INVESTIGATION OF POLYMER MODIFIED ASPHALT BY SHEAR AND TENSILE COMPLIANCES

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Paper prepared for presentation

at the Material Characterization for Inputs into AASHTO 2002 Guide Session

of the 2004 Annual Conference of the
Transportation Association of Canada
Québec City, Québec

ABSTRACT

Although C-SHRP and Superpave procedures are currently being used in the testing of polymer modified asphalt (PMA) and asphalt binders, it is believed that further laboratory investigations will have to be done in the field of loading time and temperature from the perspective of rutting, fatigue and low temperature cracking. One possible method of investigation with the advantage of providing more insight into the material structure is to characterize materials on larger time / frequency domains by accepting the Time Temperature Superposition (TTS) principle.

The goal of this paper is to summarize the findings from the tests of the PMA binders that were examined by the dynamic shear and bending beam rheometers (DSR and BBR). Two commercially available binders of different performance grades (PG's) were investigated. Binder results were compared with the results of mastic - mix of asphalt binder and mineral filler, and hot mix asphalt (HMA). This was investigated using a dynamic mode (oscillations) and creep sample test. The TTS principle was applied to the obtained master curves from the isochrones of three of the tested materials (PMA, mastic and HMA). Preliminary results showed that the performance of shear compliance of the HMA is similar to binder and mastic at short loading (and/or low temperatures) but exhibited different behavior at long time loading (and/or high temperatures).

The paper also discusses a question of the relation between the shear and tensile compliances (J,D(t)). These were obtained for original PMA, HMA and mastic by the relaxation of the spectra from master curves. Results of the tested binders showed a relationship among these fundamental parameters, which is important for proper asphalt binder evaluation. This is in accordance with AASHTO 2002 design, where materials tend to be described by still the empirical method but based on mechanical principles.

1. INTRODUCTION

Even though asphalt binder usually constitutes five percent of the weight of the HMA, it still has a significant impact on the overall material properties. It is believed that asphalt is a simple material in terms of rheological properties as the Time Temperature Superposition (TTS) principle appears to explain behavior [1]. This theory was confirmed by testing several polymer modified binders, where viscoelastic behaviour was also found [2]. Properties of binders and polymer modified asphalts (PMA) can be relatively well described by current specifications [3] however, the trend is to use more sophisticated equipment to evaluate properties of binder, polymer modified asphalt and mastic. The characterization of PMAs and binders has been analyzed with small amplitude shear oscillations with the goal to obtain dynamic material functions. The investigation of the HMA properties is more complex. Mechanical properties of the laboratory prepared mixes are influenced by factors such as design, compaction and sample size [5]. Some testing methods used for binder, could be applied for the HMA testing at special conditions [6]. In this study, good correlations between the moduli were found using two different tests – static creep and dynamic oscillation. Experiments were carried out on thin samples, sliced from bulk briquettes. Polymer modified asphalt binder, mastic and HMA were investigated.

2. OBJECTIVE

The objective of this work is to compare different bituminous materials (asphalt, binder, mastic) measured by different techniques and to discuss obtained results and their interpretations. Rheometric Scientific, dynamic rheometer and two different asphalt binders were used in this study. These were compared with static loading conducted in bending beam rheometer at temperatures below zero. The properties of HMA were also evaluated on thin samples cut from the laboratory specimen with one tested asphalt binder. This study is especially important in the event of the new AASHTO 2002 design guide in which bituminous materials are characterized in terms of elastic properties (eg. dynamic moduli) as presented here.

