Material Characteristics of Asphalt Rubber Mixtures

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ABSTRACT

This study focused on conducting experimental program on several Asphalt Rubber (AR) mixtures to obtain their typical engineering properties and understand their field performance. Most of the laboratory program was based on tests recommended by the National Cooperative Highway Research Program, NCHRP 9-19 Project, which dealt with recommending Simple Performance Tests (SPT) for the evaluation of asphalt mixes. The laboratory tests included: consistency binder tests, triaxial shear strength, repeated load permanent deformation, dynamic modulus, flexural beam fatigue, and indirect tensile tests. The results obtained for the AR mixtures were also compared, when possible, with results obtained for conventional mixtures.

The AR mixes were those typically used in Arizona, along with an experimental mixture that was constructed by Alberta Transportation, in Canada. All laboratory test specimens were prepared using mixes that were collected during construction. The tests also included sensitivity studies of the mixtures to air voids, temperatures, and influence of confinement level.

It was concluded that many parameters obtained from the above tests were successful in describing the observed good field performance of AR mixes.
INTRODUCTION

In the last few years, the Department of Civil and Environmental Engineering at Arizona State University (ASU) has been involved with several asphalt rubber mixtures characterization studies. These studies incorporated laboratory tests from the National Cooperative Highway Research Program (NCHRP) 9-19 project, which deals with the development of Simple Performance Tests (SPT) for permanent deformation and cracking evaluation of asphalt mixtures. The studies are being conducted in cooperation with the Arizona Department of Transportation (ADOT). The research program has the ultimate goal in implementing a methodology for performance related specifications for asphalt rubber pavements, and developing typical design input parameters for local conditions.

Since construction, several projects and test sections have been monitored for rutting and cracking performance by ADOT. Projects are all located on divided highways. Both rehabilitation and new construction projects are represented. Traffic loads vary from 250,000 to 3,000,000 equivalent single axle loads (ESAL’s) per year. After many years of service (at least ten), the rut depth is no more than 5 mm and the percent cracking is no greater than 4%.

Two projects from Arizona are included in this paper: Arizona I-17 Project; and the Arizona I-40 Project. A recent AR study was also completed by ASU for Alberta Transportation, Canada. Typical laboratory test results from these studies are compared and discussed.

SCOPE OF THE WORK

Hot AR mixes were obtained from the field during construction. The mixes were reheated and compacted at the air voids level specified for each of the projects. Five AR mixtures were available for testing and they are described as follows:

Arizona I-40 Asphalt Rubber Asphalt Concrete (ARAC) Gap Graded Mixture, which is referred to as the Arizona ARAC. This mix had an in-situ air voids level of 11% and an asphalt content (AC%) of 6.8%. The stock binder used for this mix was a PG 58-22.

Arizona I-40 Asphalt Rubber Asphalt Concrete Friction Course (AR-ACFC) Open Graded Mixture, which is referred to as the Arizona AR-ACFC. This mix was placed on top of the Arizona ARAC and had an in-situ air voids content of 18% and AC% of 8.8%. Similar to the Arizona ARAC, the stock binder was a PG 58-22.

Arizona I-17 ARAC PG 58-22 Gap Graded Mix, which is referred to as the Arizona PG 58-22. This mix had an in-situ air voids of 8% and AC content of 7.5%.

Arizona I-17 ARAC PG 64-16 Gap Graded Mix, which is referred to as the Arizona PG 64-16. This mix had in-situ air voids of 5.5% and AC content of 8.0%.

Alberta ARAC Pen 150-200, which had an in-situ air voids of 9.7% and AC content of 8%. The stock binder was a Pen 150-200. A control virgin dense graded Pen 150-200 mixture was also included within the testing program. This mix had in-situ air voids of 5.4% and AC content of 5.4%.

The MnRoad test site 18 Dense Graded Mix, which is referred to as the MnRoad_18 PG64-22. This mix had in-situ air voids of 5.6% and AC content of 5.83%. The stock binder used for this mix was an AC-20.
Gyratory plugs and beams were compacted to these air void values as close as practical. Data obtained from tests of these mixtures were summarized in spreadsheets, which are reported in several publication by the Transportation / Materials Group at ASU (1, 2, 3, 4). The specific tests used for this study are the following:

1. Consistency binder tests for completeness of the material characterization
2. Triaxial shear strength of the mixtures.
3. Repeated load for permanent deformation evaluation.
4. Dynamic (complex) modulus for stiffness evaluation.
5. Flexural beam test for fatigue cracking evaluation.
6. Indirect tensile tests for thermal cracking evaluation.

