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Performance based Characterization of Bituminous Binders

[1] Sreenivasarao Kari, [2] Mr. B. Krishna Naik, M.tech

[1]M. Tech Student, Department of Civil Engineering, MVR College of Engineering and Technology (autonomous) paritala, India.

[2]Assistant Professor, Department of Civil Engineering, MVR College of Engineering and Technology, paritala, India.

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Abstract - This research focuses on the rheological properties of bituminous binders commonly used in India, considering their performance characteristics at high and intermediate field temperatures. The study evaluates the impact of temperature, rate of loading, and amount of loading on bitumen grades 80-100 and 60-70, both unmodified and modified with crumb rubber. Additionally, the effect of aging on these properties is analyzed. The findings indicate that the binders meet the rutting and fatigue criteria as per the Superior Performing Asphalt Pavement (Superpave) specifications.
Keywords: Bitumen, Rheological Properties, Performance Characteristics, Crumb Rubber, Aging, Superpave, Rutting,

1. Introduction

Flexible pavements are a critical component of road infrastructure, known for their cost-effectiveness and ease of maintenance compared to rigid pavements. These pavements, primarily constructed with bituminous layers, offer flexibility in adapting to various traffic and environmental conditions, making them a preferred choice in countries like India. The bitumen used in flexible pavements plays a pivotal role in determining the pavement's durability and performance. Traditional unmodified bitumen, such as 80/100 grade, has been widely used due to its availability and satisfactory performance under moderate conditions. However, with the increase in traffic loads and extreme weather conditions, there is a growing demand for modified binders that can better withstand the stresses imposed on road surfaces.

Crumb Rubber Modified Bitumen (CRMB), an advanced binder that incorporates recycled rubber from used tires, has gained prominence for its enhanced elasticity and resistance to common pavement distresses such as rutting and fatigue cracking. CRMB not only improves the performance of flexible pavements but also contributes to sustainability by recycling waste rubber. Despite the advantages of modified binders like CRMB, Indian road construction specifications largely rely on empirical tests, such as penetration tests, which do not fully predict real-world performance. The need for performance-based specifications, which assess materials based on their behavior under actual traffic and environmental conditions, is becoming increasingly recognized.

This paper aims to explore the performance characteristics of two commonly used binders in Indian flexible pavements—unmodified bitumen (80/100 grade) and Crumb Rubber Modified Bitumen (CRMB 55). By analyzing the behavior of these binders under various loading and environmental conditions, this study seeks to provide insights that could inform the development of new material specifications tailored to India's road infrastructure needs. The research is intended to contribute to more durable and cost-effective pavement solutions, addressing the prevalent issues of rutting, fatigue cracking, and premature pavement failure.

2. Objectives:

The primary objective of this research is to investigate the rheological properties of bituminous binders, with a focus on evaluating their resistance to fatigue cracking and rutting in flexible pavements. Specifically, this study aims to:

1.Compare the Rheological Behavior of Unmodified and Modified Bitumen**: Examine the performance of commonly used unmodified bitumen grades (80/100 and 60/70) and Crumb Rubber Modified Bitumen (CRMB 55) under varying temperature and loading conditions, providing insights into their viscoelastic behavior.

2. Assess Ageing Effects: Investigate the impact of ageing on the rheological properties of these binders using Pressure Aging Vessel (PAV) and Thin Film Oven (TFO) methods, simulating long-term and short-term aging conditions respectively.

3. Characterize Viscoelastic Properties: Analyze the linear viscoelastic properties of the selected bitumens at different frequencies and temperatures, focusing on complex shear modulus and phase angle curves. This will help in understanding how the binders respond to dynamic loading and temperature variations.

4.Evaluate Performance Against Pavement Distresses: Assess the binders' resistance to rutting and fatigue cracking by correlating the rheological test results with field performance metrics, identifying which binders offer superior performance under typical Indian road conditions.

5. Provide Recommendations for Binder Selection: Based on the analysis, offer practical recommendations for the selection and specification of bituminous binders to enhance pavement durability, optimize performance, and reduce maintenance costs.

2.1 Scope of the work

This research focuses on evaluating the rheological properties of unmodified bitumen (80/100 and 60/70 grades) and Crumb Rubber Modified Bitumen (CRMB 55) to assess their performance in flexible pavements. Using a dynamic shear rheometer (DSR), the study investigates the viscoelastic behaviour of these binders, specifically analysing complex shear modulus (G*) and phase angle (δ) at various temperatures and frequencies. Creep tests are conducted to examine long-term deformation under constant stress.

