Center for Infrastructure Engineering Studies

Acquisition of a High-Quality Temperature Chamber

by

David N. Richardson

A University Transportation Center Program
at Missouri University of Science & Technology

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16. Abstract

With the Missouri Department of Transportation (MoDOT) beginning to implement the new Mechanistic-Empirical (M-E) Design Guide for New and Rehabilitated Pavements, the need exists for various types of testing of hot-mix asphalt (HMA) mixes used by MoDOT in its flexible pavements. In particular, the American Association of State Highway and Transportation Officials (AASHTO) test protocol T 322 is utilized to determine HMA properties needed as inputs to pavement distress prediction models within the M-E Pavement Design Guide (MEPDG) Software. The primary properties derived from T 322 are creep compliance and tensile strength. These properties are determined using indirect tension methods and are temperature dependent. Creep compliance is a parameter used in the thermal cracking distress model within the MEPDG Software and is determined at 0, -10, and -20°C while tensile strength is an input to the fatigue cracking distress model and is determined at temperatures ranging from -20 to +20°C.

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ACQUISITION OF A HIGH-QUALITY TEMPERATURE CHAMBER

FINAL REPORT

David N. Richardson, Associate Professor
Missouri University of Science and Technology
126 Butler-Carlton Hall
Rolla, MO 65409
Telephone: 573-341-4487
dnr@mst.edu

A temperature chamber with a range of -30°C to 100°C that can be integrated with various dynamic and static loading units has been purchased for construction material research. The equipment will be useful to evaluate the temperature-dependent performance of pavement materials such as asphaltic cement concrete (ACC), portland cement concrete (PCC), unbound granular base aggregates, and roadbed soils. However, specimens of metal, composites, and wood could also be evaluated across a significant range of temperatures.

The chamber was recently used for a Missouri Department of Transportation (MoDOT) project in which various hot-mix asphalt (HMA) mixes were tested to evaluate their low-temperature or thermal cracking properties. In particular, the AASHTO T 322 test protocol was utilized to determine HMA properties needed as inputs to pavement distress prediction models within the new M-E Pavement Design software. The properties derived from T 322 are creep compliance, tensile strength, and Poisson's ratio, all of which are temperature dependent. Creep compliance and tensile strength are parameters used in the thermal cracking distress model within the M-E Pavement Design software and is typically determined at 0, -10, and -20°C while tensile strength is determined at temperatures ranging from -20 to +20°C.

The temperature chamber will be used for materials research by faculty and students at the Missouri University of Science and Technology.



APPENDIX A

DETERMINATION OF CREEP COMPLIANCE AND TENSILE STRENGTH OF HOT-MIX ASPHALT FOR WEARING COURSES IN MISSOURI

MoDOT expressed the desire to have MST perform the T 322 testing on several HMA mixes used in wearing (surface) courses throughout the state. MoDOT needs the T 322 results to calibrate default distress models currently employed in the MEPDG Software. The following appendix is the report submitted to the MoDOT after the T 322 testing was completed with the acquired high-quality temperature chamber sponsored by the University Transportation Center at Missouri University of Science & Technology.

Organizational Results Research Report

April 2008
OR08.018

Determination of Creep Compliance and Tensile Strength of Hot-Mix Asphalt for Wearing Courses in Missouri

Prepared by Missouri University of Science and Technology and Missouri Department of Transportation

FINAL REPORT
RI05-052

Determination of Creep Compliance and Tensile Strength of Hot-Mix Asphalt for Wearing Courses in Missouri

Prepared for the

Missouri Department of Transportation
Organizational Results

By

David N. Richardson, P.E.
Steven M. Lusher, E.I.T.
Missouri University of Science and Technology
(Formerly University of Missouri-Rolla)

