

BITUMEN RUBBER ASPHALT MIX TESTING FOR SOUTH AFRICAN PAVEMENT DESIGN METHOD

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ABSTRACT

The South Africa National Road Agency Ltd has entered into a research and laboratory testing agreement with the CSIR to support the revision of the South African Pavement Design Method (SAPDM). The research includes characterising a bitumen-rubber semi-open graded mix, known in South Africa as BRASO. The general concern was whether the BRASO asphalt mix can be tested under the same test conditions as conventional asphalt mixes using the recently developed test protocols for SAPDM. This paper presents the analyses of laboratory testing data of a BRASO mix. The fundamental mechanical properties, including dynamic modulus, permanent deformation and beam fatigue characteristics of the BRASO, were determined in laboratory to enable future monitoring of the field performance of BRASO. It is anticipated that the test results presented in this paper will provide the required basis to develop reliable BRASO resilient response and damage models for SAPDM.

1 INTRODUCTION

Bitumen rubber (BR) asphalt due to its proven flexibility is a unique paving material which has the potential to improve performance of road and airfield pavement applications, in areas where the expected cause of failures is associated with oxidative ageing and fatigue cracking. Bitumen rubber asphalt has been used successfully in South African road construction for over 30 years. However, traffic loading has significantly increased over this period.

There is some (legitimate) concern that current test methods for BR asphalt in South Africa do not cater for the additional demands imposed on this type of mix, particularly since current methods do not sufficiently consider field performance based properties such as fatigue and permanent deformation as well as the stiffness of the mix. There was also some concern as to whether BR asphalt can be tested under certain laboratory conditions designed for conventional mixes to assess their stiffness and deformation properties, and whether BR asphalt can be properly characterised for inclusion into the new South African pavement design method (SAPDM). These mixes include a bitumen-treated base (BTB) mix with a 40/50 binder, a coarse continuously graded mix together with a medium continuously graded mix with A-E2 binder and a medium continuously graded mix with a 60/70 penetration grade binder.

This paper presents test results of a laboratory testing program conducted on bitumen-rubber semi-open graded mix (BRASO) using a recently developed hot-mix asphalt test protocols for South Africa. The test results were used to assess applicability of resilient response models on the BRASO, and to develop a time-temperature related master curve to predict dynamic modulus as well as determine permanent deformation and fatigue characteristics of the mix. The aim is to increase the understanding of the mix, its properties and its suitability for different applications on roads in South Africa.

2 MATERIALS AND SAMPLE PREPARATION

2.1 Raw materials source and preparation

Raw materials (aggregate and binder) were sampled at Much Asphalt's Eikenhof asphalt plant in accordance with Technical Methods for Highways (TMH1) procedure (TMH5, 1981). Both the aggregates and binder were sourced at the plant. In the laboratory, to further ensure homogeneity of the materials sampled, bags of similar aggregate sizes were mixed together by riffing and quartering. Aggregates were oven dried at approximately 140°C, after which the materials were split by riffing to the approximate quantities required for the various compactions. Dry sieve analyses were then be carried out on randomly selected bags to ensure that the material has been adequately riffled (three bags tested per aggregate size). The required grading (target grading) was made up in triplicate and tested using wet sieve analysis for conformance with South African specifications.

2.2 Mix preparation

In South Africa, hot-mix asphalt samples are produced in accordance with the methods in TMH1. The bitumen-rubber semi-open graded mix (BRASO) used in this study was designed by Much Asphalt. The mix design was reproduced and then tested in the CSIR laboratory. The crumb rubber modified binder used in the mix was taken from the centre of heated and stirred bitumen tanks at the asphalt plant.

The mixing temperature for the binder was determined using the method in TMH1 Method C2 (TMH1, 1986). The aggregates and binder were prepared in accordance with the protocols in TMH1. After mixing, the loose material was conditioned using a method known as "short term ageing". The aim is to simulate the aging that takes place during the production of the mix at the plant and transport to site. The procedures are described by Von Quintus *et al.* (1991) and Bell *et al.* (1994). Short term aging conditioning is achieved by aging the loose mix in an oven at compaction temperature for four hours before compaction. The mix was manufactured at 170°C and compacted at temperature of about 145°C, after having been short-term aged for four hours in an oven set at the compaction temperature.

Although both short-term and long-term aged samples were prepared for the study, the intent of this paper is not to compare effect of ageing. However, only the short-term ageing samples are discussed in this paper. Long-term ageing is achieved when compacted specimens made from short term aged mix are put back into the oven and aged for five days at a temperature of 85°C. The BRASO samples presented in this paper were compacted to a design air voids content of 5.6% using a design binder content of 7.5%.

The mix was used to produce compacted slab samples for beam fatigue and shear testing, and gyratory compacted cylindrical samples for dynamic modulus testing. The slabs were compacted using the Transport Research Laboratory (TRL) slab compactor in accordance with the CSIR in-house test protocol. From the slabs, rectangular prismatic beams of dimensions 400 x 60 x 50 mm were cut for the beam fatigue testing, and cores of size 150mm diameter x 50 mm high were cut for shear testing. An Industrial Process Controls Ltd (IPC) servopac gyratory compactor was used to produce cylindrical samples of 150 mm diameter and 170 mm high in accordance with the American Association of State Highway and Transportation Officials (AASHTO) test procedure AASHTO T312 (AASHTO, 2009). The compacted samples were trimmed and cored to produce 100 mm in diameter by 150 mm high samples for dynamic modulus testing.

