PHYSICAL PROPERTIES OF ASPHALT-RUBBER BINDER

by

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ABSTRACT
A study was performed to determine how the physical properties of asphalt-rubber binder change with select variables. The physical properties studied were the low-, intermediate-, and high-temperature rheological properties, measured with the bending beam rheometer, dynamic shear rheometer, and rotational viscometer, respectively. The physical properties of the asphalt-rubber binder were determined to be dependent on the curing time, rubber content (weight percent), rubber particle size, and base asphalt type. By controlling these variables, an asphalt-rubber binder with improved low-temperature cracking resistance, improved mid-temperature rutting resistance, and a non-detrimental high-temperature compaction viscosity, all relative to the base asphalt, can be produced.
INTRODUCTION
The federal government has mandated that asphalt-rubber utilization be at a level of at least 20% for all new, federally funded asphalt pavement construction by 1997. This means that on average, all asphalt binders must contain a minimum of 4% ground tire rubber. As a convenient working definition, asphalt-rubber is defined to have 9.1 Kg (20 lb) of rubber per ton of hot mix, which means the binder is approximately 20% rubber by weight percent. If 20 percent of the roads are asphalt-rubber, this is 20%×20% or on average 4% rubber in all binder used in all roads. This mandate was enacted without proper consideration of the physical properties, and thus the performance characteristics of asphalt-rubber binder. The physical properties of asphalt-rubber binder must be understood and optimized if the implementation of ground tire rubber into asphalt is to result in acceptable pavement performance.

It is necessary to study the physical properties of asphalt-rubber binder at a diverse set of temperature conditions to begin to understand the behavior of asphalt-rubber binder. A binder will experience stresses over a wide range of temperatures, from 193°C (380°F) during hot mix and compaction to -26°C (-15°F) in a typical climate. Furthermore, an average binder may be subjected to annual temperature variations of 67°C (120°F) or more and daily variations of nearly 28°C (50°F) in some regions of the country.

Proper compaction is essential for sound road construction. The newly constructed pavement should have enough air voids to avoid flushing, but not so many as to shorten road life. According to Linden, et al. (1) pavement life is reduced by about 10 percent for each percent increase in voids above 7 percent. In addition, the air void content is a major factor affecting rutting at elevated service temperatures. Although rutting is primarily dependent upon the aggregate design and compaction procedure, Roberts et al. (2) state that increased resistance to rutting can be obtained by using stiffer asphalt cement. Typically, an asphalt that is relatively stiff at higher temperatures will also be stiff at low temperatures and thus highly susceptible to low-temperature cracking.

Therefore, it is essential that a binder should have a relatively low viscosity at compaction temperatures to allow for proper compaction. Proper compaction reduces the percentage of air voids and therefore eliminates the major cause of rutting and rapid oxidation. In addition, an excellent binder should have a reasonably high viscosity at elevated pavement temperatures to further retard rutting and yet also have a relatively low viscosity (and stiffness) at low temperatures to avoid cracking. Thus, the perfect binder should not be highly susceptible to temperature changes.

The main objective of this work is to study the effect of select variables upon the high-temperature (> 121°C (250°F)) and intermediate-temperature (90°C (194°F) to 0°C (32°F)) viscosities as well as the low-temperature stiffness as measured at -15°C (5°F). The variables examined in this study include rubber content (weight percent), rubber particle size, asphalt type, and curing time.

MATERIALS
Five asphalts were used in this study. SHRP ABM-1 AR-4000 and SHRP ABL-2 EB-10 were acquired from the SHRP Materials Reference Library in Austin, Texas, subsequently relocated to Reno, Nevada. An AC-5 was acquired from the Diamond Shamrock refinery.
located in Dumas, Texas, and an AC-5 was also acquired from Fina refinery located in Big Springs, Texas. The fifth asphalt studied, 'Made AC-5', was produced in the lab by blending SHRP ABM-1 and Sun Hydrolene 125, a highly aromatic extending oil, to AC-5 viscosity specifications. Crumb rubber of -10 and -40 mesh were acquired from Granular Products, also known as Tire Gator, located in Mexia, Texas.