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Creep compliance and indirect tensile (IDT) strength of hot-mix asphalt (HMA) are the two primary inputs to the low-temperature or thermal cracking module in the new Mechanistic-Empirical Pavement Design Guide (M-E PDG) software. Creep compliance is defined as time-dependent strain per unit stress, while IDT strength is best defined as HMA strength when subjected to tension. AASHTO T 322 test protocol was used as reference for this work. However in preparation for the laboratory work performed at the Missouri University of Science and Technology many experts were consulted as to how IDT creep/strength testing and calculations are actually being performed. Using MoDOT supplied test specimens, six different plant-produced wearing (surface) course mixes were tested. Four mixes were tested at three levels of percent air voids: 4, 6.5, and 9% and two mixes were tested only at 6.5% air voids. Per requirements of the M-E PDG, creep testing was performed at 0, -10, and -20 degrees Centigrade (°C) and IDT strength testing was performed at -10°C. Additional IDT strength testing was performed at 4.4 and 21°C (40 and 70 °F) per MoDOT's requirements. Poisson's ratio was determined from the creep testing while tensile failure strain was determined from the IDT strength testing. Trends such as increasing creep compliance and decreasing tensile strength with increasing % air voids and/or temperature were confirmed. The presence of recycled asphalt pavement (RAP) in a mix tended to decrease the creep compliance (increase the stiffness) and increase the tensile strength compared to similar mixes without RAP.</td></tr>
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EXECUTIVE SUMMARY

Creep compliance and indirect tensile (IDT) strength of hot-mix asphalt (HMA) are the two primary inputs to the low-temperature or thermal cracking module in the new Mechanistic-Empirical Pavement Design Guide (M-E PDG) software. Creep compliance is defined as time-dependent strain per unit stress, while IDT strength is best defined by what its name implies: HMA strength when subjected to tension.

The test protocol used as the reference for this work is American Association of State Highway and Transportation Officials (AASHTO) test method T 322. However in preparation for the laboratory work that was performed at the Missouri University of Science and Technology (Missouri S&T), many experts (see Acknowledgements) were consulted as to how IDT creep/strength testing and calculations are actually being performed.

MoDOT supplied the test specimens. Six different plant-produced wearing (surface) course mixes were tested. Four of the mixes were tested at three levels of percent air voids: 4, 6.5, and 9%. The remaining two mixes were tested only at 6.5% air voids. Per requirements of the M-E PDG, creep testing was performed at 0, -10, and -20 degrees Centigrade (°C) (32, 14, and -4 degrees Fahrenheit (°F), respectively) and IDT strength testing was performed at -10°C. Additional IDT strength testing was performed at 4.4 and 21°C (40 and 70 °F, respectively) per MoDOT's requirements. Poisson's ratio was determined from the creep testing while tensile failure strain was determined from the IDT strength testing.

All required results were obtained. Trends such as increasing creep compliance and decreasing tensile strength with increasing % air voids and/or temperature were confirmed. The presence of recycled asphalt pavement (RAP) in a mix tended to decrease the creep compliance (increase the stiffness) and increase the tensile strength compared to similar mixes without RAP.

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INTRODUCTION

With the Missouri Department of Transportation (MoDOT) beginning to fully implement the new Guide for Mechanistic-Empirical (M-E) Design of New and Rehabilitated Pavement Structures (*1*), the need existed for various types of testing of hot-mix asphalt (HMA) used by MoDOT in its flexible pavements. The American Association of Highway and Transportation Officials (AASHTO) test method T 322-07 (*2*) is utilized to determine HMA properties that are needed as inputs to the M-E Pavement Design Guide (M-E PDG) software.

Two HMA properties derived from AASHTO T 322-07 are creep compliance and tensile strength. Creep compliance is defined as time-dependent strain per unit stress while indirect tensile (IDT) strength is best defined by what its name implies; HMA strength when subjected to tension. Both properties are determined using the IDT method; i.e. a cylindrically shaped specimen is loaded in compression across its diameter thus indirectly causing tension in opposite directions perpendicular to and beginning at the line of loading. As HMA is considered a visco-elastic material, creep compliance and tensile strength are not only dependent on the HMA mix constituent properties, constituent proportions, and compacted mix properties (e.g. % air voids), both are also temperature dependent. Additionally, creep compliance is dependent on the load/unload duration and tensile strength is dependent on load rate.

The contract was started when T 322-03 (*3*) was the current version for determining creep compliance and tensile strength using IDT methods. T 322-07 was published in the summer of 2007. Some changes to T 322-03 were in response to results published in the National Cooperative Highway Research Program (NCHRP) Report 530 (*4*). Especially in the context of M-E PDG inputs, creep compliance and tensile strength determination has been a moving target and, thus, experts (see Acknowledgements) were contacted in regard to how these properties are actually being obtained in practice. It is fair to say that there were about as many methods promoted and opinions expressed as there were contacts. Nonetheless, T 322-07 was adhered to as closely as possible, with a few exceptions (see Technical Approach section).