3. EXPERIMENTAL

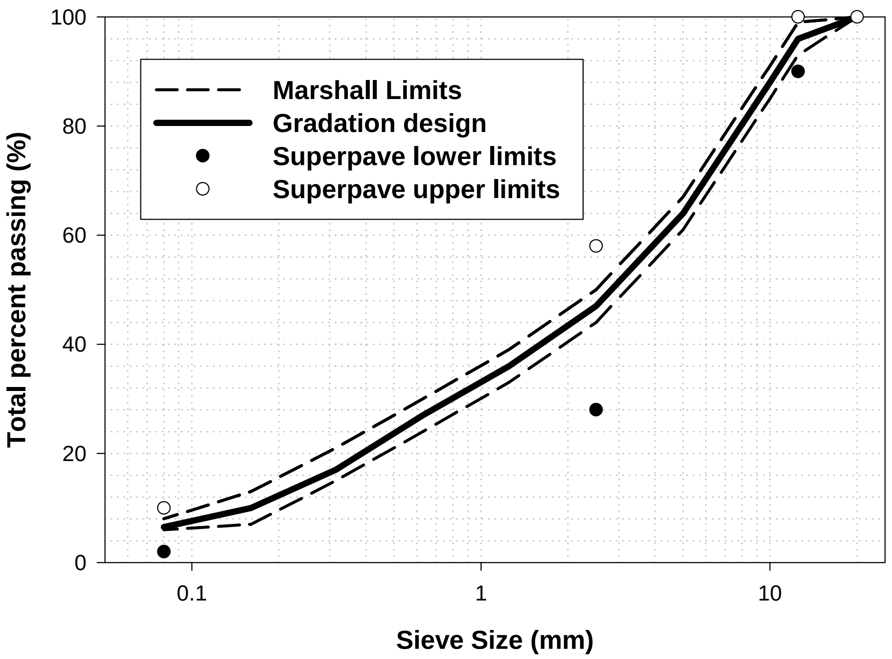
3.1. Materials and Sample Preparations

Samples of HMA were taken at the construction site, directly from the paver and compacted in the laboratory by a linear kneading compactor, in accordance with the density achieved at the site (2343 kg/m^3). The desired mix design met all standards, defined by local authorities, Table 1. Gradation curves met SHRP specifications as seen in, Figure 1. Bulk compacted specimens were cut into small samples by the diamond saw. Average dimensions were taken from each sample, which were individually measured several times. Two different sample types were prepared. The first, used in the BBR, had the dimension criteria prescribed by the SHRP specifications. The approximate weight of this specimen was 20 grams (125 x 12.5 x 6 mm). The second set of samples tested in the DSR apparatus had smaller dimensions (55 x 3 x 11mm) at an average weight of five grams.

Table 1. Hot mix asphalt design criteria

MARSHALL CHARACTERISTICS	LIMITS
VMA (%)	14 min
Plant Mix Moisture (%)	0.2 max
Marshal Stability (N)	7 100 min
Flow (0.25mm units)	10 - 16
Air Voids (%)	3 - 5

Figure 1. Hot mix asphalt grain size distribution curve



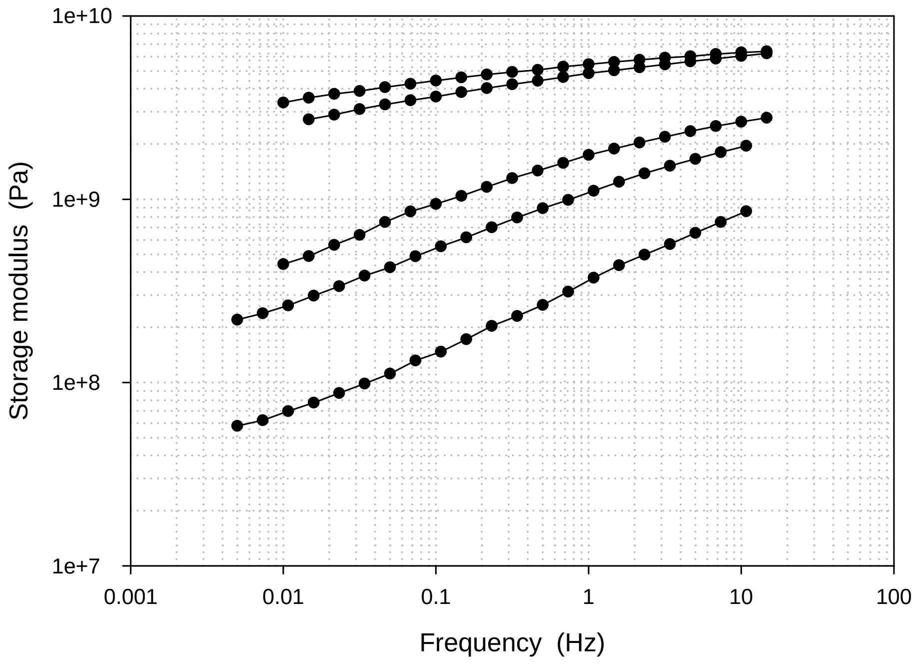
Polymer modified asphalt (PMA) of PG 64-28, was used in this mix. This was made possible by blending of neat asphalt binder PG 52-34 (A200/300 pen grade) and 4% commercially available copolymer. The Rolling Thin Film Oven (RTFO) test was applied to the binder in order to simulate properties of PMA in a newly built road. Mastic was prepared in the lab by mixing mineral filler and aged PMA in a ratio of 1:1, similar to the ratio used in the HMA. The specific gravity of the mineral filler was 2700 kg/m^3. HMA samples were sliced from the bulk specimen, RTFO aged PMA and mastic were poured into the prepared preheated molds. The dimensions of such samples correspond to the HMA -for BBR (125 x 12.5 x 6 mm) and for DSR (55 x 3 x 11mm).