EXPERIMENTAL METHODS

Mixing Apparatus
To produce the asphalt-rubber binders, asphalts and rubbers were 'cured' or mixed at high temperatures (> 177 °C (350 °F)). Curing, for the purpose of this paper, is defined as an increase of viscosity without oxidation, with oxidation being measured by the carbonyl peak area of the infrared spectrum. The curing process, as carried out in this laboratory, involves mixing rubber and asphalt at high temperatures with a 5.1 cm (2") diameter blade driven by a 49.7 W (1115 hp) variable speed motor. Mixing occurs in a 0.95 liter (1 quart) or 3.74 liter (1 gallon) sized paint can under a nitrogen blanket to prevent the binder from oxidizing or aging.

Bending Beam Rheometer
Low-temperature rheological properties of the asphalt-rubber binders, were evaluated using a bending beam rheometer (BBR). Anderson et al. (3) concluded that the BBR is the best choice for determining low-temperature properties of binders. The BBR consists of a loading mechanism, LVDT, temperature bath, and appropriate controls. The specimen, loading mechanism, and LVDT are submerged in a constant temperature ethanol bath prior to and during testing.

A constant load of 0.1 Kg (0.22 lb) is applied at the center of a 6.35 mm×12.7 mm×127 mm binder beam which is supported at both ends on half cylindrical supports. The deflection of the beam is measured continuously during loading and an MS-DOS based software program calculates the flexural creep stiffness, S(t), at selected time intervals and the m-value. The flexural creep stiffness is the ratio obtained by dividing the maximum bending stress in the beam by the maximum bending strain and describes the low-temperature stress-strain-time response of the binder within the linear viscoelastic response range at a particular time. The m-value is the absolute value of the slope of log S(t) versus log time. Both S(t) and the m-value have been correlated with the low-temperature thermal cracking of binders (4).

Current SHRP Binder Specifications for grading the minimum pavement design temperature based on creep stiffness, require that the S value not exceed 300 MPa at the 60 second test time and that the m-value exceeds 0.300. These specifications are for grading pressure aging vessel (PAV)-aged asphalt binder. Currently, SHRP binder specifications are not available for either PAV-aged or unaged asphalt-rubber binders. For the purpose of this study, an unaged asphalt-rubber binder must possess a creep stiffness value of less than 300 MPa at the 60 second test time, and an m-value in excess of 0.300 to pass specifications. All bending beam results were obtained at a beam testing temperature of -15 °C (5 °F). The authors realize that the BBR is not sensitive enough below 75 MPa and therefore for certain binders, lower testing temperatures would be better able to detect the effects of the addition of
rubber. The beam specimens were produced and the bending beam rheometer was utilized as specified in AASHTO Designation TP1.

**Dynamic Shear Rheometer**

The intermediate-temperature rheological properties were tested with a Carri-Med CSL-500 dynamic shear rheometer configured in a parallel plate geometry. This instrument has the capability of providing either a constant stress-mode (its natural mode) or a constant-strain mode. Rheological properties can be measured over the temperature range of 0 °C (32 °F) to 90 °C (194 °F).

This instrument is operated in the constant-stress oscillation mode for analysis of neat asphalt samples but constant-strain mode is necessary for asphalt-rubber. The behavior of asphalt samples is non-Newtonian at intermediate oscillatory frequencies. However, by utilizing the constant-stress mode, a limiting complex viscosity, $\eta^*$, is usually obtained at low frequencies even for highly aged samples using the time-temperature superposition principle (5). For asphalt-rubber samples, however, at low frequencies a limiting complex viscosity is not obtained. To complicate matters further, the strains induced in the asphalt-rubber binders at low frequencies are quite large and may cause partial destruction of the bonds formed between the asphalt and rubber during the curing process. Therefore, it is necessary to operate the Carri-Med in the constrain-strain mode for asphalt-rubber samples.