3 LABORATORY TESTING PROGRAM

3.1 Dynamic modulus testing

The current pavement design methods have adopted the dynamic (complex) modulus as the most appropriate for determining hot-mix asphalt (HMA) stiffness for flexible pavement design (SANRAL, 2007; NCHRP 1-37A, 2004). The dynamic modulus measured from laboratory testing can be used for the resilient response characterisation of asphalt mixes.

Dynamic modulus testing was conducted on the BRASO mix using a recently developed CSIR protocol for HMA mixes in South Africa (Anochie-Boateng *et al.*, 2010). A commercially available Universal Testing Machine (UTM-25) was used to conduct the dynamic modulus tests on the BRASO mix. The test setup includes a temperature environmental chamber, which is capable of controlling the test temperatures of the specimen. A haversine compressive load pulse with no rest periods was applied by the UTM-25 testing device on the gyratory compacted BRASO mix specimens of 100 mm in diameter and 150 mm high at five test temperatures of (-5, 5, 20, 40, 55°C) and six loading frequencies (25, 10, 5, 1, 0.5, 0.1Hz). The specimen's vertical deformation was determined by averaging the readings of three axial linear variable displacement transducers (LVDTs). Axial stresses and the corresponding axial strains were recorded for the last five load cycles for each test to compute the dynamic modulus of the samples tested. A total of 20 load cycles were applied on the specimens at each loading condition.

Five specimens were tested at each loading condition to conform to the CSIR dynamic modulus test protocol (Anochie-Boateng *et al.*, 2010). Strain controlled testing was followed such that the measured strain was always maintained within the range of 75 to 125 microstrains. The applied stress was varied so that the magnitudes of the strains were limited to approximately 100 microstrains in order to ensure linear behavior of the sample.

3.1.1 *Dynamic modulus test results and analyses*

Analysis of laboratory test data of asphalt mix stiffness for mechanistic-empirical pavement design purpose often involves generation of master curves. Hot-mix asphalt master curves are used to account for the effects of temperature and frequency (or loading rate) on stiffness modulus, and are generated using the time-temperature superposition principle. It allows for test data collected at different temperatures and frequencies to be shifted along the frequency axis relative to a reference temperature to form single characteristic master curve. Detailed step by step construction of master curves for South Africa asphalt mixes is described in the CSIR test protocol (Anochie-Boateng *et al.*, 2010). A master curve was produced for the BRASO mix tested.

A non-linear least square regression technique was used to fit the data with a sigmoidal function defined in Equation 1. Using the time-temperature superposition principle, the dynamic modulus test data were then shifted horizontally relative to the temperature of 20°C (reference temperature).

The master curve relationship is presented as follows:

$$\log |E^*| = \delta + \frac{\alpha}{1 + e^{\beta + \gamma \left[\log(f) + c \left[10^{A+VTS \log T} - 10^{A+VTS \log(527.67)} \right] \right]}} \quad (1)$$

where

- $|E^*|$ = dynamic modulus
- δ = minimum value of $|E^*|$
- $\delta + \alpha$ = maximum value of $|E^*|$
- β, γ = shape parameters of the model

The fitting parameters ($\alpha, \beta, \delta, \gamma$, and c) were determined through numerical optimisation of Equation 1 using the stiffness modulus values data of the BRASO mix obtained from laboratory testing.

Recall that a short-term oven ageing for four hours at 145°C was used to prepare the BRASO mix. In this condition, the viscosity as a function of temperature was expressed using the American Society for Testing Materials (ASTM) viscosity-temperature relationship (ASTM D2493, 1998) given in Equation 2.

$$\log \log \eta = A + VTS \log T_R \quad (2)$$

where

- η = viscosity (Pa.s)
- T_R = temperature (K)
- A = regression intercept
- VTS = regression slope of viscosity temperature susceptibility

The temperature dependency of the dynamic modulus is incorporated in the reduced frequency parameter, f_r in Equations 3a and 3b. The reduced frequency is defined as the actual loading frequency multiplied by the time-temperature shift factor, $a(T)$.

$$f_r = a(T) \times f \quad (3a)$$

$$\log f_r = \log f + \log a(T) \quad (3b)$$

where

- f = frequency, Hz
- $a(T)$ = shift factor as a function of temperature
- T = temperature

Figure 1 represents the dynamic modulus master curves for five replicate BRASO samples, and Figure 2 presents the detailed master curve at five temperatures produced for the BRASO mix using the average dynamic modulus values of the 5 replicate samples tested. It can be seen that the test data obtained at the low test temperatures (-5°C and 5°C) were shifted to the right whereas the high test temperatures (40°C and 55°C) data were shifted to the left to meet the master curve.