The test results were used, when possible, to establish a relative ranking of the mixtures, among others being tested at ASU, according to their expected rutting or cracking potential.

At the time of finalizing this paper, not all the tests and analysis were completed. For some tests, results from three AR mixes were available; whereas for other tests, five mixes were completely evaluated. This is described when every test is discussed.

**ASPHALT RUBBER BINDER CHARACTERIZATION**

**Binder Characterization Theoretical Background**

The characterization of the crumb rubber modified (CRM) binders was performed using conventional binder consistency tests (penetration, softening point, and viscosity). The intent of these tests was for descriptive comparative purposes only, and not for specification control. Other modified binder studies showed that conventional binder consistency tests yield rational results and can be used as a general guide (5).

Most refined asphalt cements exhibit a linear relationship when plotted on a log-log viscosity (centipoise) versus log temperature (in degree Rankine: \( R = F + 459.7 \) F) scale (6). The approach uses only viscosity units (centipoise) to define the viscosity-temperature relationship. In addition, an approach to convert all penetration (pen) and softening point measurements into viscosity units is described in references (1, 5). This approach was used in the analysis of tests results conducted on CRM binders.

**Test Results and Analysis for the CRM Binder Characterization**

Four different CRM binders were available for this study with their corresponding conventional binders. Consistency tests presented above where performed at original binder, and two aged conditions. For brevity, only the original test conditions are discussed in this section. Graphical plots were generated to evaluate and compare the viscosity-temperature relationship for all binders. A comparison of the plots with the virgin stock binder showed that all AR binders had improved viscosity-temperature susceptibility than their corresponding virgin stock binders. Figure 1 shows the viscosity-temperature relationships of all the AR binders and a conventional ADOT PG 76-16 binder. As it can be observed, the viscosity-temperature susceptibility of the
rubber modified binder are better than the stiff conventional binder, both at high and low temperature conditions. An extrapolation of the predicted line suggests that at cold temperature conditions, the AR binders are softer than the virgin binder. These characteristics agree with observed field performance, where AR mixes are known to have better response against permanent deformation, and low-temperature cracking.

TRIAXIAL SHEAR STRENGTH TESTS

Test Conditions

Triaxial strength tests, unconfined and confined were conducted using two replicates for all mixtures. These tests provided the standard cohesion “c” and the angle of internal friction “$\phi$” parameters for each tested mixture. The test was carried out on cylindrical specimens, 100 mm (4 inches) in diameter and 150 mm (6 inches) in height, prepared as described in references (1, 2). The tests were conducted at 37.8°C (100°F). In addition to the unconfined test, two additional confining pressures were used: 138, and 276 kPa (20 and 40 psi). The specimens were loaded axially to failure, at the selected constant confining pressure, and at a strain rate of 1.27/mm/mm/min (0.05 in/in/min).

Test Results

Figure 2 shows plots of the Mohr-Coulomb failure envelope represented by the cohesion “c” and angle of internal friction “$\phi$” for the four compared mixtures.

The plots show that the Arizona conventional dense-graded mixture SRB PG64-22 has 133% higher cohesion than the Arizona AR-ACFC, and 35% higher cohesion than the Arizona ARAC and Alberta AR mixes. At the same time, both of the Arizona asphalt rubber mixes have higher angle of internal friction compared to the standard ADOT mixture. Higher cohesion and angle of internal friction indicate higher resistance to shearing stresses and smaller potential for permanent deformation of the mixture. The asphalt rubber open graded mix (Arizona AR-ACFC) has much lower resistance to shearing stresses than the other tested mixes. In addition to the expected behavior of an open graded mix under unconfined test condition, this observation is also supported by the fact that the AR-ACFC mix is utilized as a non-structural layer.