To analyze the asphalt-rubber samples, it is necessary to determine the strain level that insures the data is obtained in the linear viscoelastic region. The strain level for measurement is determined by specifying several different strains and observing the strain response wave. The strain level where the response to a sinusoidal stress input is a sinusoidal strain wave, implying the strain is within the linear viscoelastic region, is chosen as the strain level for measurement. This results in strain levels of approximately 0.5% to 200% depending upon the temperature.

An additional complication to the measurement of asphalt-rubber properties is the presence of the rubber particles. As a result, it is necessary to determine the gap width for the parallel plate geometry. This gap width is strictly a function of the rubber particle size and content. The gap width for a given rubber size and content is determined by measuring the rheological properties of a given asphalt-rubber at multiple gap settings. To insure the elimination of the 'gap effect', the gap width is chosen such that the rheological properties taken at as wide or wider gap widths, are independent of the gap width.

**Brookfield Rotational Viscometer**

A Brookfield rotational viscometer Model RVF 7 is used to obtain the high-temperature (>121 °C (250 °F)) viscosities of the asphalt-rubber binders. Torque is applied to a spindle placed in the binder sample which is contained in a thermostatically controlled beaker. The relative resistance to rotation is measured for a given rotational speed. The relative resistance, the spindle size, and the rotational speed are then used to calculate the viscosity, $\eta$.

**FTIR**

The carbonyl area, which is a good measure of oxidation, is measured to determine if the asphalt was oxidizing during the curing process. A Mattson 5020 Galaxy Series Fourier
Transform Infrared (FTIR) Spectrometer is used to measure the infrared spectrum. The FTIR uses a Zinc Selenide Attenuated Total Reflectance (ATR) prism to collect the spectrum as described by Jemison et al. (6). The area under the peak between 1650 and 1820 wavenumbers (cm⁻¹) is defined as the carbonyl area.

**GPC**

GPC analyses are performed to determine how the molecular size distribution changes during the curing process. These are performed using a Waters 712 sample processor, a Waters 600E controller, and a Waters 410 Differential Refractometer (RI). The carrier solvent is helium-sparged HPLC grade THF at a flow rate of 1 mL/min. To efficiently separate the asphalt-rubber binders, three columns with pore sizes of 1000Å, 500Å, and 50Å are connected in series. The 1000Å and 500Å columns are 30.5 cm (1 foot) in length and are packed with ultrastyragel particles. The 50Å column is 61.0 cm (2 feet) in length and is packed with PLgel particles. The column temperature is controlled at 40 °C (104 °F). Samples are prepared by dissolving 0.20 to 0.25 grams, depending on rubber content, in 10 mL of THF and filtering through a PTFE syringe filter with a pore membrane size of 0.45 micron. Thus, sample preparation removes all rubber particles greater than 0.45 microns, since asphalt is soluble in THF and rubber is not.

**RESULTS**

Two separate studies were performed. In the first study, curing time and temperature were held constant and the rubber content and particle size were varied for four asphalts. In the second study, rubber content and particle size were held constant in three separate asphalts and the effect of curing time was varied.

**First Study: Curing Time and Temperature Held Constant**

SHRP ABM-1, SHRP ABL-2, Diamond Shamrock (DS) AC-5, and Made AC-5 were blended with Tire Gator -10 and -40 mesh particles at levels from 5 to 20% rubber. Curing time and temperature were held constant at 1 hour and 177 °C (350 °F), respectively.

**Low-Temperature Properties**

The four asphalts chosen represent a wide range of creep stiffness values. The BBR properties of all neat asphalts studied in this work are given in Table 1. SHRP ABM-1 has the worst low-temperature properties, failing to meet both low-temperature criterion at -15 °C (5 °F). The neat asphalt with the best low-temperature properties is the SHRP ABL-2, which easily exceeds the low-temperature specifications. The DS AC-5 asphalt also passes both criteria. The final asphalt used in this set of experiments is the Made AC-5. The Made AC-5 has BBR properties that are a vast improvement over the SHRP ABM-1 binder's BBR properties, but still does not have a passing creep stiffness value.

