Evaluation of Neat and Modified Asphalt Binders in Relation to Fatigue Cracking by means of Rheological Characterization

Iuri Bessa[1], Kamilla Vasconcelos[2], Verônica Castelo Branco[3], Liedi Bernucci[4]
([1,2,4] Universidade de São Paulo, Av. Professor Almeida Prado, Trav. 2, N. 83, São Paulo/SP, Brazil, [1]iuribessa@usp.br, [2]kamilla.vasconcelos@usp.br, [4]liedi@usp.br)
([3] Universidade Federal do Ceará, Campus do Pici, S/N, Bloco 703, Fortaleza/CE, Brazil, veronica@det.ufc.br)

ABSTRACT

The prediction of asphalt pavements deterioration in relation to the main stresses has been proposed by different researchers by means of laboratory characterization combined with performance models. Tests performed in different asphalt materials – asphalt binder, asphalt mix and fine aggregate mix (FAM) – have been used to obtain the resistance of these materials in relation to rutting and fatigue cracking. Regarding fatigue cracking resistance characterization, there is no universal consensus on the testing method, the failure criterion, and specimen geometry. The laboratory testing of asphalt binders is relevant because fatigue is highly dependent on rheological properties of these materials. Tests to obtain the linear viscoelastic parameters, time sweep tests (TST), and linear amplitude sweep (LAS) tests were done in the present research at the temperature of 20°C, for three different types of asphalt binders: one neat asphalt binder classified as 30/45 for penetration grade, one SBS-modified asphalt binder, and one highly modified asphalt binder (HiMA). The results obtained from the different tests were compared. The mains conclusions were that there is a good linear correlation between the fatigue lives obtained for the LAS test and the ones obtained from the TST results but the values are five higher for the latter.

Keywords: asphalt binders; rheological tests; fatigue cracking resistance.

1. INTRODUCTION AND BACKGROUND

Many researchers have developed and enhanced different test methods with the objective of predicting the fatigue cracking resistance of asphalt mixes by means of asphalt binder characterization. According to Kennedy et al. [1], fatigue cracking is highly dependent on the type and quality of the asphalt binder used in hot mix asphalts (HMA), with its effect corresponding to an estimate of 60%. The stiffness and damage characteristics of these materials tend to provide a good indication of the fatigue resistance of asphalt mixes constituted by them [2].

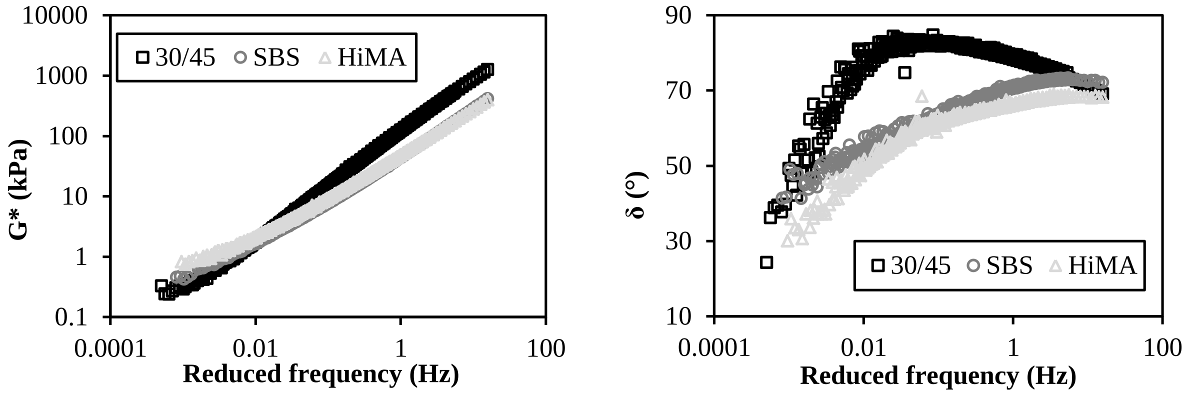
In the late 1980s, as part of the Strategic Highway Research Program (SHRP), the project entitled Binder Characterization and Evaluation was developed to provide a better understanding of asphalt binders chemical and physical properties and how these properties affect the performance of asphalt pavement structures. Before SHRP, the existing empirical specification tests were not able to describe or predict in-field performance of asphalt pavements [3]. Besides that, the empirical characterization did not truly differentiate the behaviour of modified asphalt binders from neat binders [4]. Thus, rheological tests were implemented, and a new classification based on the performance grade (PG) was developed. The PG methodology addresses the Superpave parameter ($G^*\times\sin\delta$) to characterize the fatigue resistance of asphalt binders. The PG specification currently limits the maximum value of G*×sinδ to 5,000kPa and 6,000kPa for standard (L) and heavy/very heavy traffics (H/V), respectively, at the testing frequency of 10rad/s [5]. Although this parameter is part of the standard Superpave classification, several researches have unsuccessfully tried to correlate it to the fatigue resistance of asphalt mixtures, especially containing modified binders. The main reason is that the parameter is obtained in the linear viscoelastic (LVE) region of the materials tested. Therefore, other test methods and new parameters have been developed [6], such as the use of damage-induced tests.