Additionally, the study simulates short-term and long-term aging effects through the Thin-Film Oven (TFO) and Pressure Aging Vessel (PAV) to understand how aging influences the rheological characteristics of the binders. The findings provide a comparative analysis of unmodified and modified binders, with a focus on their resistance to rutting and fatigue cracking. Conducted at the Transportation Laboratory, MVR college, this research contributes valuable insights for improving pavement design and durability.

3. Experimental investigations:

3.1 Evaluation of bitumen properties

Aggregates used in bituminous pavement construction were Material Properties of Bituminous Binders Used

In this study, three types of bituminous binders were utilized: 80/100 penetration grade bitumen, 60/70 penetration grade bitumen, and Crumb Rubber Modified Bitumen (CRMB 55). The 80/100 and 60/70 penetration grades are unmodified binders commonly used in flexible pavements. The CRMB 55 is modified with crumb rubber to enhance its performance, particularly in resisting rutting, cracking, and other distresses under traffic and temperature variations.

The rheological properties of these binders were assessed using a dynamic shear rheometer (DSR), focusing on key parameters like complex shear modulus (G*) and phase angle (δ). Additionally, short-term aging was simulated using the Thin-Film Oven Test (TFO), while long-term aging was modeled through the Pressure Aging Vessel (PAV). This evaluation provided insights into how aging and modification affect the stiffness, elasticity, and overall performance of these binders, aiding in optimizing pavement design.

3.2 Test specification

The rheological properties of the bitumen binders were determined following AASHTO Designation: T 315-08, which outlines the procedure for evaluating asphalt binder performance using a Dynamic Shear Rheometer (DSR). This method measures the dynamic shear modulus (G*) and phase angle (δ) in oscillatory shear mode using parallel plate geometry, providing a comprehensive understanding of the material's viscoelastic behavior.

The test is applicable for binders with dynamic shear modulus values ranging from 100 Pa to 10 MPa, at temperatures between 6°C and 88°C, and an angular frequency of 10 rad/s. The test procedure involves applying a sinusoidal oscillatory shear stress to the bitumen sample and recording its deformation response. The resulting values of G* and δ are crucial for assessing the binder's performance under different temperature and loading conditions, offering key insights into the material's resistance to deformation and durability, essential for predicting asphalt pavement performance.

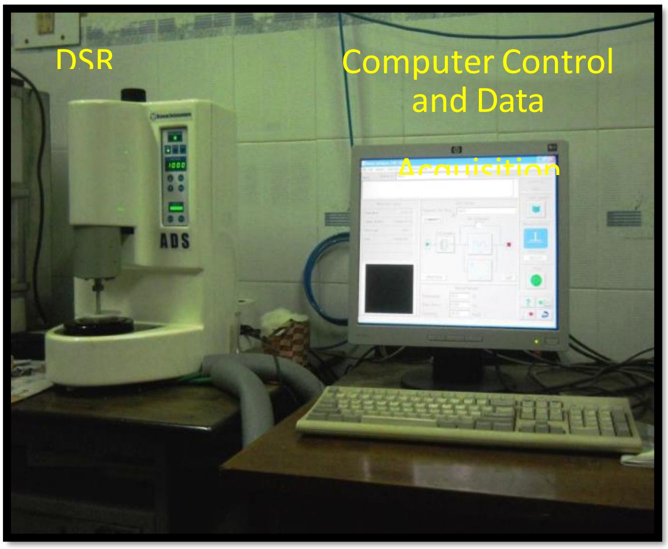

Fig.1 Dynamic Shear Rheometer

3.3 Specimen geometry

Bitumen binders used in this study were (80-100 and 60-70) penetration grade bitumen, which is the most widely used in India. The second binder is crumb rubber modified bitumen which is also commonly used in India.

Specimen Geometry:

1. High-Temperature Specimen Geometry When testing asphalt binders at high temperatures, it is essential to consider the specimen geometry to ensure accurate results.To prevent melting and maintain stability, the following specification is recommended: Diameter:A larger diameter (25 mm) enhances stability and minimizes the risk of melting during testing.

Fig.2 .25 mm diameter - 1mm thickness

4. Experimentation

Ageing of Bitumen

Short-Term Ageing (TFO):

The Thin-Film Oven (TFO) test simulates short-term ageing by heating bitumen binder at 163°C for 5 hours. This method follows AASHTO T 179 and ASTM D 1754 standards

Long-Term Ageing (PAV):

Pressure Aging Vessel (PAV) testing further ages TFO-treated binders at 100°C and 2.10 MPa for 20 hours. Standard: AASHTO R 28.