SHRP ABM-1 and Tire Gator -40 mesh rubber were blended at rubber contents of 5, 10, 15, and 18 percent by weight. The addition of rubber had positive effects on both the creep stiffness and the m-value of the binder. This is shown in Figure 1 for both the creep stiffness and the m-value. The creep stiffness decreased and the m-value increased as the rubber content increased. The best results were achieved with the highest rubber content, 18
percent, which had a creep stiffness of 214 MPa and an m-value of 0.29. The creep stiffness value of 214 MPa is a vast improvement over the tank asphalt value of 1018 MPa and is even lower than the specification creep stiffness value of 300 MPa. However, the m-value of 0.29, an improvement over the asphalt m-value of 0.24, is still below the low-temperature specification m-value of 0.300. SHRP ABM-1 blends showed the greatest improvement for any asphalt in the study, illustrating the potential of rubber to greatly enhance the low-temperature properties of neat asphalts.

The Made AC-5, a SHRP ABM-1 derivative, was combined with Tire Gator -10 mesh and Tire Gator -40 mesh rubber particles from 5 to 20 percent in 5 percent rubber increments. The addition of both rubber sizes had favorable effects on the BBR properties. This is shown in Figure 2 for both the creep stiffness and the m-value. For a rubber content of 15 percent, both asphalt-rubber binders exceeded the low-temperature stiffness requirements, with the Tire Gator -40 mesh binder having values of 144 MPa and 0.46, and the Tire Gator -10 mesh binder having values of 192 MPa and 0.39 for creep stiffness and m-value, respectively. The smaller granular size, -40 mesh, was better able to improve the low-temperature properties than the larger granular size, -10 mesh. The smaller rubber particles have more surface area per unit mass than the larger rubber particles. It is theorized that this allows the smaller rubber particles to be swelled more by the asphalt and thus to form more bonds with the asphalt during the curing process than are possible with comparable amounts of the larger rubber particles.

The DS AC-5, which passed both low-temperature specifications at -15 °C (5 °F), was blended with Tire Gator -10 mesh and Tire Gator -40 mesh rubber particles in rubber weight percentages of 5, 10, 15, and 20. Once again the addition of rubber improved both the creep stiffness and m-value relative to the base asphalt. The low-temperature values improved from a creep stiffness value of 180 MPa and an m-value of 0.34 for the neat asphalt beam, to 70 MPa and 0.39 for the 20 percent rubber content Tire Gator -10 mesh binder, and to 40 MPa and 0.43 for the 20 percent rubber content Tire Gator -40 mesh binder. Once again the smaller -40 mesh particles were better at influencing the properties than the larger -10 mesh particles.

The SHRP ABL-2 binder easily exceeded the low-temperature specifications for the creep stiffness properties. The SHRP ABL-2 was mixed with Tire Gator -10 mesh and Tire Gator -40 mesh rubber particles in rubber weight percentages of 5, 10, 15, and 18. The creep stiffness and m-value were so exceptional for the neat asphalt that the addition of rubber has only negligible effects on the low-temperature properties of the asphalt at -15 °C (5 °F). The creep stiffness value decreased from 58 MPa for the SHRP ABL-2 binder to 49 MPa for the 18 percent Tire Gator -10 mesh binder and decreased to 42 MPa for the 18 percent Tire Gator -40 mesh binder. The benefit of using the smaller particle size was once again illustrated.

The addition of rubber had only positive effects on the low-temperature rheological properties of the tested asphalts. The higher the rubber content, within the range studied, the greater the improvement in the low-temperature properties. In addition, the smaller rubber particles improved the low-temperature properties better than comparable amounts of larger rubber particles. Furthermore, the benefits obtained by adding rubber were the greatest for the neat asphalt with the worst low-temperature properties, SHRP ABM-1.
Intermediate-Temperature Properties

To evaluate the intermediate-temperature rheological properties, the dynamic shear rheometer is utilized. Measurements of complex viscosity, $\eta^*$, are made at multiple temperatures. From this it is possible to determine a binder's susceptibility to temperature. The data are plotted according to the Arrhenius model for viscosity temperature functionality. The Arrhenius model predicts that log complex viscosity is a function of reciprocal temperature. The slope of this line can be considered as an activation energy for the viscosity, or the temperature susceptibility.

