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Relationship between multiple stress creep recovery (MSCR) binder test results and asphalt concrete rutting resistance in Brazilian roadways

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HIGHLIGHTS

- Asphalt binders and mixtures lab results, and field rutting behavior are presented.
- Modeling of mix rutting behavior and simulation of pavements behavior are performed.
- MSCR and FN tests and LVECD results are contrasted with field behavior of pavements.
- Weak correlations between MSCR results and rutting behavior of mixes (lab or field).
- Good agreement between LVECD prediction and rutting measurements on test sections.

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ABSTRACT

The selection of an asphalt binder that resists permanent deformation is a challenge, particularly to relate such resistance to the corresponding asphalt mixture behavior in the field. The main goal of this paper is to evaluate the relationship between asphalt binders' rutting resistance obtained in the laboratory with field observations of mixtures containing those binders. The performances of three monitored test sections were evaluated in Brazil. The rutting resistance of the asphalt mixtures was evaluated in laboratory by the Uniaxial Repeated Load and by the Triaxial Stress Sweep (TSS) tests. The corresponding asphalt binders were tested for the Performance Grade (PG), as well as for the percentage of recovery (R) and the non-recoverable compliances (J_{nr}) through the Multiple Stress Creep and Recovery (MSCR) test. Rutting performance prediction was conducted using Layered ViscoElastic analysis for Critical Distresses (LVECD) and TSS test results. The results pointed out that the characterization of the asphalt binders by itself is not sufficient to estimate the rutting behavior of the corresponding asphalt mixtures, because of the important role of the aggregates. Nevertheless, poor results in MSCR binder tests tend to indicate mixtures with poor performance (field and laboratory), i.e., the binder test can be used to avoid selecting binders that may lead to permanent deformation.

1. Introduction

Rutting is one of the most common distresses in asphalt pavements. In addition to accelerated pavement degradation, the referred distress reduces user's comfort and safety, and increases operational costs. Although all layers have a role in its development, nowadays most permanent strain is due to the excessive deformation of the asphalt surface course [1]. Such strain occurs mainly at temperatures above 60 °C (easily observed in Northeastern Brazil pavements), when the binder stiffness is reduced and the material flows due to its viscoplastic behavior. It is believed that the accumulated strain in the asphalt binder, as a result of traffic, is key for the rutting of asphalt pavements [2]. Although the stiffness of the binder has a significant effect on the mixture behavior, wear resistance, and particularly the interlocking of aggregates [3,4] and their shape properties (sphericity, angularity and texture) [5] contribute primarily to the rutting resistance. Those different factors show the complexity of analyzing this distress.

Polymer modification of binders has been consolidated in recent decades as an effective technique for dealing with the increasingly critical conditions of load and temperature to which pavements are subjected during service life [6,7]. The selection of a binder that resists permanent deformation is still a challenge, as there is limited research correlating binder rheology to the rutting behavior of the corresponding asphalt mixtures in the field [8,9]. Tests on binders that may be related to resistance to

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permanent deformation include: i) empirical tests traditionally performed such as penetration, softening point and ductility [10]; ii) classical linear viscoelastic characterization in the Dynamic Shear Rheometer (DSR), and iii) more recent tests such as the Multiple Stress Creep and Recovery (MSCR) [11,12], also performed in the DSR.

The main goal of this paper is to investigate relationships between asphalt binders' resistance to permanent deformation (obtained in the laboratory using MSCR tests) and the rutting resistance of asphalt mixtures containing those binders, as observed both in the laboratory and in the field.

2. Experimental procedures to assess rutting resistance

2.1. Uniaxial repeated load test

The most used laboratory test in Brazil for permanent deformation evaluation in asphalt mixtures is the Uniaxial Repeated Load test (sometimes called Flow Number test). It is often used to rank mixtures, but it cannot be used for performance prediction, i.e., for estimating rutting evolution with time (specific rut depth in the field after a certain traffic). In this test, a compressive stress is applied to unconfined cylindrical samples (150 mm height and 100 mm diameter), with a haversine pulse load of 0.1 s followed by 0.9 s of rest, during which a contact load is still applied. The peak stress value is 204 kPa during loading, and 10.2 kPa (5% of peak load) is applied during the rest period, at 60 °C [13]. Test results include the accumulated permanent strain (ε_p) versus number of cycles (N) curve, which is divided in three zones. In the primary zone, specimen densification occurs at an elevated rate; the secondary zone contains smaller and approximately constant strain rates; and the tertiary zone indicates the specimen failure. The number of cycles in which the tertiary zone starts is known as Flow Number (FN), and it is where plastic deformation rate is minimal. The test is stopped when (i) FN is reached, (ii) at 10,000 cycles, or (iii) when the mixture reaches a total strain of 2% [14]. FN is a popular parameter used for screening mixtures with respect to rutting resistance, and literature presents attempts to improve the analysis of FN results [15].

