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Review

Advanced analytical techniques in fatigue and rutting related characterisations of modified bitumen: Literature review

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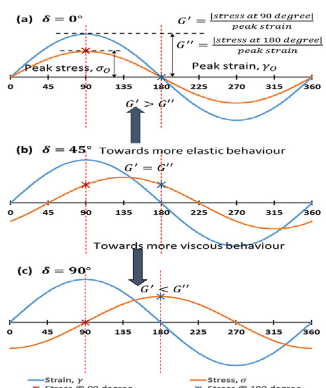
HIGHLIGHTS

- Addressing the property-related performance of bituminous binders.
- Using only a single binder property cannot adequately describe the binder contribution.
- The modified binders have a complex behaviour depending on stress degree and rate.
- The fatigue failure point should be identified based on fundamental criteria.

GRAPHICAL ABSTRACT



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ABSTRACT

Fatigue and rutting are the two major failure distresses in flexible pavement that affect significantly the serviceability of pavement. The properties of bitumen have a direct effect on controlling the fatigue and rutting distresses. Because of the increase in vehicular loading and repetitions, the modification of neat bitumens becomes a widespread practice to improve their mechanical properties. Any improvements obtained from developing modified binders need be reflected by fundamental testing parameters. The empirical testing methods and Superpave grading procedure that were developed mainly for unmodified bitumens have failed in many cases to predict the performance of modified bitumens. Evaluation the influence of such modifiers needs be based on characterising accurately the inherent resistance of binders to fatigue and rutting damage. The most advanced tests and fundamental analysis methods for characterising the fatigue and rutting properties of binders, are discussed and presented in this paper. These include fatigue and ductile fracture evaluation of binders using time sweep and double-edged notched tension (DENT) tests. For bitumen rutting evaluation, the SHRP rutting parameter, Shenoy rutting parameter, ZSV and MSCR are discussed. The dynamic shear rheometer (DSR) has been largely used to characterise fundamentally the viscoelastic properties of bitumens. A detailed description of the main elements associated with the DSR and Dynamic Mechanical Analysis (DMA) are also presented in this paper.

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1. Introduction

Asphalt mixtures are the main materials used to construct the bituminous layers of flexible pavements. An asphalt mixture is a composite material consisting of aggregate and bitumen. The aggregate particles form the skeleton matrix that is cemented together by bitumen. Bitumen is a viscoelastic, thermoplastic, complex material that behaves differently with temperature and loading time. It is purely viscous at high temperatures and/or under slow moving loads; at those conditions, the materials become prone to permanent deformation (rutting). It is also totally elastic and eventually brittle at low temperatures and/or high rapid loads and subsequently the materials become apron to the low-temperature cracking. However, within 10–35 °C in-service pavement temperatures, where the pavement is subjected to a considerable part of its repetitive traffic loads, the main mode of distress is fatigue cracking. The asphalt pavement is adequately hard and elastic to dissipate excessive repetitive loads through crack initiation and eventually propagation.

It is well recognised that the damage resistance of asphalt mixtures is significantly related to the properties of bituminous binders. Therefore, characterising the mechanical properties of binders and improving them by means of modification has been a topic of intensive studies for many years [1–7]. Testing only binders is deemed to be much easier and cost effective than asphalt mixtures. However, the challenge is to find the most representative binder tests and parameters to describe the binder contribution to damage resistance. Identifying these tests and parameters would essentially and rationally guide the pavement engineers to optimise and select the most appropriate binder for a specific condition. Consequently, this would contribute to maximise the value of pavements and enhance their performance. There are many variables associated with the modification of bitumen (i.e. type of modifier, modifier content, and blending conditions). The selection of optimal combination of these variables should be based on specific properties of modified bitumens that can correlate well with the performance of pavement.

The dynamic shear rheometer (DSR) is usually used to characterise fundamentally the viscous and elastic properties of binders at wide range of temperatures. The DSR has also been used to apply repeated cyclic loading at specific loading and temperature condition until the specimen fails. The test provides continuous viscoelastic measurements which are used to assess the internal damage characteristic of materials during fatigue evolution [8–12]. This approach has been shown to provide an independent fatigue law regardless of loading mode and frequency when the fatigue analysis is based on the dissipated energy method. The healing potential of binders can also be evaluated by introducing short rest periods among the continuous loading sequence in fatigue test [13,14].

Characterising the fracture properties, by means of essential work of fracture using the double-edged notched tension (DENT) test, has also been shown to be a promising approach for characterising the ductile fracture of bituminous binders [15–19].

In terms of rutting properties of binders, many rutting parameters have been developed to characterise the rutting resistance. SHRP parameter has been widely used to assess and grade the different binders based on the measured complex modulus and phase angle. The SHRP parameter has been increasingly criticized for the lack of correlation to pavement performance [8,18,20–23]. Other parameters including Shenoy parameter, Zero Shear Viscosity (ZSV) and creep compliance (Jnr) using the Multiple Stress Creep Recovery (MSCR) test, have been shown to provide more fundamental binder rheological evaluation that predict well the binder contribution to the rutting performance of pavement.

These fundamental analysis methods for characterising the fatigue and rutting properties of binders, are discussed and presented in this paper. A detailed description of the main elements associated with the DSR and Dynamic Mechanical Analysis (DMA) are also presented in this paper

2. Dynamic shear rheometer (DSR)

The dynamic shear rheometer is used to measure the viscoelastic response of materials when subjected to a given load state (degree and rate), and a given temperature. The load can be applied in a sinusoidal (oscillatory) mode, or in a creep and recovery mode. The sinusoidal load is normally applied under strain-controlled loading in which a small strain within the linear viscoelastic range is used and the resulting stress is measured. On the other hand, in the creep and recovery mode, a stress-controlled load is normally applied and the resulting strain is measured. The principal measurements taken by the DSR are the torque (T) and angular rotation (θ). The other mechanical properties are computed based on these measurements. Fig. 1 shows the main configuration of DSR testing.