An Arrhenius plot of SHRP ABM-1 and its asphalt-rubber blends of 10 and 18% rubber content of Tire Gator -10 and -40 mesh are shown in Figure 3. At the higher intermediate-temperatures, 90 °C (194 °F), 60 °C (140 °F), and 40 °C (104 °F), the addition of the rubber increased the complex viscosity. At the lower intermediate-temperatures, 25 °C (77 °F), 10 °C (50 °F), and 0 °C (32 °F), the addition of rubber had a negligible effect or decreased the complex viscosity. The binder viscosity at the higher intermediate-temperatures was dependent upon the percentage of rubber and increased with rubber content. The complex viscosity was also dependent upon the particle size, with the -10 mesh particles increasing the complex viscosity slightly more than the -40 mesh particles for a given rubber content. The intermediate-temperature susceptibilities of all the asphalts and their blends are given in Table 2. Figure 3 and Table 2 shows that the addition of rubber improved the temperature susceptibility of the SHRP ABM-1 asphalt. Furthermore, the temperature susceptibility is dependent upon the rubber content and improved with rubber content. However, the improvement in temperature susceptibility is independent of rubber particle size, with the temperature susceptibilities of the two different 18% blends being equal and the two different 10% blends also being equal.

Figure 4 shows the Arrhenius plot of SHRP ABL-2 and its asphalt-rubber blends of 10 and 18% of Tire Gator-10 and -40 mesh. Figure 4 and Table 2 once again show that the temperature susceptibility improved with rubber content and the improvement is independent of rubber particle size. Furthermore, the complex viscosity increased at the rutting temperatures, and the increase was once again dependent upon the rubber particle size, with -10 mesh particles being better at building viscosity than -40 mesh particles. Similar results were also obtained for the DS AC-5 and the Made AC-5, with the results shown in Table 2 for both, and Figure 5 for the Made AC-5.

The addition of rubber greatly enhanced the intermediate-temperature properties of the tested asphalt-rubber binders. The temperature susceptibilities improved and the complex viscosities at rutting temperatures increased with increasing rubber content. The intermediate-temperature properties of the tested asphalt-rubber binders were somewhat dependent upon the rubber particle size, with the temperature susceptibility being independent of the rubber particle size and the complex viscosity at the higher rutting temperatures being dependent upon the particle size. The dependence was that the larger -10 mesh particles increased the complex viscosity more than the smaller -40 mesh particles. For a given rubber content, particle size, and temperature of interest, the increase in the complex viscosity relative to the base asphalt was dependent upon the base asphalt.

High-Temperature Properties
The high-temperature (> 121 °C (250 °F)) results of SHRP ABM-1 and Made AC-5 and their asphalt-rubber blends of 10 and 18 or 20% rubber content of Tire Gator-10 and -40 mesh are shown in Figure 3 and 5, respectively. The addition of the rubber increased the high-temperature viscosity, $\eta$, of the binder, with the viscosity increasing with increasing rubber content, and this increase would complicate the compaction process. The increase in viscosity was dependent upon the rubber particle size, with the -40 mesh particles generally increasing the viscosity more than comparable amounts of -10 mesh particles. It is theorized that the increased surface area per volume or weight of the smaller -40 mesh particles enhances the ability of the particles to be swelled by and thus bond with the asphalt part of the binder and thus be better viscosity builders than the larger particles.

Second Study: Curing Time Varied
SHRP ABM-1, SHRP ABL-2, and the Fina AC-5 were cured with 10 percent Tire Gator -40 mesh rubber at 177 °C (350 °F) for up to 60 hours.