Figure 3 shows that the BRASO mix tested has lower stiffness than the four conventional asphalt mixes tested for the SAPDM project. This trend is expected. The BR binder is less viscous compared to the binders used in the conventional mixes. It appears that the recoverability of deformation is far greater in BRASO when compared to the other mixes.

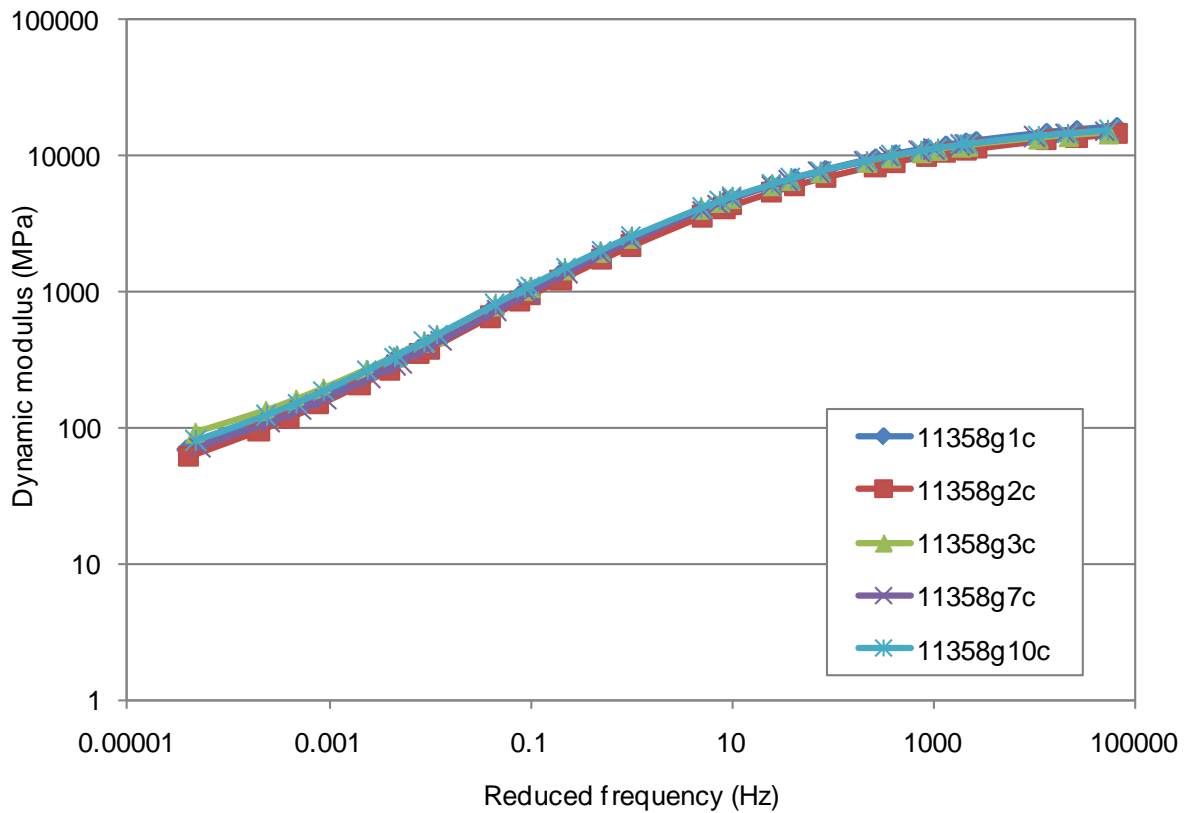


Figure 1 Dynamic modulus master curve for 5 replicate BRASO samples

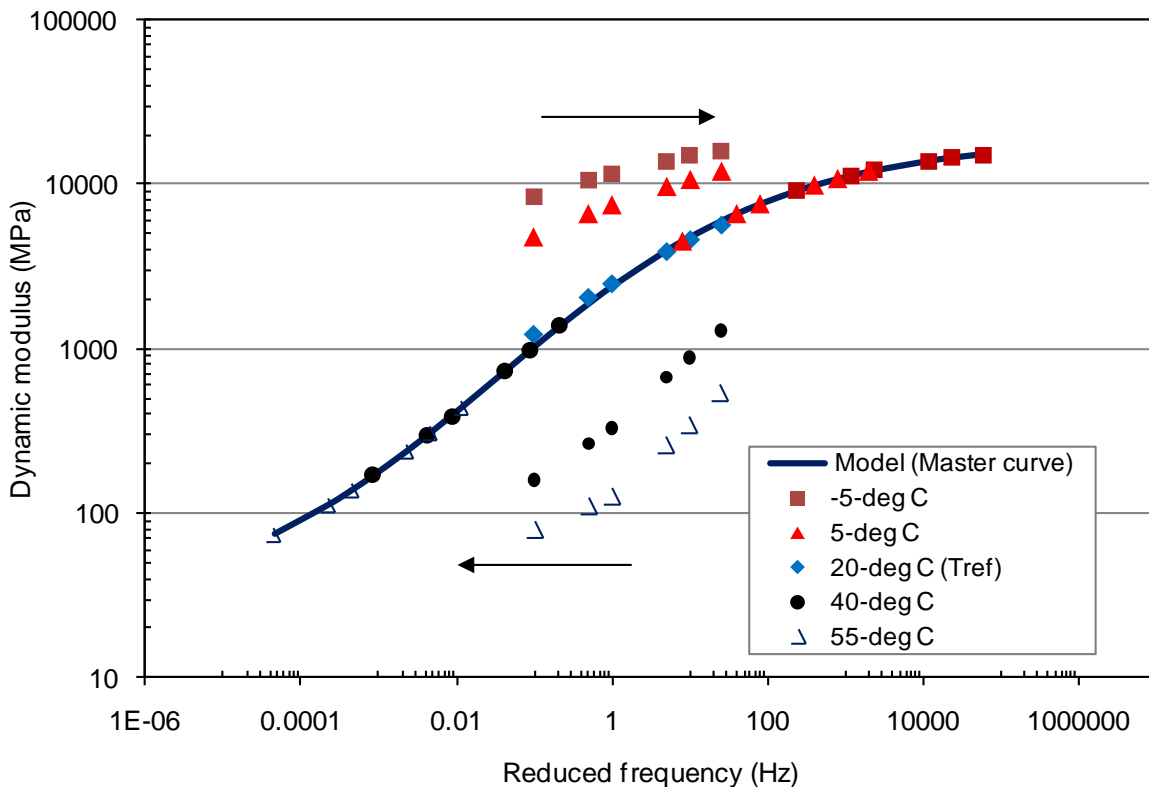


Figure 2 Average dynamic modulus master curve for BRASO mix

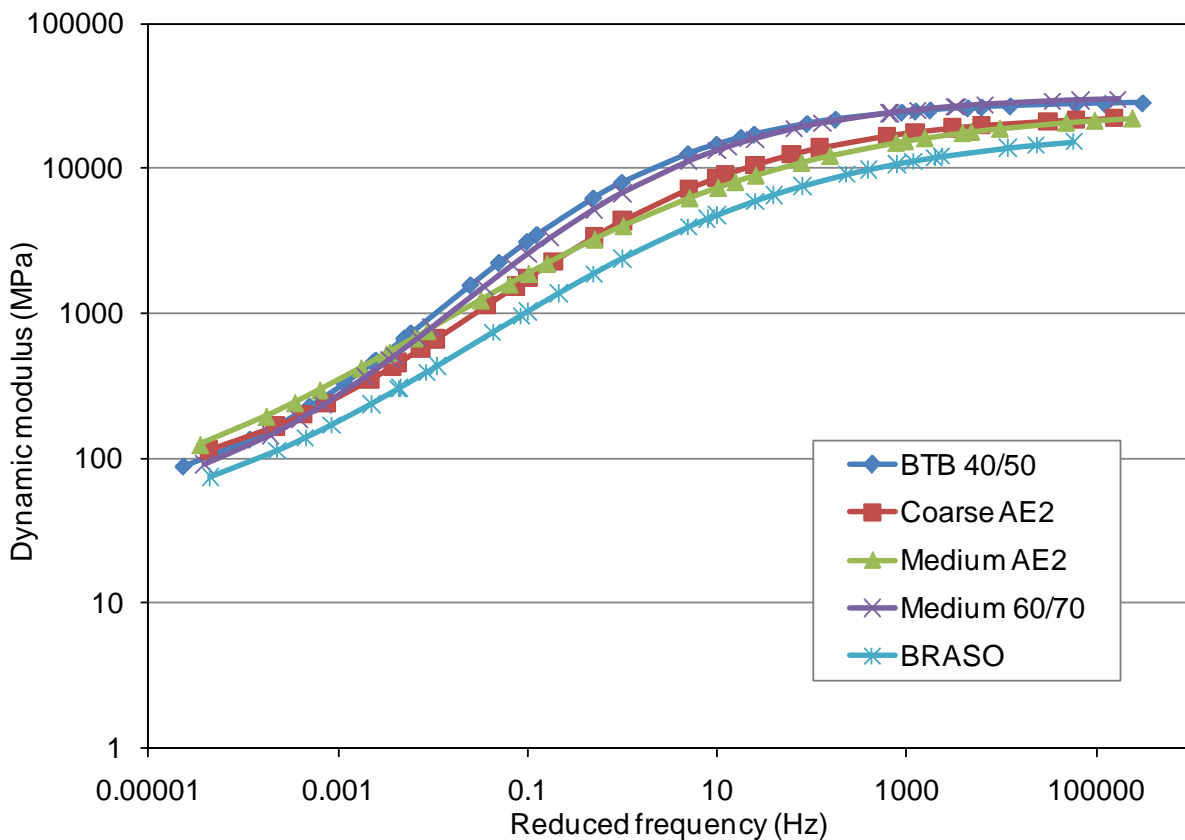


Figure 3 Comparison of dynamic modulus (stiffness) of BRASO with conventional mixes

3.2 Permanent deformation testing

The repeated simple shear test at constant height (RSST-CH), also known as Superpave shear test is used for determination of permanent shear strain and complex shear modulus G^* of asphalt samples. The test procedures are based on AASHTO standard test method AASHTO 320-03 (AASHTO, 2007), with certain alterations and improvement to better suit the requirements of the revision of the SAPDM project (Anochie Boateng et al, 2010). The SST-CH specimen was glued to platens at the top and the bottom. A horizontal cyclic shear load is introduced to the sample by moving the bottom platen using the shear actuator of the shear tester. The response of the sample, in terms of shear displacement is measured using the linear variable displacement transducer (LVDT) mounted horizontally. The horizontal or shear LVDT measures the differential displacement between the top and bottom platen. In the original test method the LVDTs were mounted to the asphalt material itself, but this often led to LVDTs coming loose during the test. The current AASTHO method allows both mounting to the specimen and mounting to the platens. During the test the height of the sample is kept constant by the vertical actuator responding to movement of an LVDT mounted vertically.