PERMANENT DEFORMATION TESTS

Repeated Load/ Flow Number Test

One approach to determine the permanent deformation characteristics of paving materials is to employ a repeated dynamic load test for several thousand repetitions and record the cumulative permanent deformation over the test period (7). The cumulative permanent strain curve is defined by three zones: primary, secondary, and tertiary. In the primary zone, permanent deformations accumulate rapidly. The incremental permanent deformations decrease reaching a constant value in the secondary zone. Finally, the incremental permanent deformations again
increase and permanent deformations accumulate rapidly in the tertiary zone. The starting point, or cycle number, at which tertiary flow occurs, is referred to as the “Flow Number” (8). Typical permanent deformation parameters, which are obtained and analyzed include the cumulative permanent strain, slope of the linear (secondary) portion of the cumulative plastic strain – repetitions curve, strain at failure (tertiary flow) and the flow number.

Test Conditions

Repeated load tests were conducted using cylindrical specimens, 100 mm (4 in) in diameter and 150 mm (6 in) in height. All specimens were tested in unconfined conditions at temperature of 37.8°C (100°F), in accordance to NCHRP Report 465 test protocols (8). Three replicates were used for all mixtures. A haversine pulse load of 0.1 sec and 0.9 sec dwell (rest time) was applied for target of 180,000 cycles. This number was less if the test specimen failed under tertiary flow before reaching this target level.

Tests Results

Comparisons of the test results of the tested mixes are shown in Figures 3 and 4. The results of the flow number at 37.8°C (100°F) and stress level of 210 kPa (30 psi) (Figure 3a) showed 2.5 times higher flow number for the Alberta AR mixture compared to the Conventional mix, and 13 times higher flow number compared to a selected MnRoad_18 mixture which had good field performance (8). The Alberta Conventional mix had 5 times higher flow number than the MnRoad_18 mix.

For tests conducted at 54.4°C (130°F) and stress level of 69 kPa (10 psi) (Figure 3b), the Arizona ARAC 11%AV mix showed over 16 times higher flow number than the Conventional SRB PG64-22 mix. The difference between the AR-ACFC and SRB PG64-22 mixtures was relatively small (about 22%).

The results of axial strain at failure for the tests conducted (Figure 4) showed that the AR mixtures have 3 to 4 times higher strain at failure than the Conventional mixes. Higher strain at failure is an indicator of good mixture stability to the applied loads.

THE DYNAMIC (COMPLEX) MODULUS E* TEST

Background

For linear viscoelastic materials such as asphalt mixes, the stress-strain relationship under a continuous sinusoidal loading is defined by a complex number called the complex modulus $E^*$ (9), which has a real and imaginary part that defines the elastic and viscous behavior of the linear viscoelastic material. The absolute value of the complex modulus $|E^*|$, is defined as the dynamic modulus. Mathematically, the dynamic modulus is defined as the maximum (peak) dynamic stress ($\sigma_o$) divided by the recoverable axial strain ($\varepsilon_o$): $|E^*| = \sigma_o / \varepsilon_o$. 


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By current practice, dynamic modulus testing of asphalt materials is conducted on unconfined cylindrical specimens having a height to diameter ratio equal to 1.5 and uses a uniaxially applied sinusoidal (haversine) stress pattern (8).

The dynamic modulus (stiffness) response of an asphalt mixture is known to be dependent on temperature, rate of loading, aging level, confinement level and mixture characteristics; such as binder stiffness, aggregate gradation, binder content, and air voids. To account for the effect of temperature and rate of loading, a master curve is constructed which is built using as a reference any arbitrary temperature value (8). Using this dynamic modulus master curve, analysis and comparisons between several mixtures and conditions can be made.

**Test Conditions**

E* tests were performed either unconfined or with varying confinement levels. A servo hydraulic testing machine was used to load the specimens. The load was varied with temperature to keep the specimen response within the Linear Viscoelastic region, LVE (initial strains about 20-25 micro-strains). A dynamic sinusoidal stress (continuous wave) was applied and measured through the machine load cell, whereas, the deformations were measured using spring-loaded LVDT’s (Linear Variable Differential Transducers). The specimen instrumentation method used was the one developed by the ASU Research Team (8, 10).

The test specimens used were cored from laboratory compacted Gyratory plugs approximately 100 mm (4 in) in diameter and 150 mm (6 in) high. For each specimen, a full factorial of test frequencies (0.1, 0.5, 1, 5, 10, and 25 Hz) and approximate temperatures of -10, 4.4, 21.1, 37.8, and 54.4 °C (14, 40, 70, 100, and 130°F) were used. Each specimen was tested in an increasing order of temperature, and for each temperature level, specimens were tested in a decreasing order of frequency. This temperature-frequency sequence was carried out to cause the minimum damage to the specimen before the next test.