Low-Temperature Properties
Addition of rubber caused an improvement in the low-temperature properties of SHRP ABM-1, as discussed previously. Increased curing time caused further improvements at a steady rate. This is shown for the creep stiffness and the m-value in Figure 6. After 2 hours of curing time, the creep stiffness improved from 1018 MPa to 817 MPa and the m-value improved slightly from 0.24 to 0.25. After 8 hours of curing time, the creep stiffness decreased to 669 MPa and the m-value increased to 0.29. While these values do not meet the low-temperature specifications, they are a vast improvement over the neat asphalt values.

A Fina AC-5 having initial BBR properties of 126 MPa for creep stiffness and an m-value of 0.44, both passing the SHRP criteria at -15 °C (5 °F), was also studied. The low-temperature properties of the binder improved with the initial addition of rubber, but remained relatively constant during further curing. This is shown for the creep stiffness and the m-value in Figure 7. The initial measurements made after the addition of rubber and 3 hours of curing show that the creep stiffness improved to 98 MPa and show that the m-value remained relatively unchanged. Additional curing results in no further measurable changes in either the m-value or the creep stiffness. The final creep stiffness after 41 hours of curing is 95 MPa.

SHRP ABL-2 has excellent low-temperature properties with a creep stiffness value of 58 MP (Table 1). Addition of rubber to this asphalt produced similar results as the Fina AC-5, with the addition of rubber slightly improving the low-temperature properties and the length of curing time having no measurable effect on either the creep stiffness or m-value.

The curing time can be a very important variable for determining low-temperature binder properties. For a tested asphalt with poor low-temperature properties, the addition of rubber caused a large improvement in properties after one hour of curing. These low-temperature properties continued to improve with increasing curing time. For a tested asphalt with acceptable or excellent low-temperature properties, after the improvement from adding rubber and curing for one hour, the curing time had a negligible effect on creep stiffness.

Intermediate-Temperature Properties
Figure 8 shows the complex viscosities of the SHRP ABM-1 asphalt-rubber binder increasing with curing time for the temperatures of 40, 60, and 90 °C (104, 140, and 194 °F). Figure 8 also shows the complex viscosities at 0, 10, and 25 °C (32, 50, and 77 °F) remaining relatively constant with curing time. This combination of the complex viscosities increasing at the higher temperatures and the complex viscosities remaining relatively constant at the lower temperatures with curing time, represents an improvement in the temperature susceptibility of the binder with curing time, a smaller slope after 8 hours (Figure 8).

Figure 9 shows the complex viscosities of the Fina AC-5 asphalt-rubber binder increasing with curing time for all the intermediate-temperatures. At the higher temperature of 60 °C (140 °F), the complex viscosities of the neat asphalt, the 12-hour binder, and the 60-hour binder are 470, 1088, and 4769 dPa·s (poise), respectively. At the lower temperature of 0 °C (32 °F), the complex viscosities of the neat asphalt, the 12-hour binder, and the 60-hour binder are 3.840×10^7, 3.987×10^7, and 1.031×10^8 dPa·s (poise), respectively. The temperature susceptibility improved with the addition of rubber, but remained constant with curing time.

Evidently, the amount of curing time is very important for controlling intermediate-temperature properties. A tested binder's complex viscosity increased with curing time for the rutting temperatures of 40 and 60 °C (104 and 140 °F). The temperature susceptibility of a tested binder improved or remained constant with curing time. The intermediate-temperature performance of a binder only improved with curing time, with rutting temperature complex viscosities increasing and temperature susceptibilities decreasing or remaining constant.

**High-Temperature Properties**

Initially, the high-temperature viscosity of the binder increased with the addition of rubber. This increase in viscosity is associated with particles and the fact that the particles are swelled by the asphalt. However, the high-temperature viscosity of an asphalt-rubber blend decreased with curing time. This is shown in Figure 9 for a Fina AC-5 rubber blend. Although, the viscosity of the asphalt-rubber decreased, the viscosity never decreased enough to be equal to the viscosity of the base asphalt.

