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Review Of Literature Survey For Performance-Based Characterization Of Bituminous Binders

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ABSTRACT
This literature review presents an overview of studies conducted on the performance-based characterization of bituminous binders. Bituminous binders play a crucial role in the performance and durability of asphalt pavements. Understanding their properties and behavior is essential for developing high-quality and long-lasting road surfaces.The review begins by discussing the traditional characterization methods for bituminous binders, such as penetration, softening point, and viscosity tests. It then highlights the limitations of these tests in capturing the true performance characteristics of binders, particularly in terms of their resistance to rutting, fatigue cracking, and moisture damage.Subsequently, the review focuses on performance-based tests that have been developed to overcome the limitations of traditional methods. These tests include the Dynamic Shear Rheometer (DSR), the Bending Beam Rheometer (BBR), and the Multiple Stress Creep Recovery (MSCR) test. The principles, procedures, and parameters measured by these tests are explained, along with their relevance to binder performance.Furthermore, the review discusses the application of performance grading systems, such as the Superpave system, which utilize performance-based tests to classify binders based on their expected performance in the field. The advantages of performance grading systems over traditional specifications are highlighted, including their ability to account for regional climate variations and traffic conditions.Several studies evaluating the performance of different types of binders, such as modified binders and recycled binders, using performance-based tests are also reviewed. The findings demonstrate the effectiveness of performance-based characterization in predicting the performance of bituminous binders under various loading and environmental conditions. The literature survey emphasizes the significance of performance-based characterization for accurately assessing the properties and performance of bituminous binders. The review provides a foundation for further research and development of binder specifications that align with the desired performance requirements of asphalt pavements.

Keywords: *Bituminous binders, Performance-based characterization, Asphalt pavements, Traditional characterization methods, Performance-based tests, Performance grading systems.*

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I. INTRODUCTION

With the rapid growth of road transportation infrastructure in India, significant investments are being made by the government to improve the road network under various programs. Flexible pavements, which consist of bituminous layers, are commonly used in India due to their lower initial and maintenance costs. The most commonly used bituminous binders include unmodified binders like 60/70 or 80/100 bitumen and modified binders such as CRMB. However, the current Indian specifications for these binders rely on empirical tests that have limited correlation with their actual field performance.For instance, the penetration test, which measures the hardness or softness of a binder based on the depth of penetration of a standard needle, does not provide a direct indication of its field performance. As the demand for bituminous road infrastructure grows, it becomes crucial to consider the use of performance-based specifications for the materials used in these constructions. By adopting performance-based specifications, the investments made in these projects can be justified by ensuring that the materials meet the desired performance requirements.Performance-based specifications focus on evaluating the actual performance of bituminous binders under specific loading and environmental conditions, rather than relying solely on empirical tests. This approach allows for a more accurate assessment of the binders' field performance and helps in selecting materials that can deliver the desired pavement performance over their service life. By embracing performance-based specifications, India can enhance the quality and durability of its road network, maximizing the benefits of the significant investments being made in the sector.