In the RSST-CH (performed to standard protocol) a horizontal shear force of 69 kPa was applied to the cylindrical specimen. The load was applied for 0.1 second followed by a 0.6 second rest period. The horizontal deformation was measured over the height of the specimen during the test. The rate at which permanent shear strain accumulates in the material during the test has been used to predict deformation in the field. RSST-CH permanent deformation tests were performed at three different temperatures and two

densities. Tests run up to 30 000 repetitions or 5% permanent strain, whichever was reached first.

The BRASO sample was tested at two densities, i.e. design density (DD) (5.6%) and field density (FD) (close to 7%). This was done to characterise the permanent deformation of material during the stable condition of its design life (design density) and during the phase immediately after construction (field density).

3.2.1 Permanent deformation test results and analyses

The average shear deformation curves for the specimens compacted to design and field densities are shown in Figure 4. The accumulation of permanent strain at field density is faster than at design density due to the lower density of the former. The resistance against permanent deformation of the BRASO was significantly lower than that for any of the other mix types tested in the SAPDM project (see Figure 5). The results indicate that the mix type may not be suitable for situations with slow moving heavy vehicles such as inclines and intersections. This finding is in line with international guidelines on the use of BR mixes. Under the SAPDM project, the data of the RSST-CH will be used for the development of permanent deformation models for BRASO.

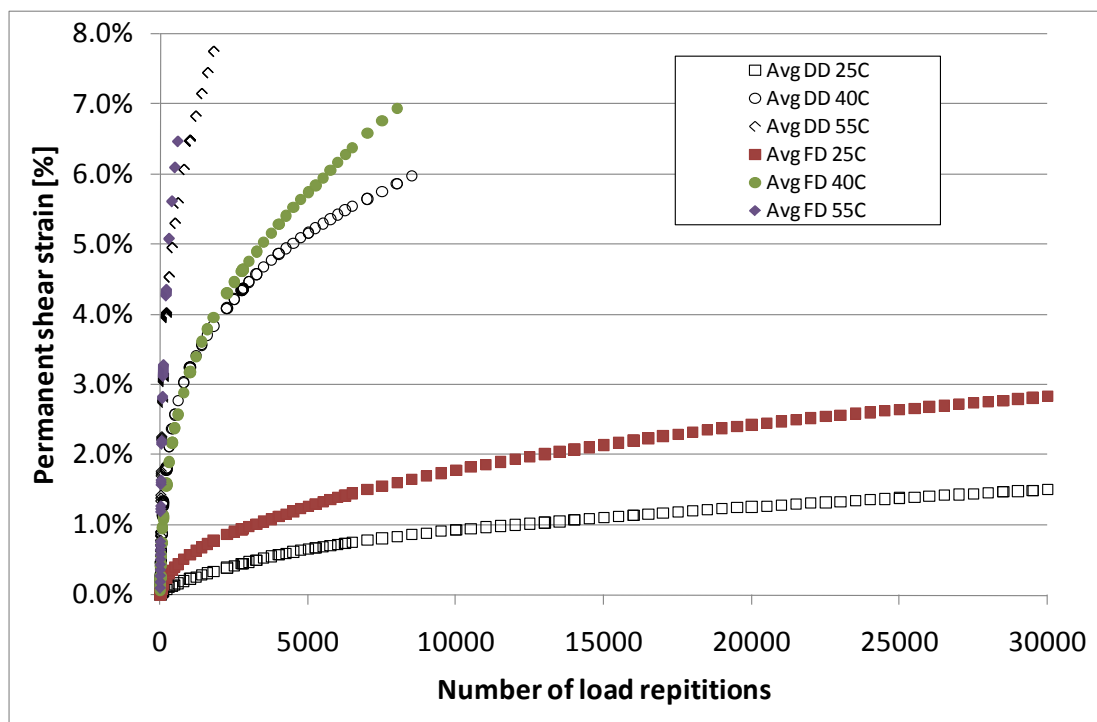


Figure 4 Comparison of permanent deformation behaviour at design and field densities