Among the main existing laboratory tests that provide the fatigue behaviour of asphalt binders, the time sweet test (TST) and the linear amplitude sweep (LAS) test have been currently in use for a few years [7-18]. The TST can be a stress-controlled or a strain-controlled test and it consists in the application of a cyclic loading at constant frequency. There are no standard values for frequency and strain/stress amplitude to be used. Some authors indicate the use of 10rad/s and 10% of strain to accelerate the test. It is important to ensure that the test is performed at strain levels that are outside the LVE region, since asphalt pavements have non-linear damage behaviour [19]. The LAS test [20] consists in applying an amplitude sweep from 0 to 30% with linear increment on the strain value, during 300 seconds, and at the constant frequency of 10Hz.

This research aims to compare results from different fatigue cracking resistance tests performed in asphalt binders. Three materials were studied: one neat asphalt binder and two modified binders.

2. MATERIALS AND METHODS

The asphalt binders were tested for fatigue behaviour by means of different methods: the Superpave parameter G*×sinδ, TST, and LAS test. The materials studied were a neat asphalt binder classified as 30/45 for penetration and two modified binders were tested: one SBS-modified binder one HiMA, with 2.5 and 7.0% of polymer, respectively. The empirical characteristics of the asphalt binders meet with the required criteria provided by Brazilian standards. All the tests were performed in the dynamic shear rheometer (DSR). Before the characterization of the asphalt binders in relation to their fatigue cracking resistance, master curves for dynamic shear modulus (|G*|) and phase angle (δ) were obtained and plotted in Figure 1. The master curves were provided by a frequency sweep (0.1 to 100rad/s) and a temperature sweep (10 to 76°C, with intervals of 6°C) at constant strain amplitude of 0.1%. The reference temperature was 40°C.



(a) (b)

FIGURE 1 Master Curves of the Asphalt Binders (40°C): (a) Dynamic Shear Modulus, |G*| and (b) Phase Angle, δ

The master curves present clear differences between the neat and the modified binders. At high frequencies (which is related to low temperatures), the neat binder has higher values of G*. The comparison between the modified binders indicates that there is no clear difference between both materials in the entire frequency range. Regarding the elastic properties of the materials studied, the neat binder has higher values of phase angle at most of the temperatures analysed, and the HiMA has the lowest values for this parameter. This indicates that the modified binders are more elastic than the neat binder, which is expected, since the polymers added to the binders tend to make them more flexible. The comparison between the SBS-modified binder and the HiMA indicates that the latter is more elastic (lower phase angle values) in the entire temperature/frequency range.

3. RESULTS AND DISCUSSION

3.1 Superpave Fatigue Parameter

Different approaches and analyses were performed in the present research in order to characterize the fatigue behaviour of asphalt binders. First, the Superpave parameter G*×sinδ was obtained, at the frequency of 10rad/s. The asphalt binders were firstly aged at the rolling thing film oven test (RTFOT). Figure 2a presents the values of G*×sinδ at the several testing temperatures; the limit value of 6,000kPa (for heavy/very have traffic levels) is also plotted.

The results indicate that the three binders have similar behaviour regarding the Superpave parameter for fatigue cracking characterization. According to the results, the modified binders would likely have a good resistance to this distress for the temperature of 20°C or higher, but the neat binder would only meet the Superpave criterion for temperatures higher than 25°C, which is still satisfying, considering that the fatigue cracking occurs at intermediate temperatures. If the entire temperature range is considered, it can be noticed that the neat binder is more susceptible to temperature changes, while the HiMA has the least temperature susceptibility.

3.2 Time Sweep Test (TST)

The development of new test methods to predict fatigue behaviour of asphalt binders is based on the premise that the Superpave parameter is not able of capturing differences among neat and modified binders. In the present research, the time sweep test was performed in three different amplitude levels in order to obtain the fatigue live curves for each material tested. First, strain sweep tests were performed [21] to define the LVE region of the asphalt binders so that the strain amplitudes considered in the TST could be selected. The test was conducted at 10Hz and the strain sweep was done from 0.1 to approximately 12%. There are different methodologies to obtain the LVE region of asphalt materials [22]. The present research considered the American Society for Testing and Materials (ASTM) standard method, which indicates that 90% of the initial value of G* is the limit for the LVE region. The TST was performed at 10Hz at different strain levels for each material (2, 4 and 6% for the neat binder; and 6, 8 and 10% for the modified binders), ensuring that the all the values were outside the LVE region. Strain levels outside the linear viscoelastic zone were used to account for the damage behaviour of the materials. The strain level of 6% was used for the three binders. Bahia et al. [6] consider that the frequency of 10Hz might be very high, but this value was selected in order to reduce the testing time and to correlate to results from the 4PBBT performed in asphalt mixes, which uses the same frequency level. Figure 2b shows the curves obtained.