MoDOT contracted with Missouri University of Science and Technology (Missouri S&T) to perform the creep compliance and tensile strength testing on several HMA mixes used in wearing (surface) courses throughout the state. Test results are needed by MoDOT to calibrate the M-E PDG thermal (low-temperature) cracking distress models to local conditions; e.g. locally available HMA mix constituents.

OBJECTIVES

The objective of this project is to determine creep compliance, Poisson's ratio, tensile strength, and tensile failure strain of several HMA surface mixes in general accordance with AASHTO T 322-07. The test results will include creep compliance, Poisson's ratio, tensile strength, and tensile failure strain data for six different plant-produced mixes. The specimens, provided by MoDOT, will be tested for creep compliance (and Poisson's ratio) at 0, -10, and -20°C, and for tensile strength at -10, 4.4, and 21°C. Tensile failure strain will be determined for all six mixes at -10°C, and additionally at 4.4 and 21°C on four of the mixes (per MoDOT's requirements). Those same four mixes will be tested at three levels of % air voids: 4, 6.5, and 9%. The remaining two mixes will be tested at 6.5% voids only. All testing will include three replications per treatment combination.

TECHNICAL APPROACH

General

The technical approach included choice of materials and target specimen properties, determination of mix properties, specimen fabrication, determination of actual specimen properties, creep compliance and tensile strength testing, and data reduction.

Materials and Target Specimen Properties

MoDOT sampled six different plant-produced surface mixes, selected the level(s) of % air voids at which each compacted mix would be tested, and fabricated the test specimens for the creep compliance and tensile strength testing. Table 1 gives information about the mixes, the target % air voids of the IDT specimens, and the minimum number of replicate tests (creep and strength) required per treatment combination.

Table 1: HMA Mixes and Target % Air Voids

HMA Mix Type	MoDOT ID [Description] % RAP** (Aggregate Type)	Virgin PG Binder Grade	No. Replicate Tests		
			4% Voids	6.5% Voids	9% Voids
Superpave	06-101 [SP125B] (Dolomite)	76-22 (modified)	3*	3*	3*
Superpave	06-150 [SP125C] 10% RAP (Limestone)	70-22 (modified)	3*	3*	3*
Superpave	06-125 [SP125C] (Limestone)	64-22	3*	3*	3*
Superpave	06-105 [SP125C] 10% RAP (Dolomite)	70-22 (modified)		3	
Superpave (Stone Matrix)	06-84 [SP125BSM] (Porphry)	76-22 (modified)	3*	3*	3*
Marshall	07-123 [BP-1] 20% RAP (Dolomite)	64-22		3	

*Additional IDT strength testing at 4.4 and 21°C (40 and 70°F, respectively)
**Recycled Asphalt Pavement

It is important to point out why it is advantageous to perform more testing at 6.5% air voids than 4 and 9%: the M-E PDG requires that as-constructed properties be used as inputs to the Thermal Cracking module within the software. A level of 6.5% air voids generally describes the average level of compaction immediately post-construction. MoDOT's specifications require *in-place* (as-constructed) densities of 94 ± 2% of theoretical maximum specific gravity (G_{mm}) for Superpave (SP) mixes (i.e. 4 – 8% voids), ≥94% of G_{mm} for Stone Matrix Asphalt (SMA) mixes (maximum of 6% voids), and ≥92% of G_{mm} for Bituminous Pavement (BP) mixes (maximum of 8% voids). Thus, 6.5% air voids fits nicely within the specifications for all three mix types. Additional testing at 4 and 9% air voids allows for the development of relationships between material properties determined through testing and the level of air voids. Therefore the prediction of material properties can be made at different levels of voids other than those actually used during testing.