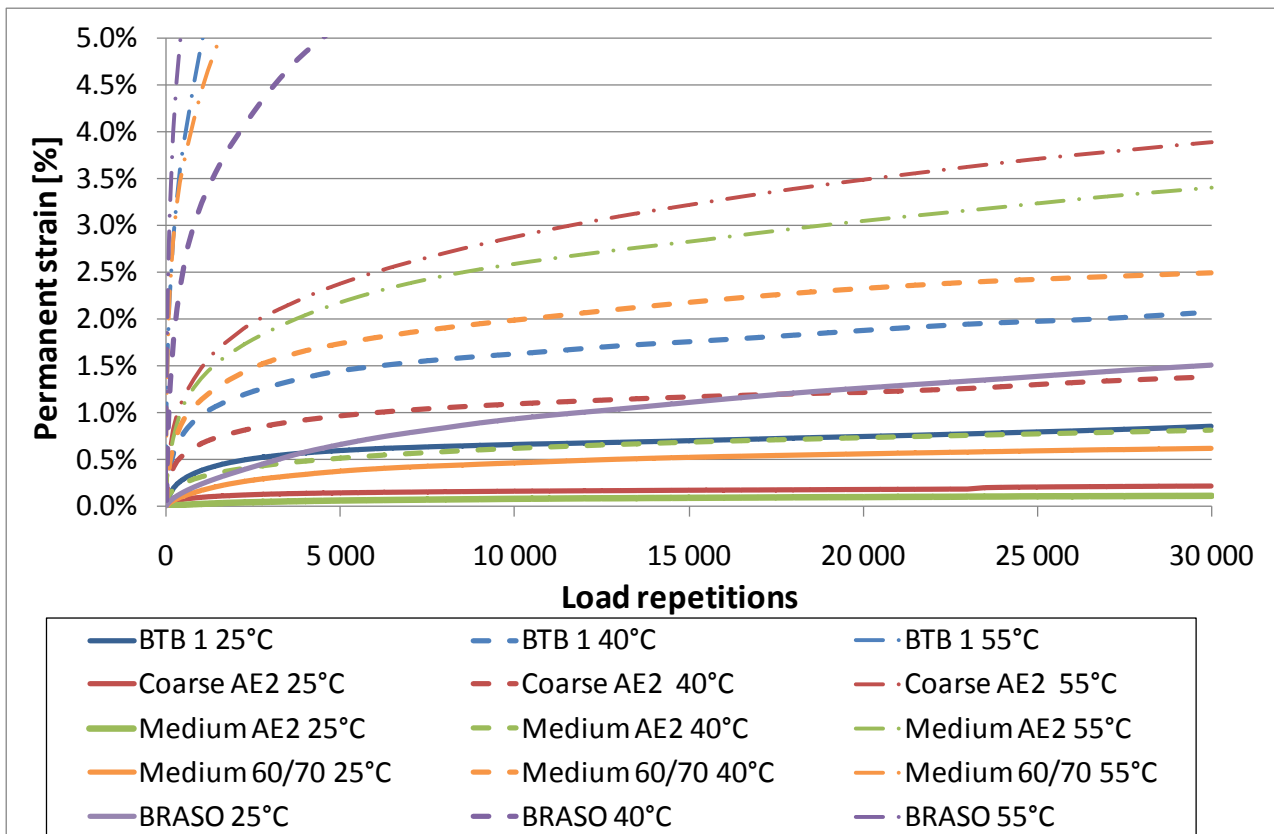


Figure 5 Comparison of permanent deformation of BRASO with conventional mixes at design density

3.3 Beam fatigue testing

Fatigue is a phenomenon in which a road pavement is subjected to repeated stress levels until failure. Fatigue life obtained from the third-point loading fatigue test recommended by (NCHRP 1-37A, 2004; SANRAL, 2007) is a key input parameter for flexible pavement design to predict cracking in hot-mix asphalt. The fatigue testing was conducted using an IPC standalone third-point loading bending beam device. The tests were performed according to CSIR test protocol for determining beam fatigue characteristics of asphalt mixes in South Africa (Anochie-Boateng *et al.*, 2010).

The experimental testing program was designed to conduct the fatigue tests at four strain amplitude levels of 200, 400, 600 and 800 microstrains, and at 3 test temperatures of 5, 10 and 20°C. However, tests were conducted at higher strain levels ranging from 400 to 1400 microstrain to reduce extremely long durations of testing on the BRASO samples. Tests were conducted on the prepared prismatic beam specimens of 400 x 63 x 50 mm. A continuous sinusoidal load was applied on the specimens at a frequency of 10 Hz.

The fatigue test was conducted under controlled-strain loading conditions. The loading was extended to reach a final stiffness reduction of 70% of the initial stiffness to collect additional data for analysis. Thus, fatigue life of the BRASO mix was defined as the number of cycles corresponding to 70% reduction in the initial flexural stiffness. Initial stiffness modulus is defined as the modulus measured at the 50th load cycle similar to the standard AASHTO T 321 (AASHTO, 2009) test procedure for HMA samples.

3.3.1 Beam fatigue test results and analyses

The beam fatigue on the BRASO mix was conducted at two levels of air void contents, i.e. at design and field voids. As indicated earlier, the design voids for the mix was 5.6%, and target field voids content was 7%. The results presented in this paper are for design air voids.

Figure 6 represents applied strain versus fatigue life of the BRASO sample at the three test temperatures. It can be seen that high fatigue life was obtained at low strain level and high test temperature for the BRASO mix. On the other hand, low fatigue life was obtained at high strain level and low test temperature. These trends follow the fatigue behaviour obtained from conventional asphalt mixes (e.g., medium continuously graded mix with 60/70 penetration grade binder) tested under the SAPDM testing programme.