Fig.3 Pressure Vessel Ageing for long term ageing

Bitumen, as a critical binder in road construction, significantly influences pavement durability and performance under varying environmental and loading conditions. Rheological testing is essential to predict bitumen's behavior, especially its viscoelastic properties, which exhibit both elastic (recoverable) and viscous (non-recoverable) characteristics. The Dynamic Shear Rheometer (DSR) is one of the primary tools used to evaluate the bitumen's rheological properties, measuring the complex modulus (G*) and phase angle (δ) across a range of temperatures. This helps predict the material's stiffness and its resistance to deformation under traffic and high temperatures.

For low-temperature performance, the Bending Beam Rheometer (BBR) assesses bitumen's creep stiffness and stress relaxation, crucial for predicting crack resistance in cold climates. Another important test, the Multiple Stress Creep and Recovery (MSCR), focuses on bitumen's ability to recover from stress, particularly in polymer-modified bitumen (PMB), which is designed to enhance elasticity and rutting resistance. MSCR helps gauge the binder's ability to withstand repeated traffic loads.

Emerging methods, such as the Linear Amplitude Sweep (LAS), streamline fatigue testing by predicting binder performance under cyclic loading, while **temperature sweep tests provide insights into bitumen's behavior across a wide temperature spectrum, identifying critical transitions between brittle and ductile states.

Recent advancements, such as -scale rheological testing and microscopy techniques like scanning electron microscopy (SEM), offer new insights into the microstructural properties of bitumen and its additives. These methods are becoming increasingly important for understanding long-term performance and the effects of environmental aging, further enhancing the selection of durable, resilient binders for modern infrastructure.

5. Results and discussion

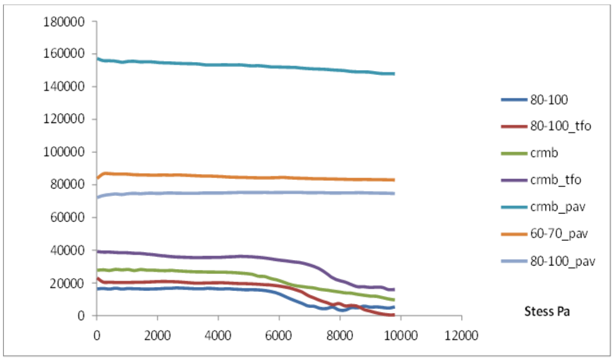

Fig.4 Complex shear modulus G* versus stress

The results of various binders were compared to establish their linearity limits. Based on these limits, input parameters for other sweep tests were selected for different bitumen binders. It was observed that the linear range for most binders falls between 100 Pa and 8000 Pa. To simplify the testing process, a uniform stress level was adopted across all bituminous binders. Consequently, 500 Pa was chosen as the constant stress for the frequency sweep test applied to all binders.

5.1 **Frequency sweep test result**

The highest loading frequency of 50 Hz was chosen to represent high traffic speeds, while the lowest frequency of 0.1 Hz was selected to simulate loading conditions typical of slow-moving traffic. The test results, including complex shear modulus and phase angle at various frequencies for all binders, are presented in Figures 5.2 to 5.5.