3.2. Testing Procedures

In order to obtain as many data points as possible, PMA, mastic and HMA beams were subjected to creep in BBR for 480 seconds. A temperature of -28 ^{o}C was chosen for the comparison of all studied materials with the standard loading force of 1000 mN.

Rheometric ARES, a strain controlled rheometer, was used to test materials in dynamic mode. Asphalt binder and mastic samples were tested in the form of torsion bar geometry at temperatures ranging from -28 to 10 ^{o}C. Oscillations were applied to the HMA at a similar temperature range (-22 ~ 10 ^{o}C). Isochrones of G' and G'', were obtained in the same frequency domain (0.005 ~ 10 Hz) at strains which did not exceed the linear viscoelastic limit. An example of storage modulus of HMA is presented in Figure 2.

Figure 2. Hot mix asphalt isochrones of storage modulus (G') at temperature range 10 ~ - 22 °C



4. THEORY

4.1. Bending Beam

The three point loading bending theory has been known to the asphalt industry for more than a decade and was successfully implemented in the SHRP specification. Resultant creep stiffness modulus $S(t)$ is the inverse of creep compliance presented as shown in Equation 1:

$$S(t) = \frac{1}{D(t)} \qquad \text{Equation 1}$$

The equation for calculating creep stiffness is:

$$S(t) = \frac{PL^3}{4bh^3\delta} \qquad \text{Equation 2}$$

where L, b, h are the sample dimensions, δ is the recorded deflection and P is the applied force.

At low temperatures, materials nearly exhibit ideal elastic behaviour or behave as viscoelastic solid. Stress-strain ratio in tension is described by the fundamental constitutive equation where relaxation moduli in shear $G(t)$ and bulk $K(t)$ are present. The Young's modulus is related to these as seen in Equation 3:

$$\sigma(t) = \varepsilon \times \left[\frac{9G(t) \times K(t)}{G(t) + 3K(t)} \right] = \varepsilon \times E(t) \quad \text{Equation 3}$$

In a time interval when $K(t)$ is greater then $G(t)$ by several orders of magnitude, equations can be simplified as show:

$$E(t) = 3 \times G(t) \quad \text{Equation 4}$$

$$D(t) = J(t)/3 \quad \text{Equation 5}$$

4.2. Dynamic Oscillations

Strain and stress are functions of time and they are connected by a constitutive equation, where the linear viscoelastic material is in the simple shear has the form of constitutive equation [8].