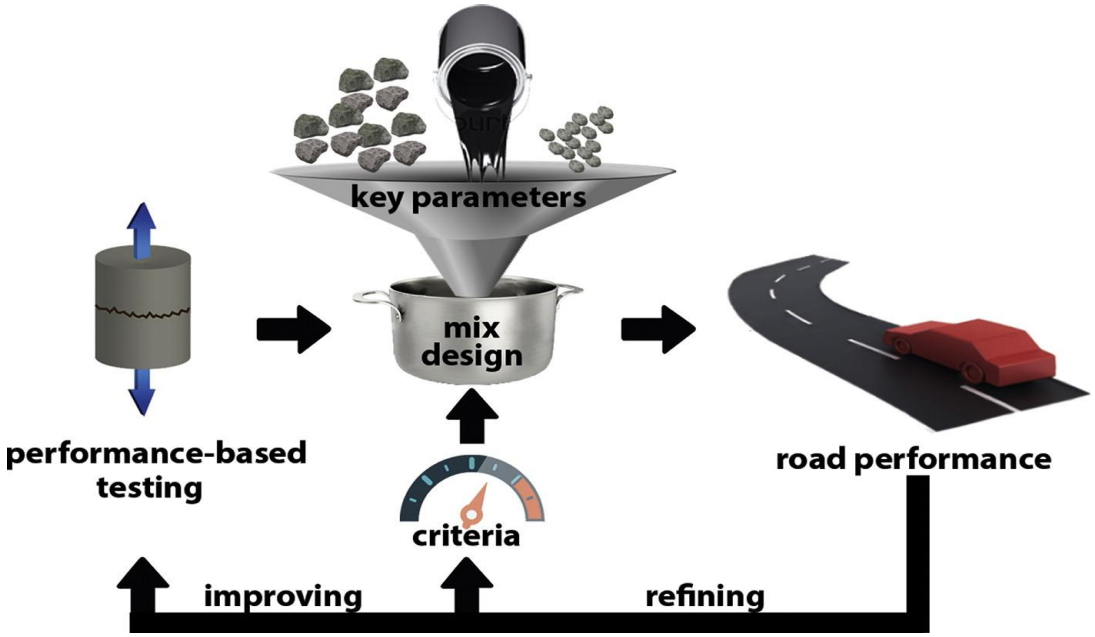

Figure 1: Performance Based Bitumen Binder (Zaumanis et al. 2019)

II. INDIAN SCENARIO AND ASSOCIATED PROBLEMS

In India, the grading of bitumen is currently based on the penetration test, which is conducted at a standard temperature of 25°C. However, this test does not provide information about the viscous or elastic behavior of bitumen at the actual test temperature, which can vary significantly in different climatic conditions.One of the most common challenges faced by bituminous pavements worldwide, including in India, is rutting during hot summer months. As the temperature rises, bitumen softens and becomes more susceptible to deformation under the weight of loaded truck tires. This leads to rutting and corrugations in the wheel tracks of the roadway, compromising the pavement's performance and safety.Conversely, during colder periods or after a sudden drop in temperature, bituminous pavements can become excessively brittle. This brittleness makes them prone to fatigue cracking when subjected to heavy loads, further deteriorating the pavement's condition.To address these issues, it is crucial to consider the temperature susceptibility and rheological properties of bitumen. The selection of bitumen with appropriate temperature susceptibility characteristics can help prevent rutting during hot weather, while choosing a bitumen that remains sufficiently elastic at lower temperatures can reduce the risk of fatigue cracking.To overcome the limitations of the penetration test, it is essential to adopt performance-based specifications that consider the rheological properties of bitumen. Tests such as the Dynamic Shear Rheometer (DSR) and the Bending Beam Rheometer (BBR) can provide valuable information on the viscoelastic properties and low-temperature performance of bitumen.By incorporating performance-based specifications that account for temperature susceptibility and rheological properties, India can improve the durability and performance of its bituminous pavements, ensuring their resistance to rutting and fatigue cracking under varying climatic conditions.

III. CHARACTERIZATION OF BITUMINOUS BINDERS

Characterization of bituminous binders involves assessing their properties and performance to ensure their suitability for use in asphalt pavement construction. This process plays a crucial role in developing durable and high-quality road surfaces. The characterization typically includes evaluating various aspects such as physical, rheological, chemical, and mechanical properties of the binders.

- Physical characterization involves determining parameters like penetration, softening point, viscosity, and ductility, which provide insights into the consistency, hardness, and temperature susceptibility of the binders. Rheological characterization focuses on measuring parameters like complex modulus, phase angle, and creep compliance to understand the viscoelastic behavior and response of the binders under different loading and environmental conditions.
- Chemical characterization involves analyzing the composition of the binders, including the presence of additives or modifiers, to assess their compatibility and potential interactions with other components in the pavement mix. Mechanical characterization involves evaluating properties such as tensile strength, fatigue resistance, and adhesion to assess the binder's ability to withstand traffic loads, temperature fluctuations, and other stressors.

Various testing methods and equipment are employed for the characterization of bituminous binders, including the Dynamic Shear Rheometer (DSR), the Bending Beam Rheometer (BBR), and the Multiple Stress Creep Recovery (MSCR) test. These tests provide valuable data on the binder's performance under different conditions and aid in the selection of appropriate binders for specific applications. Overall, the characterization of bituminous binders is essential for ensuring the quality and performance of asphalt pavements, enabling the development of durable and safe road infrastructure.

IV. SURVEY OF LITERATURE

This section aims to provide a literature review on the rheological properties of bituminous pavements. The review encompasses the examination of the chemical composition and viscoelastic characteristics of bitumen, as well as the classification of common distresses observed in flexible pavements. Additionally, the literature discusses the ageing processes that occur within pavements over time. Finally, the review explores the laboratory methods and approaches employed to assess the rheological properties of bituminous binders.