Three replicates for each test condition were used, and a minimum of two replicates was used when material availability was an issue. Factors like air voids, binder type, and confinement level variations were evaluated. In addition, the AR E* responses were compared with E* values from other mixtures tested at ASU. These comparisons were made using the constructed master curves and the Modular Ratio Concept (11).

**Test Results**

A comprehensive documentation of the test results on the various asphalt rubber mixtures tested can be found in several publications by the authors (1, 2, 3, 4).

The Asphalt Rubber E* responses followed a logical trend when air voids variation were compared. That is, a mix with 5% air voids content had a stiffer behavior than a mixture with 8% air voids. Similarly, AR mix with a PG 58-22 stock binder had a softer behavior than an AR mix using a PG 64-16 stock binder.

A great difference in E* response was found when specimens were tested at unconfined conditions and confined conditions, especially when the unconfined response was low (soft). Increments in E* values up to 400% were found at high temperature conditions and low frequency values. This is shown in Figure 5, where typical master curves for a Gap Graded
mixture tested unconfined and at three levels of confinement: 69, 138, and 207 kPa (10, 20, and 30 psi) are shown.

An interesting observation was that for several of the replicates, the AR mixes showed similar response at high temperature conditions. That is, the \( E^* \) values at 70, 100, and 130°F were quite similar. It was surmised that the insignificant changes in the AR \( E^* \) values were due to the dominating effect of the crumb rubber at these higher temperatures in comparison to the role of the binder in the mix.

**Comparison with Conventional Mixtures**

When compared to conventional mixtures, the Asphalt Rubber mixes were generally softer at unconfined conditions. However, when confined \( E^* \) tests results were compared, it was found that the AR mixes had better response. Tables 1a and 1b rank various mixtures tested under similar conditions using the Modular Ratio concept (11). In these tables, mixes from NCHRP 9-19 test sections are also included (MnRoad, ALF, and WesTrack) (8).

Table 1a shows that the unconfined \( E^* \) test, at high temperature conditions, is not ranking the mixtures rationally according to their observed field performance. In the field, the Arizona AR mixes have shown strong resistance against rutting (permanent deformation). The unconfined tests are yielding, in general, lower \( E^* \) responses when compared with conventional mixtures. When confined tests were used for the comparison (Table 1b), the AR mixes showed stiffer behavior than any other mix, and ranked higher than the stiffest conventional mixes.

The confined Dynamic Modulus \( E^* \) test is therefore a better field performance indicator than the unconfined test. Furthermore, when a wider range of dense graded, gap and open graded mixes, are included in the comparison, confined dynamic modulus \( E^* \) tests should be performed to appropriately rank the mixes. (3, 4).

**FLEXURAL BEAM FATIGUE TESTS**

For fatigue characterization, constant strain tests were conducted at 6 levels in the range 300 to 1950 \( \mu \) strain; at load frequency of 10 Hz, and at test temperature of 21.1°C (70°F). The tests were performed according to the AASHTO TP8, and SHRP M-009 procedures. Initial flexural stiffness was measured at the 50\(^{th}\) load cycle. Fatigue life or failure under control strain was defined as the number of cycles corresponding to a 50% reduction in the initial stiffness. The loading on most specimens was extended to reach a final stiffness of 30% of the initial stiffness instead of the 50% required by AASHTO TP8 and SHRP M-009. The control and acquisition software load and deformation data were reported at predefined cycles spaced at logarithmic intervals.

**Tests Results**

Figure 6 shows a comparison of the different AR and Conventional mixtures. The fatigue models developed for the mixtures have good to excellent measures of accuracy. The comparison in Figure 6 is made at 50% reduction of initial stiffness for each mix. The relationships are rational
in that higher binder content mixes yielded higher fatigue life despite the air void content variations between the mixtures. Comparing fatigue curves for different mixes is not straightforward because of the different mixes moduli. A look at fatigue models coefficients may provide some guidance. It is noted that the asphalt rubber mixture would result in higher fatigue life than the conventional mix. The Arizona AR-ACFC and the Alberta AR mix have similar relationship and they would result in approximately 30 times longer fatigue life compared to the SRB PG76-16 mixture. The Arizona ARAC mix has lower performance than the other two AR mixtures, but still would result in approximately 10 times longer fatigue life than the Arizona conventional mix.