2.2. Triaxial Stress Sweep test

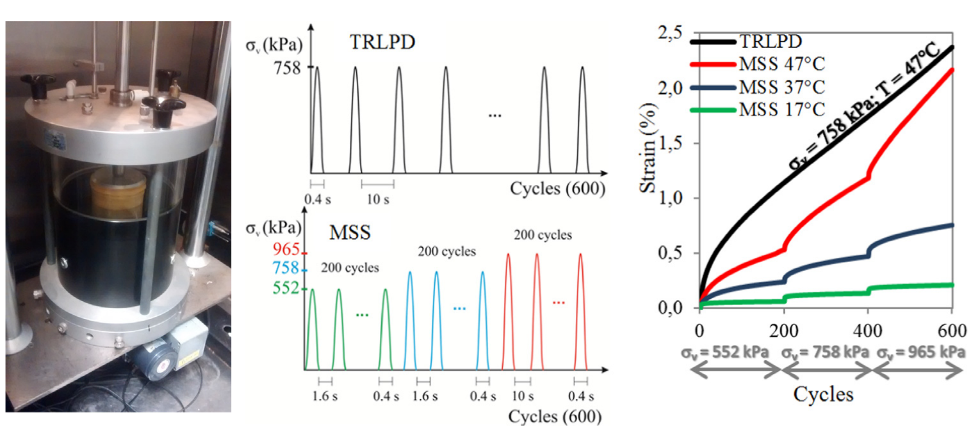
The Triaxial Stress Sweep (TSS) test is a cyclic compression test (haversine load followed by a rest period), under a confining stress (Fig. 1a). It can be used to obtain asphalt mixture properties as defined in the so-called Shift Model, which is a viscoplastic mechanical model [16,17]. The test is performed in two steps and in different specimens: the first one is the reference Triaxial Repeated Load Permanent Deformation (TRLPD) test, and the second one is the Multiple Stress Sweep (MSS) test. The goal of the TRLPD test is to obtain a reference axial strain curve versus number of cycles. For each cycle, a haversine load is applied for 0.4 s using a peak compressive vertical stress of 758 kPa (110 psi), followed by a rest period in which a contact load equivalent to 38 kPa (5.5 psi, 5% of the peak load) is applied for 10 s, at 47 °C. A total of 600 load cycles is applied. The investigated mixtures have to complete this initial reference protocol without failure in order for the Shift Model to be fitted. When the first stage of the protocol is not completed, the MSS test is not performed due to the early initiation of the tertiary zone, not allowing the fitting of the Shift Model, which requires the results of the MSS test.

After obtaining the reference curve, the MSS tests are performed, with 600 load pulses applied on a specimen at each of the three test temperatures (17, 37 and 47 °C). For low (17 °C) and intermediate (37 °C) temperatures, the load pulse is applied over 0.4 s, followed by 1.6 s rest period. At high temperature (47 °C), the load pulse is also applied over 0.4 s, but with 10 s rest period (Fig. 1b). Three levels of peak compressive vertical stress (552, 758 and 965 kPa; 200 cycles per load block, amounting to 600 cycles) are applied at each temperature (Fig. 1c). For each temperature, a different specimen is tested. During the rest periods, a contact load equivalent to 5% of the peak load is applied, i.e., over the resting time, 28, 38 and 48 kPa are applied, respectively. For all stress levels, a 138 kPa confining stress is applied, corresponding approximately to what is expected for the confining stress in the field, considering surface course thicknesses (approximately 10 cm) commonly found in Brazil [18].

The main objective of utilizing the Shift Model (Eq. (1)) is to obtain viscoplastic material properties in order to predict rutting on asphalt pavement layers from modeling. For such purpose, the Shift Model was incorporated in the LVECD (Layered ViscoElastic analysis for Critical Distresses) [19] software.

The Shift Model is based on two superposition principles: time-temperature (t-TS) and time-stress (t-SS) superposition. These superposition principles give two shift functions, i.e., reduced load time shift and vertical stress shift [20]. Eq. (1) presents the modeled reference strain curve (Eq. (1a)), followed by the two shift functions that need to be applied to obtain results at a different temperature (Eq. (1b)) and a different peak stress (Eq. (1c)).

$$\varepsilon_{vp} = \frac{\varepsilon_0 . N_{red}}{(N_I + N_{red})^{\beta}} \text{ (reference curve)} \quad (1a)$$



(a) Confined test (b) Loads (c) Stresses and temperatures

Fig. 1. Description of TRLPD and MSS tests.