Laukkanen et al.(2014) This study focused on investigating the creep-recovery behavior of bituminous binders and its relationship to the rutting characteristics of asphalt mixtures. The researchers extensively examined the Multiple Stress Creep Recovery (MSCR) test method and compared its effectiveness in predicting binder contributions to mixture rutting with other rheological indicators. The findings revealed a strong correlation between the non-recoverable creep compliance at a 3,200 Pa stress level (Jnr3200) and the accumulated strain at the end of the MSCR test (cacc), indicating their ability to accurately predict the binder's impact on asphalt mixture rutting. The relationships between these parameters and asphalt mixture rutting were found to be linear. However, while the cacc parameter may seem attractive due to its simpler calculation, it should be noted that it is not normalized by the applied creep stress, making comparisons across different stress levels challenging.

Cui et al.(2014) This research aimed to examine the impact of high-temperature volatilization on the performance of two bituminous binders. The findings revealed that as the temperature increased, the weight of the binders decreased, with the rate of reduction decreasing over time. After a certain volatilization period, the softening points of the binders increased, while the penetration significantly decreased. The volatilization conditions involving oxygen and vacuum showed no significant differences in the asphaltene and colloid properties. Additionally, it was observed that the presence of 3% Layered Double Hydroxides (LDHs) in the modified bitumen binder reduced the emission of Volatile Organic Compounds (VOC) fumes.

Riviera et al.(2015) The purpose of this experimental study was to investigate and compare the rutting properties of different bituminous binders and their corresponding mixtures with similar composition and volumetrics. Single shear creep-recovery (SSCR) tests were conducted on the binders to determine their creep compliance rate (CCR), while the bituminous mixtures were evaluated using the Flow Number (FN) obtained from repeated compressive loading tests with the Asphalt Mixture Performance Tester (AMPT). The results revealed that the ranking of binders and mixtures in terms of their rutting performance was consistent. Notably, the superior performance of the polymer-modified binder and its corresponding mixture was clearly demonstrated. A single relationship between CCR and FN, independent of binder origin and type, was identified, confirming the effectiveness of the SSCR test in capturing the contribution of the binder phase to permanent deformation in mixtures. Additionally, the potential use of CCR values for predicting FN was explored, yielding satisfactory outcomes. Future research aims to validate and generalize the CCR-FN relationship by expanding the database to include a wider range of binders and considering variations in composition and volumetrics of bituminous mixtures. A comparison with results obtained from other tests on binders and mixtures will be conducted to fully assess the advantages and potential limitations of the proposed characterization procedure.

Remisovaet al.(2016) This paper focuses on the characterization of rutting resistance in bituminous binders and asphalt mixtures by examining their rheological properties. Four different bituminous binders, including both unmodified and polymer modified types, were analyzed for rheological parameters such as complex shear modulus (G*), phase angle (δ), and dynamic viscosity (η*) at temperatures ranging from 46 to 60°C (80°C). The resistance to deformation in asphalt concrete mixtures was evaluated through rutting tests. It was observed that binders with higher values of complex shear modulus exhibited greater stiffness, indicating their ability to resist deformation.

Connell et al.(2017) Understanding the fatigue properties of bituminous binders is crucial for assessing the ageing process and predicting pavement deterioration, such as cracking and pothole formation. The economic sustainability of our road network relies on comprehending the mechanisms and rates of ageing and their impact. Researchers have long aimed to develop accelerated methods that simulate the ageing of asphalt pavements while maintaining the same ageing mechanisms observed in the field. However, achieving an exact simulation is impossible due to the inherent time constraints of laboratory testing. Instead, the goal is to approximate ageing methods that yield comparable properties between simulated and field binders at high and

low temperatures, which can be used for specification purposes. It is important to recognize the limitations of ageing methods and their influence on the correlation between laboratory and field binders. By understanding these limitations, we can emphasize the need for realistic fatigue specifications for binders while acknowledging that ageing rate is influenced by multiple factors within an asphalt layer.