There is a lack of consensus about some parameters considered during the time sweep test. The initial value of G* is normally considered as the value obtained in the first cycle of the test, but in every test performed in the present research, the value of G* required a few number of cycles to be stabilized before it would actually start decreasing. Therefore, in order to maintain a standard method for every sample tested, it was decided to consider the fifth cycle as the initial value of G*. This choice was made based on the visual analysis of the evolution of G*. At this specific cycle, most of the tests had already stabilized the values of G*.

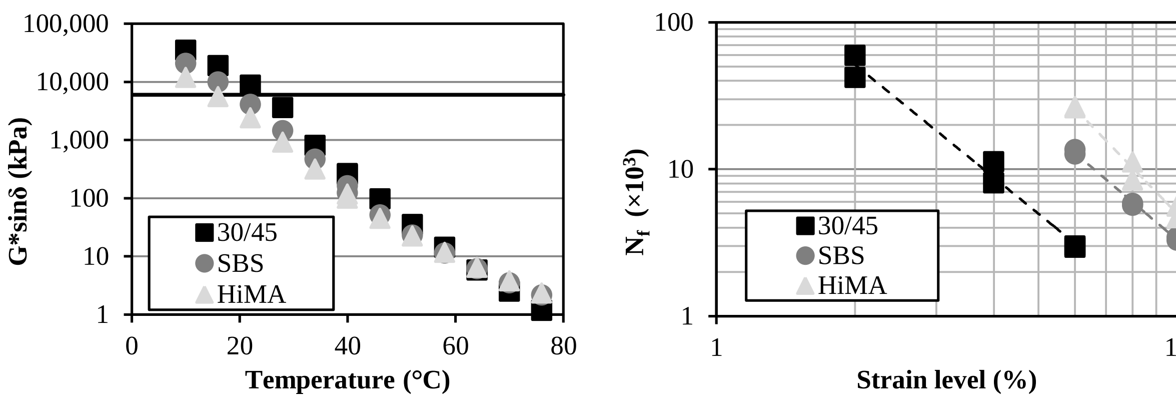


FIGURE 2 Fatigue Characterization: (a) Superpave Parameter and (b) Time Sweep Test (TST)

The HiMA has the best fatigue cracking resistance and is the most susceptible to changes on strain values. At low strain levels, this binder would provide a much higher resistance in comparison to the neat binder. This is expected, considering that normally binders with higher elasticity tend to have better fatigue resistance in strain-controlled tests.

3.3 Linear Amplitude Sweep (LAS) test

The LAS test consists in two parts. The first part is a frequency sweep from 0.2 to 30Hz at the strain amplitude of 0.1%. This step is performed in order to obtain the LVE properties of the specimen, including the relaxation and the stiffness moduli, which are later used in the calculation of the accumulated damage. The parameter alpha (α), which is later used for amplitude sweep data analysis, is calculated as the reciprocal value of the straight line slope (m) of the log storage modulus (G') versus log frequency curve. The second part of the test is the amplitude sweep, conducted at a frequency of 10Hz, with linear increments of strain amplitude from 0 to 30%. The LAS tests were performed in the present research at the temperature of 20°C. The analyses of the results were based on the simplified viscoelastic continuum damage (S-VECD) method, considering the peak stress value as the failure criterion. Figure 3a presents the change in shear stress with amplitude sweep. The peak stress value is plotted as the failure point. The fatigue lives curves are shown in Figure 3b.