Figure 7 compares fatigue life of BRASO with the four conventional asphalt mixes tested for the SAPDM project. The BRASO mix indicates longer fatigue life than the other mixes. Thus, for new road pavement construction and overlaid pavement sections, longer fatigue life predictions would be obtained for the BRASO mix than the conventional asphalt mixes.

Figure 8 shows the plot of fatigue life as a function of dissipated energy for the BRASO sample using the combined test results at temperatures of 5, 10 and 20°C, and strain levels between 400 to 1400 microstrains. The rate of change in dissipated energy appears to be constant for the BRASO sample. Thus, a clear relationship exists between fatigue life and dissipated energy. The regression analysis performed on the test data showed a reasonable high R^2 – value (0.82), which indicates strong correlation between dissipated energy and fatigue life.

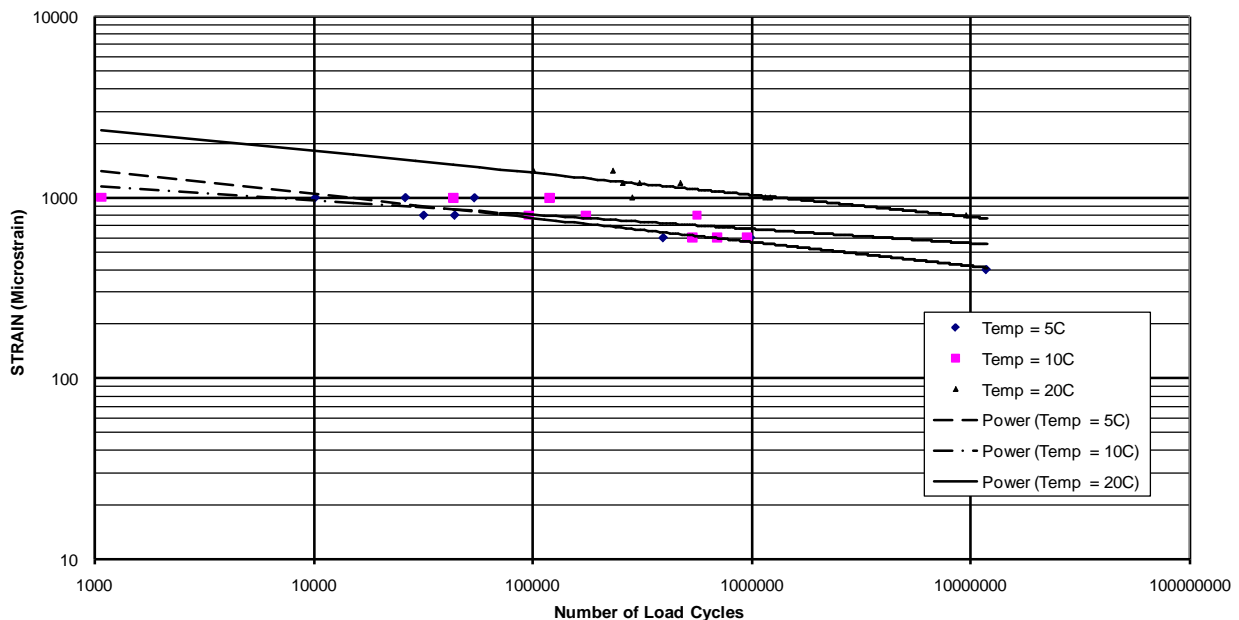


Figure 6 Strain-fatigue relationship of BRASO sample tested