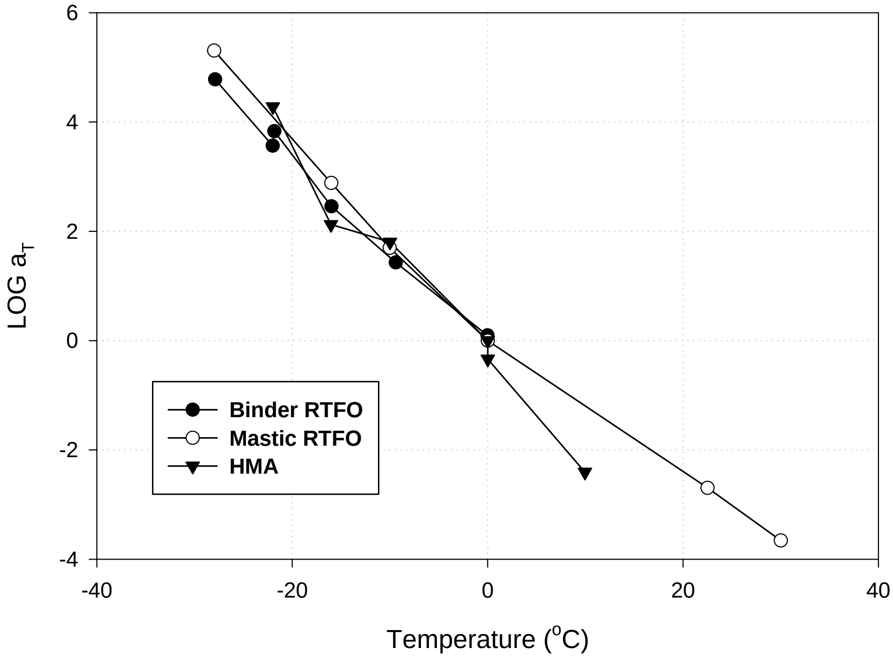
According to the linear viscoelastic theory, when the sample is subjected to the sinusoidal simple shear strain $\gamma(t)$, which is defined by angular frequency ω and small amplitude γ_o, the stress will exhibit the same, but out of phase sinusoidal pattern as applied strain. Thus the shear storage and the shear loss moduli G', G'' can be obtained. The name of G' is a derivative from the energy storage and release during the oscillatory deformation. The loss modulus G'' is associated with the dissipation and energy loss of heat during the cycling.

5. RESULTS AND DISCUSSION

The theory used in this study is relatively simple and can be divided in two parts in accordance of the test used. Part of the Superpave specification is an asphalt binder evaluation at high and intermediate temperatures. Dynamic oscillation in shear, done by sinusoidal loading, was applied to the sample which is placed between parallel plates. The evaluation of the material is based on principles of linear viscoelasticity [8, 9]. Storage G'(ω)and loss G"(ω) moduli were obtained and used for further calculations.

TTS principle can be applied for all materials in order to create master curves [10]. This is done by commercial software, where the only inputs are measured moduli G', G" from a dynamic shear rheometer at given frequencies and temperatures. The software enables horizontal manual shifting a_T, characteristic for each temperature, the Williams-Landel-Ferry (WLF) equation [11] was used to obtain constants C_1 and C_2.

Figure 3. Horizontal shift factor a_T of asphalt binder, mastic and hot mix asphalt



Master curves of complex modulus of evaluated materials are portrayed in Figure 4 at the reference temperature ($T_{ref.}$) 0^oC. Differences among materials can be observed at low temperatures. The HMA exhibited one magnitude higher complex shear modulus in comparison to the asphalt binder. The properties of mastic were not substantially different from the properties of asphalt, at elevated temperatures. HMA showed more elastic behavior with the phase angle ranging between 30-40 degrees at intermediate temperatures than asphalt binder and mastic.

Figure 4. Master curves at $T_{ref.}$ 0^oC, asphalt binder, mastic, hot mix asphalt