Ingrassia et al.(2018) This study aimed to investigate the impact of chemical and wax additives on the tribological behavior (i.e., lubricating properties) of two base bituminous binders, with the goal of achieving temperature reduction in bituminous mixtures through Warm Mix Asphalt (WMA) technologies. Various percentages of additives were considered, and the binders underwent preliminary characterization using Fourier Transform Infrared Spectroscopy (FTIR) and viscosity analysis. Tribological tests were then conducted using a ball-on-three-plates fixture at temperatures of 85 °C and 120 °C after optimizing the test procedure. Additionally, a statistical analysis was performed to assess the significance of differences between the binders based on the tribological results. The findings revealed that the additives had the potential to influence the oxidative state of the binder. The chemical additive was capable of modifying the tribological behavior, while the wax additive primarily affected viscosity. Furthermore, the effect of the additive varied depending on the chemical composition of the base binder. Notably, a correlation was observed between minimum friction and viscosity.

San et al.(2018) According to researchers the physical properties of the aggregates, including conventional (Neat) and modified (PMB, CRMB), meet the requirements specified by the Ministry of Road Transport and Highways (MORTH). A comparison of the optimal binder content (OBC) revealed that crumb rubber modified bitumen (CRMB-55) required a higher OBC of 5.7% compared to normal bitumen VG-30, which had an OBC of 5.1%, resulting in a difference of 0.6%. The Marshall stability test showed a significant increase in stability for the modified bituminous mixtures, particularly in the case of polymer modified bitumen, which exhibited a 30% increase. The static indirect tensile strength ratio of CRMB-55 grade bitumen was found to be 10% higher than that of unmodified bitumen. Additionally, the fatigue life of bituminous concrete mixtures prepared using polymer modified bitumen demonstrated the longest life cycle, with a duration of 1879 cycles, surpassing the other mixtures.

Bueno et al.(2019) The strain-rate frequency superposition (SRFS) method is a technique used to determine the flow behavior of materials through nonlinear oscillatory shear experiments. Originally developed for studying the slow relaxation process in soft materials, this method involves shifting the behavior typically observed at very low frequencies to higher frequencies. In this study, the potential of the SRFS method for assessing the rheological properties of bituminous binders was evaluated. Oscillatory shear measurements were conducted at different constant shear strain ampliture rates and temperatures to analyze the influence of the nonlinear behavior of unmodified and polymer modified bitumen on their viscoelastic responses. The results showed that the differences in responses between the SRFS method and conventional measurements were not significant enough to extend the frequency range. However, variations in responses were observed, particularly for polymer modified binders, especially at high strain amplitudes where nonlinear behavior is typically present.

Saltanet al.(2020) This study investigates the impact of incorporating soybean oil into bituminous binders and evaluates the performance of hot mixtures using these modified binders, providing unique insights distinct from existing literature. The modification process involves adding soybean oil at additive ratios of 1%, 2%, and 3% to the bitumen at a temperature of 160°C and a mixing speed of 2,000 rpm for 60 minutes. Various conventional bitumen tests, as well as adhesion and stripping tests, are conducted on both the reference binder and the soybean oil-modified binders. Furthermore, the Superpave Volumetric Mix Design is employed to determine the optimum bitumen contents, indirect tensile strengths, and moisture susceptibilities of hot mix asphalt samples prepared using the soybean oil-modified binders. The findings reveal that as the amount of soybean oil added to the bituminous binder increases, the consistency and viscosity of the binders decrease. Additionally, while the maximum indirect tensile strength is achieved with a 1% soybean oil additive, an enhancement in resistance to moisture susceptibility is observed for all additive ratios.

Gopalamet al.(2020) The primary objective of this experimental study is to examine how different types of bituminous binders impact the performance of dense graded bituminous mixtures that incorporate recycled concrete aggregates (RCA) in place of conventional stone aggregates. The study focuses on preparing dense bituminous macadam (DBM) mixtures according to relevant Indian specifications, utilizing three commonly used bituminous binders in India: conventional VG 30 and VG 40 bitumens, and crumb rubber modified binder (CRMB). Marshall samples were prepared separately using RCA and natural aggregate (NA), combined with each of the three binders. The engineered properties of these mixtures, including Marshall characteristics, indirect tensile strength, moisture susceptibility, resilient modulus, and rutting resistance, were evaluated to assess their performance. Overall, the results indicate that the mixtures considered in this study generally meet the requirements in terms of Marshall characteristics and moisture susceptibility.