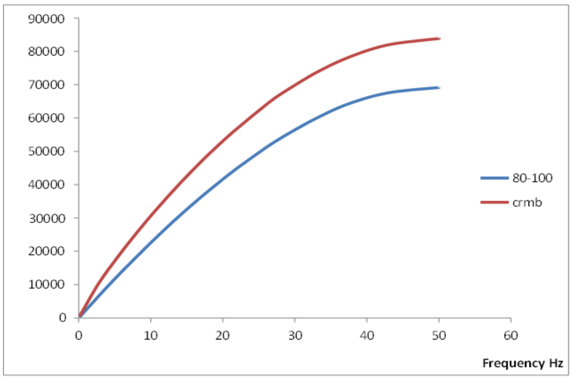

Fig.5.Complex modulus versus frequency for neat bitumen

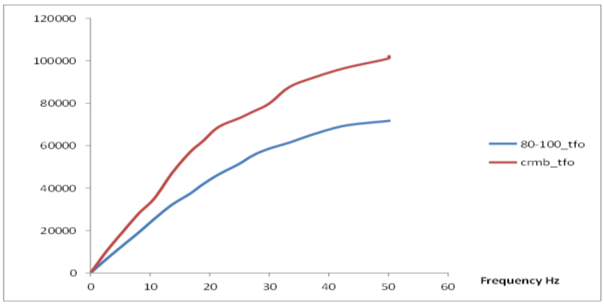

Fig.6 Complex modulus versus frequency for short term aged bitumen

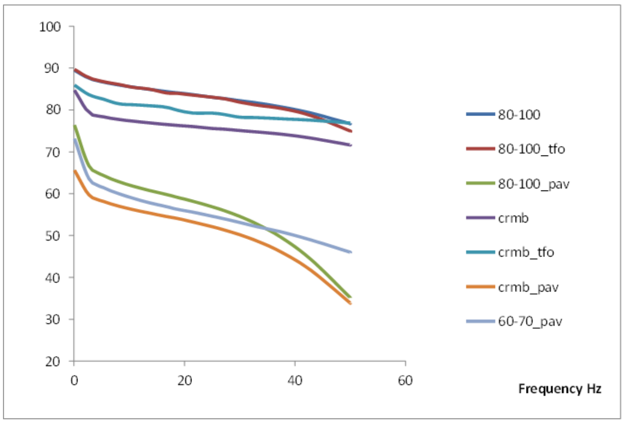

Fig.7 Phase Angle versus frequency

The shear modulus (G*) increases with testing frequency, reflecting a more rigid material response. Concurrently, the phase angle (δ) decreases, indicating the balance between the elastic (storage) and viscous (loss) components. Crumb rubber-modified bitumen (CRMB) exhibits a higher G* and lower δ compared to base bitumen, demonstrating enhanced stiffness and elastic properties. The addition of crumb rubber absorbs aromatic oils, softening and swelling the rubber particles, which results in a lower phase angle and improved elastic recovery. Complex modulus curves show that PAV-aged materials are significantly stiffer than TFOT-aged and unaged samples, emphasizing the critical impact of aging on binder performance.

5.2Temperature sweep test result

The shear modulus (G*) of binders is significantly influenced by temperature, decreasing at higher temperatures due to softer binder responses. This relationship is vital for understanding binder performance under varying environmental conditions. the rheological properties, where G* reflects material stiffness and the phase angle (δ) indicates the balance between elastic and viscous components. A higher G* and lower δ are desirable in hot climates to resist rutting, while a lower G* and moderate δ are preferred in colder climates to prevent thermal cracking. These parameters are critical for designing polymer-modified bitumen, ensuring optimal performance across diverse conditions.

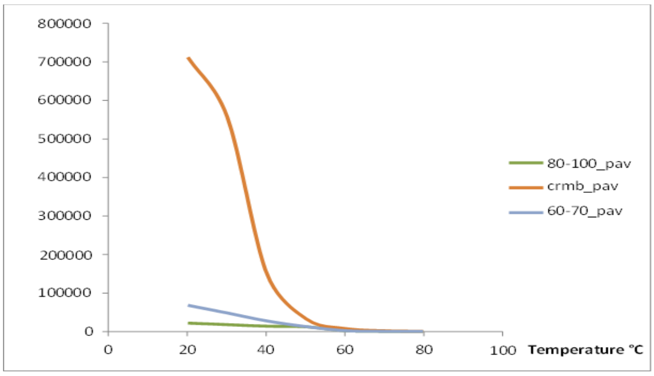

Fig.8.Complex Modulus versus temperature

6. CONCLUSION

The main objectives of this research were to characterize bituminous binders. The addition of modifiers to pure bitumen improves its viscoelastic behavior and alters its rheological properties. Furthermore, the aging process enhances rheological properties compared to those of unaged binders. After conducting laboratory tests on the binders and analyzing the data, the following conclusions have been drawn:

- The results clearly indicate that the addition of rubber to the base bitumen decreases the phase angle, which directly impacts the elastic recovery properties. This enhancement allows the bitumen to fully recover when the load is removed, thereby helping to resist rutting.

- A decrease in phase angle is generally observed after aging tests compared to the original binders. Since phase angle is a measure of the ratio between loss modulus and storage modulus, the increased phase angle (loss tangent) implies that aging leads to a greater increase in storage modulus (elastic component, G`). A high value of G` is advantageous as it minimizes the potential for further rutting during service.

- From the Multiple Stress Creep and Recovery (MSCR) tests, it is observed that the elastic recovery in the 80/100 binder is significantly lower than that of Crumb Rubber Modified Bitumen (CRMB). The 80/100 binder does not recover its original shape when tension is released, while CRMB demonstrates a greater capacity for recovery, returning to its original form more quickly after load removal. This degree of elastic recovery is a critical indicator of permanent deformation in pavement materials, highlighting the importance of binder selection in preventing deformation-related issues.

- Performance-related tests clearly indicate that CRMB outperforms the 80/100 binder in key areas. The results show a significant improvement in fatigue behavior for modified binders compared to neat binders, suggesting that CRMB can better withstand repeated loading cycles. This enhanced fatigue resistance is essential for extending the lifespan of pavement surfaces, particularly in high-traffic areas where stress concentrations lead to premature cracking. The superior properties of CRMB can be attributed to the elastomeric characteristics of the crumb rubber, which enhance the viscoelastic response of the binder. Consequently, using CRMB can result in more durable and resilient pavements, reducing maintenance costs and improving overall infrastructure performance.

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