscous.
4) G* and δ are used as predictors of HMA rutting and fatigue cracking. Early in pavement life rutting is the main concern, while later in pavement life fatigue cracking becomes the major concern. According to SUPERPAVE Specifications, rutting parameter (G*/sinδ) for an aged asphalt binder shall be ≥ 2.2 kPa. The range of rutting parameter values obtained range from 31.938 to 402.9 kPa. Similarly, SUPERPAVE specification for fatigue parameter (G*sinδ) shall be ≤ 5000 kPa. The range obtained is from 30.34 to 253.80 kPa. The section C4 has the least resistance to rutting and fatigue while section C1 has the highest. But, the values for all the sections are within permissible limits.
5) The DSR test results indicated that the binder, even after 3 to 4 years of performance, was stiff enough to resist fatigue and rutting failures. The presence of patches of rutting/ fatigue failure could be as a result of subgrade condition, drainage system and traffic load repetitions.

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