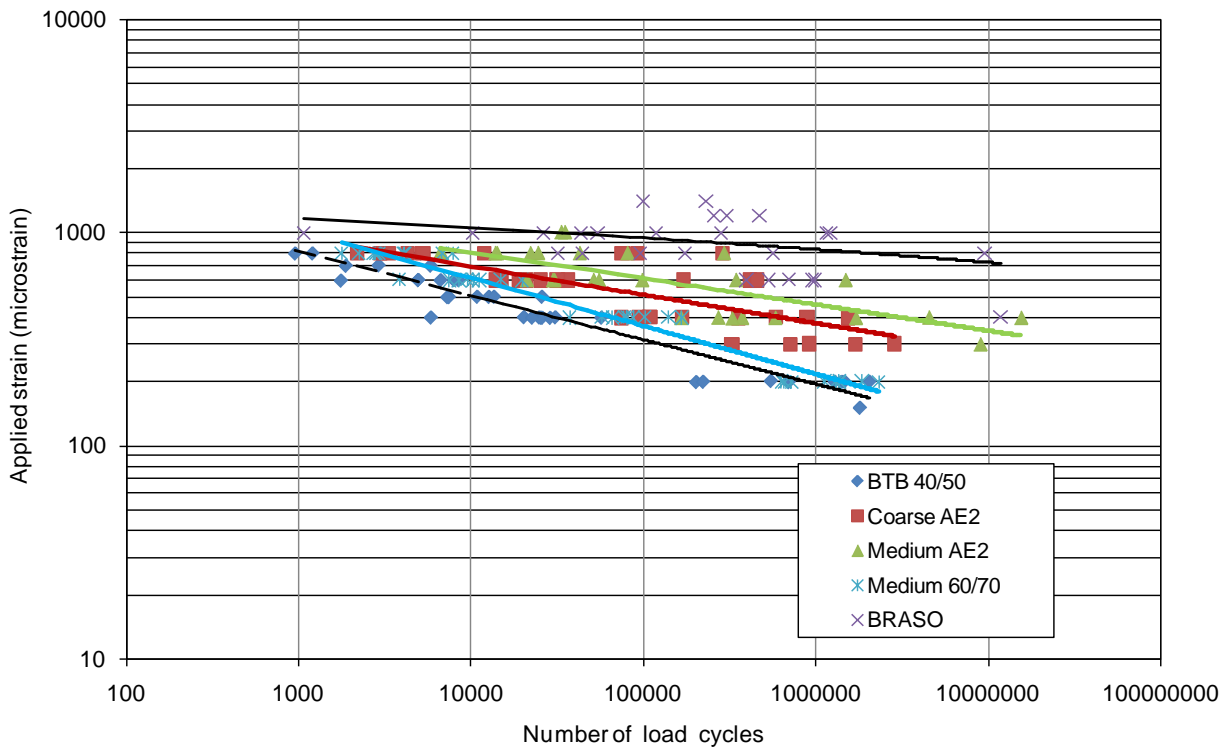


Figure 7 Comparison of fatigue life of BRASO with conventional mixes

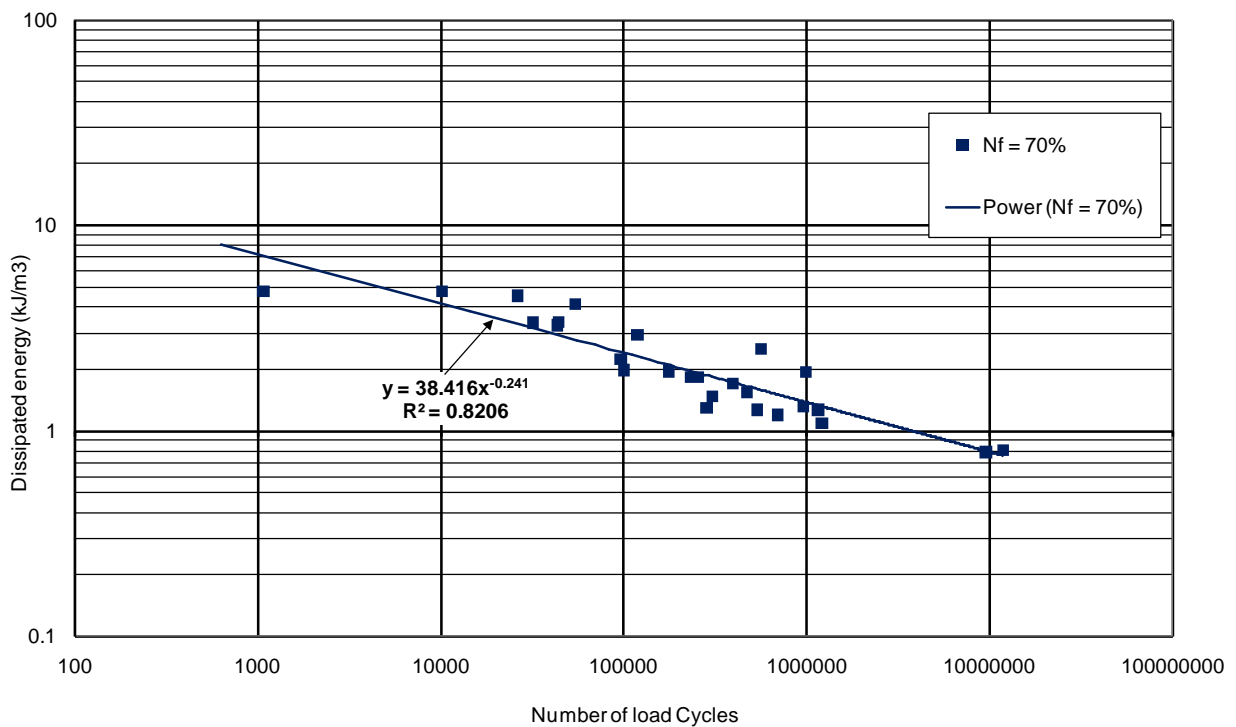


Figure 8 Dissipated energy vs. fatigue life of BRASO sample

4 CONCLUSIONS

This paper presented test results of a laboratory testing program conducted on bitumen rubber semi-open graded asphalt (BRASO). Although limited tests have been conducted thus far to provide a valid conclusion on the BRASO mix tested, the results presented from the different test procedures provide fundamental material properties of the BRASO sample tested.

The data obtained from the test programme described in the paper are sufficient to develop damage and resilient response models for the SAPDM. This process is currently underway. Models to predict the moduli of BRASO at different temperatures and loading speeds, permanent deformation, and fatigue will become available to industry in 2012.

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