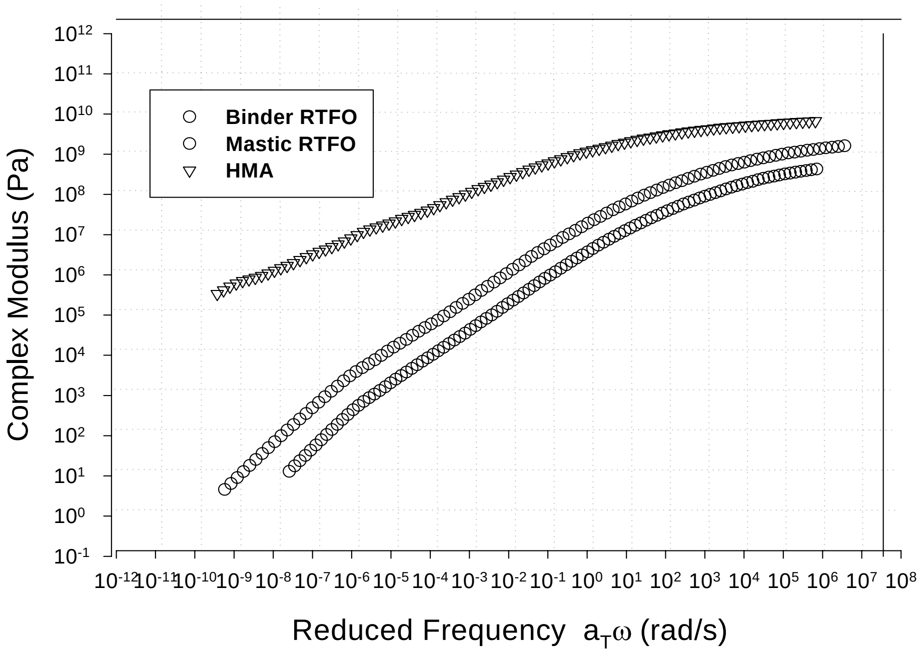
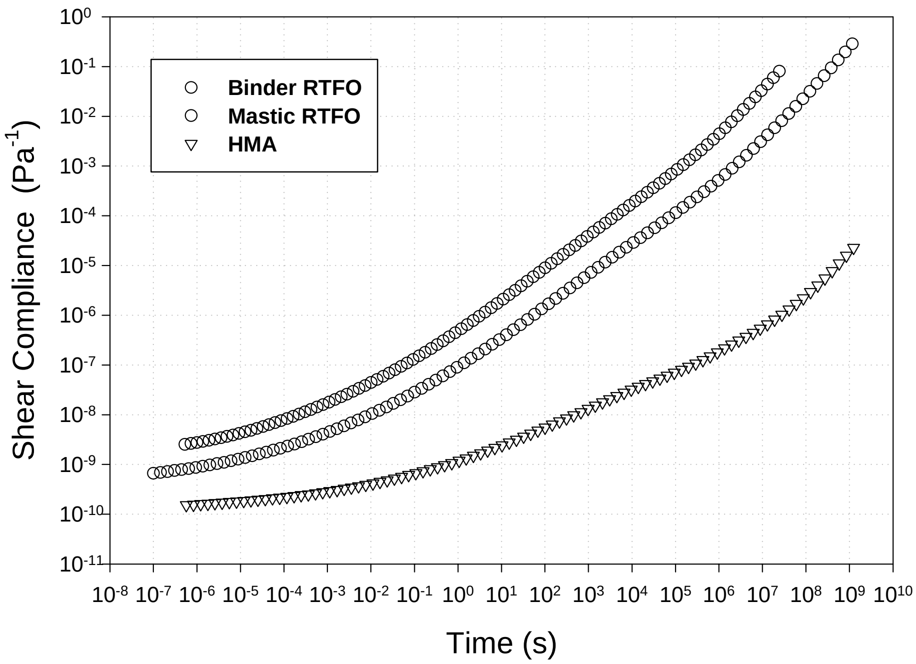
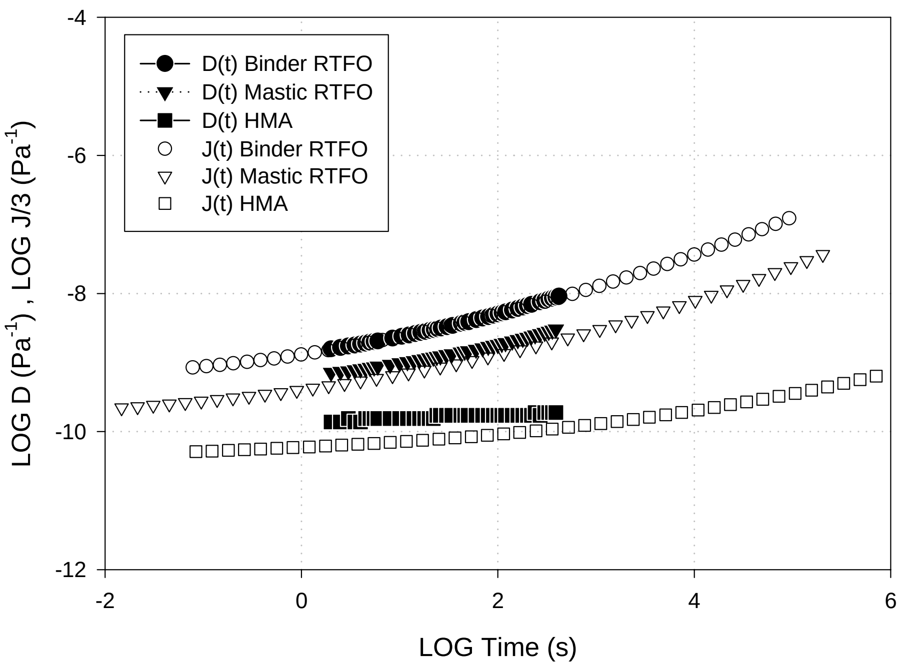