INDIRECT TENSILE CREEP AND STRENGTH TESTS

The Indirect Tensile Strength Test

The indirect tensile strength was measured by applying load at a constant rate of deformation of 12.5 mm/min (0.5 in/min). The strength test was stopped when the applied load went to zero (i.e., total failure of the specimen occurred). The horizontal tensile stress at the center of the test specimen was calculated. The indirect tensile strength is the maximum stress developed at the center of the specimen in the radial direction during loading for a fixed geometry. The fracture energy or energy until failure were calculated as the area under the load-vertical deformation curve.

The Indirect Tensile Creep Test

The static creep test in the indirect tensile mode uses a single load-unload cycle. A constant static load was applied to the specimen for a time of 1,000 seconds and horizontal deformations were recorded during the loading time. The applied load was a percentage of the horizontal tensile strength of the material. The horizontal deformations were recorded for another 1,000 seconds after the load is removed to measure the recovery of the specimen.

Test Conditions

Both indirect tensile cracking tests were carried out according to the procedure described in the draft indirect tensile tests protocol for the AASHTO 2002 Design Guide level 1 and level 2 (8). Three replicates were used for all mixtures. All test specimens were sawed from gyratory fabricated specimens. The test specimen was approximately 38 mm (1.5 in) in thickness and 150 mm (6 in) in diameter. Vertical or horizontal LVDT’s were used on the specimen for measuring the horizontal and vertical deformation using a gage length of 76.2 mm (3 in) for both. The tests were carried out at three temperatures: 0°C (32°F), -10°C (14°F) and -15°C (5°F).

Test Results - Indirect Tensile Strength Test

Figure 7 presents a summary of the test results for the AR and Conventional mixtures. In Figure 7 (a), the highest strength is observed for the Arizona conventional mix at all three test
temperatures; whereas lower strength values and little difference are observed for the AR mixes. Figure 7 (b) on the other hand shows that higher tensile strains are obtained for the AR mixtures at the three test temperatures. The difference between the AR mixtures and the Arizona conventional mix is lower at -10°C (14°F), but it is distinct at the other two temperatures. Higher energy until failure (Figure 7 (c)) was not observed as an advantage for the AR mixes over the conventional mix at 0°C (32°F). The difference among the mixes was less at the lower two temperatures with a slight advantage for the AR mixes. Due to the different air void contents of these mixes, further analysis and testing may need to be investigated in this area.

Test Results - Indirect Tensile Creep Test

The results of tensile strain (Figure 8a) show that at temperature 32°F (0°C) the Alberta AR mix has approximately 3 times higher strain than the Arizona ARAC and AR-ACFC mixtures. At temperatures -10 and -15°C (14 and 5°F) the difference between the three AR mixtures is insignificant. An interesting observation is that the all three asphalt rubber mixtures have the lowest tensile strain at temperature -10°C (14°F).

Considering the creep compliance parameter (Figure 8b), it can be observed that the Alberta AR mix has the highest values for all three temperatures. The biggest differences among the mixes can be observed for the higher temperature. At 0°C (32°F) the Alberta AR has over two times higher value compared to the Arizona ARAC and AR-ACFC mixtures. At lower temperatures, the difference between the mixtures is insignificant.

An interesting trend can be noticed observing the slope of the compliance curve (Figure 8c). At temperature 0°C (32°F) the Arizona AR-ACFC mix has the highest slope, 60% higher than the Alberta AR and 100% higher than the Arizona ARAC mixture. At temperature -15°C (5°F) a difference between the mixtures does not exceed 5%.

A general observation for all the results is that the values of the parameters as well as differences between mixtures decreased with decreasing temperature. Theoretically, there is a temperature (low temperature) at which different mixtures have the same parameters / response irrespective of the type of asphalt. This is rational considering that at very low temperatures, the asphalt looses its viscoelastic properties and behaves like a solid. The mixture response may depend on the aggregate and possibly on the crumb rubber if it is present in the mix. Beyond this point, the differences between conventional and asphalt rubber mixtures may become more distinct. It is possible that at low temperatures, the crumb rubber takes over the asphalt role and is decreasing the stiffness of the mixture. This results in higher resistance for low-temperature cracking compared to conventional mixtures.