Eskandarsefatet al.(2021) This paper focuses on investigating the key distinctions between industrial-grade and paving-grade bituminous binders. It is divided into two main sections: 1) a review of the colloidal

structure of these materials and the specific properties required for their respective industrial and paving applications, and 2) an extensive range of experimental tests used to study and compare the bituminous binders. The study primarily examines a 160/220 industrial bitumen and compares it to a paving-grade bitumen with the same penetration, as well as a lower penetration 70/100 bitumen. Various analyses were conducted, including physical, chemical, thermal, microstructural, and rheological assessments, to gain a comprehensive understanding of these bituminous binders used in different applications. The results of the tests revealed that although the asphaltene content and its characteristics significantly influence the properties of the bitumen, they are not the sole determining factors. The study also identified the Peri phase (associated with resins) as an important contributor to the bitumen's physical visco-elastic properties, as evidenced by the examination of chemical structures using Atomic Force Microscopy (AFM). Notably, the AFM analysis revealed a notable distinction in microstructure between the industrial-grade bitumen and the paving-grade ones.

Galkin et al.(2022) The objective of this study is to assess the impact of aging methods commonly used in the road industry of Ukraine on the properties of road viscous bitumens and bituminous binders that are modified with various additives. The research focuses on viscous bitumens and modified bituminous binders, which are widely utilized in the domestic road industry. The aging methods employed include the domestic method ГОСТ 18180, which has traditionally been used in Ukraine to evaluate property changes in bituminous binders under the influence of technological temperatures, and the internationally recognized RTFOT method. Experimental data reveals that aging according to the ГОСТ 18180 method has a slightly greater impact on property changes compared to aging through the RTFOT method. The breaking point temperature, which serves as an indicator of aging, is the least sensitive to variations between the two aging methods. However, it should be noted that the conditions of the aging method significantly influence the quality of bitumens modified with adhesive additives.

Aitkaliyevaet al.(2022) The focus of this study is to investigate the structural and thermophysical properties of waste polyethylene terephthalate (PET). The findings indicate that the polymer waste contains functional groups and exhibits specific thermal characteristics, suggesting its potential use as a modifier in road construction applications.

Vysotskaya et al.(2023) This study focuses on evaluating the impact of polymer compatibility and various plasticizers on the properties and long-term stability of polymer modified bitumen (PMB). The initial stage of the research involved determining the fundamental characteristics of the base materials (bitumen and plasticizer) to understand the influence of plasticizers on PMB stability. The concentration of the plasticizer was varied to control the structure formation of the binders, using fuel oil M 200, oil I-50, "Uniplast," selective oil purification extract (SPE), and "Katgol" as plasticizing additives. Various properties such as volatility at PMB preparation temperatures, aniline point indicator, and the composition of plasticizing components were investigated. The experiment revealed the changes in standard properties of the modified binders and their thermal stability (delamination and weight loss during thermal treatment) due to the composition and compatibility of the plasticizer with the polymer. It is recommended to assess the compatibility of the plasticizer and polymer prior to the preparation of laboratory PMB compositions. The study provides recommendations for effectively utilizing plasticizers to achieve desirable polymer-bitumen binder compositions.

V. SUMMARY

The paper presents a review of literature related to the performance-based characterization of bituminous binders. The objective of the review is to provide an overview of the various methods and techniques used to assess the performance of bituminous binders and to identify the key parameters that influence their performance.The review begins by discussing the traditional binder characterization methods, such as penetration, softening point, and viscosity tests, which are based on empirical correlations. However, these methods have limitations in accurately predicting the performance of binders under different conditions.The paper then focuses on the development of performance-based tests that aim to assess the specific performance characteristics of bituminous binders. These tests include dynamic shear rheometer (DSR), bending beam rheometer (BBR), and multiple stress creep recovery (MSCR) tests, among others. These tests measure properties such as complex shear modulus, phase angle, stiffness, and rutting resistance, which provide a more comprehensive understanding of binder behavior.Furthermore, the review discusses the use of advanced techniques such as Fourier transform infrared spectroscopy (FTIR), atomic force microscopy (AFM), and microscopy imaging to analyze the microstructure and chemical composition of binders. These techniques help in understanding the binder's molecular structure and its influence on performance.The paper also highlights the importance of incorporating environmental factors in binder characterization, such as aging, oxidative aging, and moisture susceptibility. These factors significantly affect the long-term performance of bituminous binders and should be considered in their characterization.Overall, the literature review emphasizes the need for performance-based characterization methods that capture the relevant properties and behavior of bituminous binders under different loading and environmental conditions. These methods provide a more accurate

assessment of binder performance and enable the development of improved asphalt mixtures for sustainable and durable road infrastructure.

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