It is theorized that the decrease in viscosity is caused by the degradation of the rubber particles with curing. GPC data of the curing process is shown in Figure 10. The growth of the peak in the retention time region of 20 to 25 minutes represents the mass influx of rubber into the asphalt part of the binder with curing. The data represented in Figure 10 is smaller than 0.45 μm (0.45 micron), since each sample was prepared for GPC injection with a filter that has a pore membrane size of 0.45 μm (0.45 micron). With the majority of the initial Tire Gator -40 mesh rubber particles in the size range of 300 to 600 microns, the rubber had to degrade substantially to pass through the 0.45 micron filter. Apparently, the degradation of the rubber decreases the particle size and thus lessens the effect of the particle, causing the viscosity to decrease. The decrease in high-temperature viscosity is desirable because of the compaction problems associated with the viscoelastic asphalt-rubber binder.

**CONCLUSIONS**

The rheological properties of an asphalt-rubber binder can be controlled with the variables of rubber content, rubber particle size, asphalt base, and curing time. The proper combination of these variables can produce an asphalt-rubber binder that is easily compacted at high
compaction temperatures, is not susceptible to temperature changes at roadway temperatures, and is not brittle at low-temperatures.

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DISCLAIMER
The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The Contents do not necessarily reflect the official views or policies of the FHWA. This report does not constitute a standard, specification, or regulation.
REFERENCES


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**TABLE 1** Low-Temperature Data of Neat Asphalts at -15 °C (5 °F)

<table>
<thead>
<tr>
<th>ASPHALT NAME</th>
<th>CREEP STIFFNESS at 60s (MPa)</th>
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<tr>
<td>SHRP ABM-1</td>
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<tr>
<td>SHRP ABL-2</td>
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<td>Diamond Shamrock AC-5</td>
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**TABLE 2** Temperature Susceptibilities (TS) of Neat Asphalts and Blends

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<th>ASPHALT NAME</th>
<th>ASPHALT TS</th>
<th>10% TG-10 TS</th>
<th>10% TG-40 TS</th>
<th>18 or 20% TG-10 TS</th>
<th>18 or 20% TG-40 TS</th>
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<td>AC-5</td>
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<tr>
<td>7</td>
<td>Low-Temperature Data of Curing Study Involving Fina AC-5 and Tire Gator -40 Mesh Blend</td>
</tr>
<tr>
<td>8</td>
<td>Intermediate-Temperature Data of Curing Study Involving SHRP ABM-1 and Tire Gator -40 Mesh Blend</td>
</tr>
<tr>
<td>9</td>
<td>Intermediate- and High-Temperature Data of Curing Study Involving Fina AC-5 and Tire Gator -40 Mesh Blend</td>
</tr>
<tr>
<td>10</td>
<td>GPC Data of Curing Study Involving Fina AC-5 and Tire Gator -40 Mesh Blend</td>
</tr>
</tbody>
</table>
Figure 1. Low-Temperature Data of SHRP ABM-1 and Blends

Figure 2. Low-Temperature Data of Made AC-5 and Blends
Figure 3. Intermediate- and High-Temperature Data of SHRP ABM-1 and Blends

Figure 4. Intermediate-Temperature Data of SHRP ABL-2 and Blends
MADE AC-5 AND BLENDS

\[ \eta^* \text{ at 1.0 rad/sec} \]

Figure 5. Intermediate- and High-Temperature Data of Made AC-5 and Blends

10% TIRE GATOR -40 MESH and 90% SHR P ABM-1

Figure 6. Low-Temperature Data of Curing Study Involving SHR P ABM-1 and Tire Gator -40 Mesh Blends
Figure 7. Low-Temperature Data of Curing Study Involving Fina AC-5 and Tire Gator -40 Mesh Blend

Figure 8. Intermediate-Temperature Data of Curing Study Involving SHRP ABM-1 and Tire Gator -40 Mesh Blend
Figure 9. Intermediate- and High-Temperature Data of Curing Study Involving Fina AC-5 and Tire Gator -40 Mesh Blend

Figure 10. GPC Data of Curing Study Involving Fina AC-5 and Tire Gator -40 Mesh Blend