Another observation is that, for the conventional mixture, the relationship between the parameters and temperature is almost linear. The asphalt rubber mixtures indicate rapid decrease of the values of parameters between 0 and -10°C (32 and 14°F), and after that, between -10 and -15°C (14 and 5°F), the differences are not so significant. The asphalt rubber mixtures become less sensitive to temperature change below -10°C (14°F).
SUMMARY

This study focused on conducting a laboratory experimental program on several Asphalt Rubber (AR) mixtures and binders to obtain their typical engineering properties. The tests included: consistency binder tests, triaxial shear strength, repeated load permanent deformation, dynamic modulus, flexural beam fatigue, and indirect tensile tests. The results obtained for the AR mixtures were also compared, when possible, with results obtained for conventional mixtures. All laboratory test specimens were prepared using mixes that were collected during construction.

A comparison of the CRM binders with the virgin stock binder showed that all AR binders had improved viscosity-temperature susceptibility than their corresponding virgin stock binders, both at high and low temperature conditions.

The results of the Triaxial Shear Strength Test show that the conventional dense-graded mixture had much higher cohesion than the AR open-graded mix, and a little higher cohesion than the AR gap-graded mixes. At the same time, both the Arizona AR mixes had higher angle of internal friction compared to the conventional dense-graded ADOT mixture.

The results of the Flow Number Test at 37.8°C (100°F) showed 2.5 to 13 times higher flow number for the AR mixture compared to the conventional mixes. For tests conducted at 54.4°C (130°F) the AR mix showed over 16 times higher flow number than the conventional mix. The results of Axial Strain at failure showed that the AR mixtures have 3 to 4 times higher strain at failure compared to the conventional mixes. Higher strain at failure is an indicator of good mixture stability to the applied loads.

The Asphalt Rubber E* responses followed a logical trend when air voids and confinement level variation were compared. In addition, it was found that for a better comparison with conventional mixtures, confined E* tests should be used rather than unconfined E* tests.

For the Flexural Beam Fatigue Tests the relationships are rational in that higher binder content mixes yielded higher fatigue life despite the air void content variations between the mixtures. It was generally observed that the AR mixture resulted in higher fatigue life than the conventional mix.

The results from the Indirect Tensile Strength Test showed that higher strength values for the conventional mix when compared to the AR mixes, at all three test temperatures. On the other hand higher tensile strains were obtained for the AR mixes. Higher energy until failure was also observed at lower temperatures, and may be indicative of an advantage for the AR mixes compared to the conventional mixes.

For the Indirect Tensile Creep Test there was a general observation that the values of the parameters as well as differences between mixtures decreased with decreasing temperature. Theoretically, there was a temperature (low temperature) at which different mixtures had the same parameters / response irrespective of the type of asphalt. Another observation was that, for the conventional mixture, the relationship between the parameters and temperature was almost linear. The asphalt rubber mixtures indicated rapid decrease of the values of parameters between 0 and –10°C (32 and 14°F).

Based on the test results obtained in this study, it was concluded that many parameters obtained from the above tests were successful in describing the observed field performance of AR mixes.
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TABLE 1  Summary of the Modular Ratio @ 100°F / 10 Hz for AR and Control Mixes

(a) Unconfined Condition

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Binder Type</th>
<th>AC %</th>
<th>Va %</th>
<th>Nom. Aggreg.</th>
<th>E*</th>
<th>R</th>
<th>Rank</th>
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(b) Confined Condition

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<th>Va %</th>
<th>Nom. Aggreg.</th>
<th>E*</th>
<th>R</th>
<th>Rank</th>
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† Reference Mix

Where: OG = Open Graded Mixture
       GG = Gap Graded Mixture
       DGM = Dense Graded Mixture
       CGDM = Coarse DGM
       FDGM = Fine DGM
Figure 1  Comparison of the Viscosity – Temperature Relationships.
Figure 2  Comparison of Triaxial Shear Strength Test Results.
Figure 3  Repeated Load Unconfined Test – Flow Number Results.
Figure 4  Repeated Load Unconfined Test – Axial Strain Results.
Figure 5  Comparison of E* Master Curves for the ARAC Gap Graded Mixture
Figure 6  Controlled Strain Fatigue Relationships
Figure 7  Indirect Tensile Strength Test – Summarized Results
Figure 8  Indirect Tensile Creep Test – Summary of the Results