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Evaluation of asphalt binder rutting parameters

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HIGHLIGHTS

- Rutting parameters of 9 different binders were evaluated.
- Mixes with 9 different binders were evaluated using wheel tracker.
- Binder parameter ranges for distinguishing modified binders were identified.
- The stress and frequency sensitivity of binder rutting parameters were evaluated.
- Rankings based on different parameters were examined against rut testing results.

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ABSTRACT

Rutting in asphalt mixes is a common type of distress in pavements with thick asphalt layers. It is more severe for pavements subjected to high pavement temperatures, slow moving, uphill in mountainous areas and heavy traffic loads. A number of binder rutting parameters have been proposed by different researchers for ranking/grading of the binders in terms of their rutting resistance. The suitability of different binder rutting parameters for explaining the rutting resistance of unmodified binders as well as modified binders has been a topic of research for several years. Considering that asphalt mixes in pavement layers are subjected to different conditions of temperature, loading time/frequency and stresses/strains, it is expected that these conditions will affect the way binder rutting resistance is judged. This study was conducted to examine the suitability of different binder rutting parameters for ranking of binders (unmodified as well as polymer and crumb rubber modified), distinguish modified binders from unmodified binders and for their ability to correlate with mix rutting. For this purpose, nine binders (four unmodified and five modified) were evaluated in oscillation and creep and recovery modes and various rutting parameters were examined. Oscillation tests were performed at varying frequencies and multiple stress creep recovery test was performed at different stress levels. The binder parameters were correlated with wheel tracking rut depths of bituminous concrete mix with NMAS of 19 mm. The frequency sensitivity of oscillation parameters and stress sensitivity of creep and recovery parameters were examined. J_{nr} and% recovery have been found to be stress sensitive whereas $|G*|$, δ and $|G*|/\sin\delta$ were frequency sensitive. Some of the binder parameters have distinctly different ranges of values for unmodified and modified binders. The rankings produced by ZSV and J_{nr} closely matched the ranking of the mixes identified based on wheel tracking rut depths. While both oscillation and MSCR parameters correlated well with mix rutting for unmodified binder mixes, the correlation of oscillation parameters with mix rut depth was not good for modified binder mixes.

1. Introduction

Rutting is a major distress observed in asphalt pavements. Rutting in asphalt layers is contributed by high pavement temperatures, heavy axle loads, slow moving traffic, high traffic volumes and inadequate rutting resistance of mixes. Hence, any candidate test considered to assess the rutting resistance of binders or mixes should evaluate the materials under an appropriate conditions of loading and temperature. The Superpave rutting parameter, $|G*|/\sin\delta$, measured in an oscillation test conducted at 10 rad/s frequency [1,2] was one of the earliest fundamentally based rheological parameters used to explain the rutting susceptibility of binder. In many countries softening point ($T_{R\&B}$) is typically used as a binder rutting parameter. However, with the advent of modified binders, the adequacy of the $|G*|/\sin\delta$ parameter to rank the binders in

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terms of their rutting resistance has been under scrutiny [3–9]. As a result, new binder parameters such as viscous component of creep stiffness [6–8], Shenoy's rutting parameter [10], zero shear viscosity [3,11] and low shear viscosity [12–15] have been proposed as alternative rutting parameters.

Bahia et al. [6] observed that the |G∗|/sinδ parameter did not correlate well with the laboratory measured rutting of mixes and explored the application of concepts of non-linear viscoelasticity and energy dissipation to evolve alternative binder rutting parameters. This research group also opined that cyclic loading with complete recovery in strain or stress is not appropriate for rating the contribution of binders to mix rutting caused under repeated creep cycles as cyclic loading is not a good representation of traffic loading. The viscous component of creep stiffness (G_v) estimated using a four-element Burger model using the data obtained from repeated creep test has been proposed as an alternative binder rutting parameter though no validation of the parameter was presented. Bouldin et al. [7,8] proposed a semi empirical model to refine the |G∗|/sinδ specification in which a semi-empirical model was fit between the repeated creep and recovery (RCR) test results and the data generated from the conventional frequency sweep tests conducted using dynamic shear rheometer (DSR). The main assumption made in this approach was that the strain accumulation rate depends on the binder stiffness and the viscoelastic characteristics which, in turn, depend on the phase angle (δ). Shenoy [10] extended the idea of using the frequency sweep test data to estimate percentage unrecovered strain and identified the parameter (Eq. (1)) to be maximized to minimize permanent (unrecovered) strain. Shenoy [10] did not present any mix rutting data to illustrate the superiority of his rutting parameter.