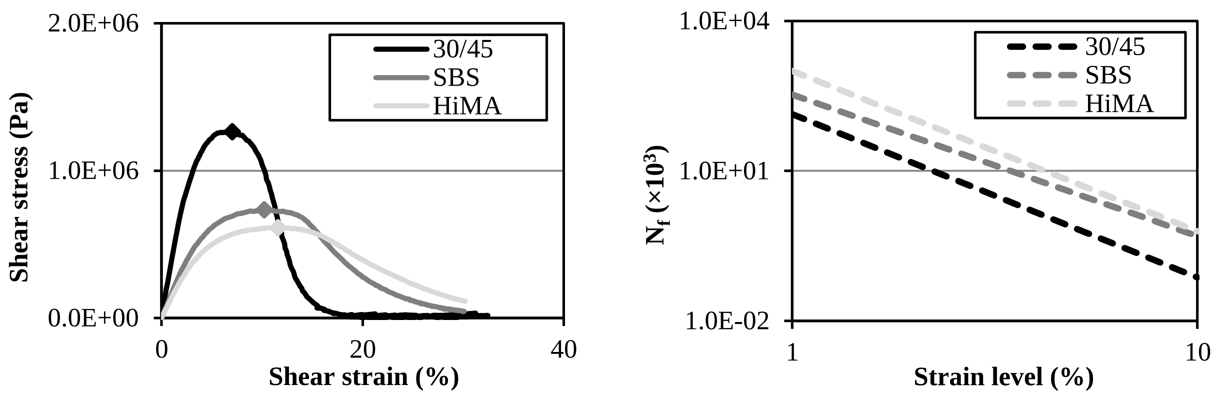


FIGURE 3 Linear Amplitude Sweep (LAS) test: (a) Stress-strain Curves and (b) Fatigue Life Curves

There is a rapid increase in the shear stress values of the neat binder in comparison to the modified binders, with a peak value of approximately 1.26MPa at the strain of 7.0%. The modified binders have a slower increase of their shear stress value, with their peak occurring in a value approximately 50% less than the value obtained for the neat binder. The SBS-modified binder has a shear stress peak value of 0.73MPa at 10.2% of strain and the HiMA has a peak value of 0.61MPa at 11.6% of strain.

The fatigue curves presented indicate that the neat binder has a lower fatigue resistance if compared to the modified binders. The slopes are very similar for both modified materials but the neat binder has a more pronounced slope, which indicates that the fatigue resistance of this material is the most affected by the strain levels. The HiMA is the most resistant among the three binders analysed, providing twice the number of cycles to failure if compared to the SBS-modified binder.

The comparison between the number of cycles to failure by means of the time sweep test and the parameter G*×sinδ is presented in Figure 4a for 6% strain. It shows that the lower the fatigue life, the higher is the value of G*×sinδ, which is expected, since the Superpave specification limits a maximum value for the parameter. Figure 4b presents the comparison between the fatigue life from the LAS test (S-VECD analysis) and the fatigue life from the TST

(50% reduction on the value of G*). The TST results are five times higher than the results from the LAS test.

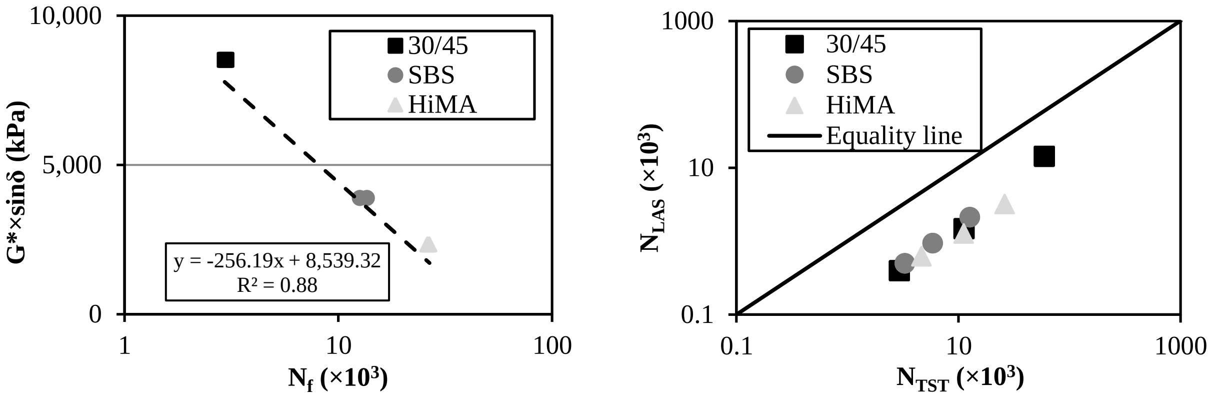


FIGURE 4 Comparison Between Fatigue Tests: (a) Superpave parameter versus TST and (b) TST versus LAS test

4. SUMMARY AND FINDINGS

This research evaluated three different asphalt binders (a neat binder, a SBS-modified binder, and a highly modified binder) in relation to their fatigue resistance by means of different methods and approaches. First, the original Superpave parameter G*×sinδ was introduced, then time sweep and linear amplitude sweep tests were performed. The different approaches considered in this research were the conventional fatigue criteria (50% of decrease on the initial value of G*) for the TST and the peak value of shear stress in the LAS test. The main findings in this research are:

- The modified asphalt binders resulted in higher fatigue lives in comparison to the neat material, and the HiMA provided the best resistance;
- The parameter G* × sinδ has a good correlation with TST results at 6% of strain amplitude;
- The results from the VECD analysis performed for the LAS test were, in general, five times lower than the traditional method of the TST, but there is a good correlation between the two approaches.

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