Figure 5. Shear compliance calculated via spectra at $T_{ref.}$ 0 ^{o}C



Since master curves were created, the shear compliance J(t) defined by discrete retardation spectra can be easily calculated [12]. In our case, IRIS, commercial software was used, as shown in Figure 5. A similar pattern can be seen between the asphalt binder and mastic. HMA exhibits different behaviour, especially with long relaxation times. The comparison between shear J(t) and creep D(t) moduli at a temperature of -28 ^{o}C is depicted in Figure 6. Data obtained by dynamic measurements were also shifted to $T_{ref.}$ -28 ^{o}C, at which temperature was the creep test in BBR was conducted. Equation 5 was used to calculate crep compliance data.

Figure 6. Comparison of the shear (J/3) and creep (D) moduli at -28 ^{o}C



6. CONCLUSIONS

The properties of HMA were investigated in sample sizes and shapes originally designed for asphalt binders (HMA small scale testing). The average weight of the HMA specimens tested in the dynamic mode was five grams. The weight of such as beam, used for and creep test did not exceed 20 grams. It was proven that HMA samples can be tested in commercially available rheometers. However, this method has to be compared with the results of the typical size HMA.

Complex modulus was obtained from the dynamic experiments done by simultaneous horizontal shifting of storage and loss moduli (G', G''). Master curves, at reference temperature 0 ^{o}C, showed evident differences among materials with respect to the complex modulus. Mastic and binder tend to be viscous even at intermediate temperatures, while the HMA phase angle remains constant and oscillates around 35 degrees value. Results showed that mineral filler presented in mastic had a small impact on shear modulus at intermediate temperatures. Based on results from the experimental part, it is believed, that mastic properties can be directly derived from the binder.

Data measured in DSR at low and intermediate temperatures were shifted in accordance with TTS to the reference temperature of -28 ^{o}C at which creep tests were conducted. Results proved good correlation between the bending beam and the dynamic shear rheometers for given materials. In accordance to these findings, DSR data can be used to predict the low temperature behaviour if TTS is applied correctly (log D = log J/3). This finding is especially important for asphalt binders and mastic, the variation between compliances of shear and creep in HMA is more obvious.

Evaluation of bituminous materials is based on fundamental properties such as shear moduli (G', G'') and creep compliance (D) and it can easily be measured by current equipment. Based on the results of committed testing, it is recommended to characterize bituminous materials by dynamic oscillations and static loading at different temperatures different frequencies and longer loading times. Description of material behaviour under these circumstances is more closely related to the actual pavement performance.

The Mechanistic - Empirical AASHTO 2002 guide accounts for all factors that change with time and affect the material response. Also, response models should be able to consider a variety of loading situations with respect to material properties. AASHTO ideas are covered in the article. Thanks to TTS dynamic moduli in shear (G',G") can be obtained for any temperature by simple shift using a_T factor. The shift is restricted only by the range of temperatures, it is recommended to measure dynamic properties in a large temperature window. The AASHTO loading is represented by using different frequencies in this case.

7. ACKNOWLEDGEMENTS

This paper was prepared with the cooperation of the Centre of Pavement and Transportation Technology (CPATT) at the University of Waterloo, Canada. The authors are especially indebted to the Natural Sciences and Engineering Research Council of Canada and to Husky Energy for their financial support in this project. The help of reviewers is also appreciated.

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