The binder parameters measured from the oscillation test are usually evaluated in the linear viscoelastic (LVE) regime of the binder by selecting an appropriate stress/strain level for conducting the test. However, considering that rutting is a phenomenon that occurs under non-linear conditions, it is necessary to evaluate binders and mixes under conditions at which a major portion of mix rutting occurs. Bahia et al. [5] demonstrated that strain dependency of binders can play a major role in the relationship between the binder and mix rheological responses. Based on computer simulations and finite element analysis, Bahia et al. [5] also illustrated that the binder in a mix can be subjected to strain levels that are much larger (ten times) than the mix bulk strains and recommended that it is necessary to consider large strains (non-linear) for testing of binders, particularly modified binders. They noted that strain levels of 20 to 50% are plausible. It has further been demonstrated by Bahia et al. [5] that the strain dependency is more at lower temperatures and/or at higher frequencies.

Delgadillo et al. [16] extended the concept of Bahia et al. [6] of using the viscous component of creep stiffness (G_v) as a rutting parameter and proposed specification limits in terms of G_v parameter. While the superiority of the binder rutting parameters obtained from an RCR (repeated creep and recovery) test over the oscillation test parameters was appreciated, questions remained about the adequacy of the binder parameters, evaluated at stress/strain levels that are much smaller than the stress/strain levels at which rutting occurs, to characterize the rutting behaviour of binders.

Kose et al. [17] carried out finite element analysis using digitized images of asphalt mixes and reported that the average and maximum strains in the binder are about 7.8 and 510 times the bulk strain of the mix respectively. Drakos et al. [18] carried out linear elastic analysis of pavements to illustrate the differences between the stresses caused by bias and radial tyres and suggested that the maximum shear stress levels near the pavement surface can be as high as 10^6 Pa. It may be noted that the typical strain levels considered for evaluating the superpave binder rutting pavement parameter, |G∗|/sinδ, are in the range of 9 to 15% for fresh binder and from 8 to 12% for short-term RTFO aged binder [19].

A number of investigators examined the significance of testing the binder in the non-linear viscoelastic regime for better correlation of the binder parameters with mix rutting. D'Angelo et al. [20] developed the multiple stress creep and recovery (MSCR) test for binders to evaluate the binders at multiple stress levels. Non-recoverable creep compliance of the binders determined from MSCR test could be related to the rutting performance of mixes evaluated using different rut testers and collected from in-service highway sections. D'Angelo et al. [20] demonstrated that the Hamburg wheel rutting test creates a high shear stress condition in the mix sample and hence the non-recoverable creep compliance measured at 12.8 kPa stress level had the best correlation with wheel tracking test data. D'Angelo [21] pointed out that different mix rutting test methods produce different stress conditions in the sample and hence, it may not be possible to identify one single stress or strain level at which binder rutting parameters should be evaluated. Laukkanen et al. [22] reported that the strain response of unmodified binders did not vary significantly in successive creep and recovery steps in the MSCR test, but for elastomeric and wax modified binders, the effect of delayed elasticity and rupture of crystalline microstructure respectively, were observed. Zhou et al. [23] carried out round robin studies and reported that MSCR parameters gave better results than |G∗|/sinδ parameters, especially for highly modified binders and that non-recoverable creep compliance measured at 0.1 and 3.2 kPa showed excellent repeatability and reproducibility, whereas the other MSCR test parameters such as stress sensitivity (J_{nr} difference) and percentage recovery parameter at 0.1 kPa were not within the acceptable limits of tolerence. Over the last two decades, several other researchers [24–27] made a comparative assessment of different binder rutting parameters evaluated in oscillation and creep and recovery modes. The general consensus was that the creep and recovery test parameters are better than the |G∗|/sinδ parameter based on the ability of parameters to rank the binders in terms of mix rutting susceptibility.

Atul Narayan et al. [28] analyzed different binder rutting parameters giving due consideration to the non-linearity of the mechanical behaviour of the binders. They proposed apparent viscosity as a new rutting parameter and also recommended the stress levels at which different binder tests (zero shear viscosity, MSCR and |G∗|/sinδ) can be conducted to achieve better correlation of binder rutting parameters with mix rutting.

It is concluded from the literature that several binder rutting parameters have been proposed in the past to evaluate the relative rutting resistance of binders/mixes. Oscillation test binder rutting parameters have been reported to be inadequate in ranking the binders, especially the modified ones. The importance of conducting binder and mix rutting tests at appropriate conditions of stress/strain, temperature and frequency has also been highlighted in the literature.

2. Research objective

The broad objective of the research work presented in this paper was to study the potential of different rutting parameters of unmodified and modified binders evaluated in the oscillation test at different frequencies and in multiple stress creep and recovery test at different stress levels to rank mixes in terms of their rutting resistance and correlate with mix rutting. The following scope of the work was selected for the purpose.