Specimen Fabrication

Having obtained the plant-produced mixes, MoDOT Central Lab staff first determined the maximum specific gravity of each mix (G_{mm}) according to test method AASHTO T 209 (*5*). Having the G_{mm} of each mix and using well established algorithms, the mix weight was determined that would produce a gyratory-compacted specimen 150 mm in diameter, 115 mm in height, and with a void content approximating the target. After the specimens were compacted and had been stored at room temperature overnight, a water-cooled masonry saw was used to first trim off at least 6 mm of height from the top and bottom of the specimen, and then saw the remainder of the specimen in half producing two IDT specimens (each with two parallel sawn faces) 150 mm in diameter and about 50 mm in height (in most cases; there was an exception for one mix). Each IDT specimen was then dried using the CoreDry® device. Bulk specific gravities (G_{mb}) and the actual % air voids of each were then determined using ASTM D 6752 (*6*) (NOTE: ASTM D 6752, essentially the CoreLok® method, is a deviation from T 322-07 which specifies AASHTO T 166 (*7*) for G_{mb} determination). Finally, each IDT specimen was measured (4 thickness and 2 diameter measurements taken and then averaged), marked, wrapped in cling wrap, and boxed for delivery to Missouri S&T. Table 2 gives more detailed information about the mixes.

Table 2: Additional Mix Properties

Mix ID	% Virgin Binder	% Binder in RAP	Total % Binder	% Fibers	G_{mm}
06-101	5.7	NA	5.7	0	2.515
06-150	5.0	4.8	5.5	0	2.467
06-125	6.5	NA	6.5	0	2.412
06-105	5.1	4.8	5.6	0	2.455
06-84	6.3	NA	6.3	0.3	2.436
07-123	4.2	5.7	5.3	0	2.501

IDT Testing

Equipment

Testing for this project was performed using a Tinius-Olsen (T-O) Super L load frame calibrated up to 120,000 lbf. The system is non-dynamic, closed-loop servo-hydraulic and is computer controlled using the software program MTestWindows by Admet. In addition to the T-O's standard load measurement device (pressure transducer), a new electronic 25,000 lbf, fatigue-rated Tovey load cell (Model FR20-25K) was mounted in-line between the loading table of the T-O and the piston connected to the lower IDT loading platen/strip, as specified in T 322-07. The Tovey load cell was cross-calibrated up to 19,000 lbf using the T-O which had been calibrated by a certified T-O technician approximately 10 months earlier. Just days before IDT testing began, the same T-O technician again calibrated the T-O and noted that no adjustments to the previous calibration were necessary thus verifying the cross-calibration of the Tovey load cell. The T-O load data output is used by the MTestWindows program for control purposes. However, for purposes of calculating creep compliance and tensile strength, the Tovey load data was used because of the load cell's faster response and higher resolution relative to the pressure transducer used in the T-O. Because all data was acquired at a rate of 10 Hz, a faster load cell response was necessary to determine with greater accuracy the time at which maximum loads occurred.

Specimen deformations were measured using new, MTS strain-gauge type extensometers (Model OSDME). The extensometers were factory calibrated for two different full-scale displacement ranges: vertical, 2.000 and 0.2000 mm compression only (utilized during strength and creep testing, respectively); horizontal, ±0.500 and ±0.0500 mm compression and tension (utilized during strength and creep testing, respectively). During creep compliance testing, the smaller range was used for increased resolution.

Data acquisition was accomplished using LabView 8.0 by National Instruments. Inputs to data acquisition were the T-O load output and table position, the Tovey load cell, and the four MTS extensometers.

The temperature chamber is MTS model 651.34. The temperature is controllable from -30 to +100°C, ±0.2°C. Figure 1 shows the equipment configuration.

Figure 1: Test Equipment Setup

Creep Compliance Testing

Creep compliance is defined in T 322-07 as "the time-dependent strain divided by the applied stress." T 322-07 specifies compacted HMA test specimens that are cylindrically shaped with a diameter of 150 ± 9 mm and a thickness (height) of 38 to 50 mm (typically). A static load is imposed along a diametral axis of the temperature controlled specimen for a specified period of time (usually 100 seconds). Creep compliance testing is non-destructive in that the load is controlled so that the upper linear-elastic boundary of the HMA (typically 500 microstrain) is not exceeded, therefore each specimen can be tested at several temperatures. However, the load must be great enough to cause sufficient horizontal deformation (≥0.00125 mm or 33 microstrain based on a 38 mm gauge length) such that noise in the data acquisition process is insignificant. During the loading period, vertical and horizontal deformations are measured on the two sawn, parallel faces of the specimen using four extensometers, two per face (see Figure 2).

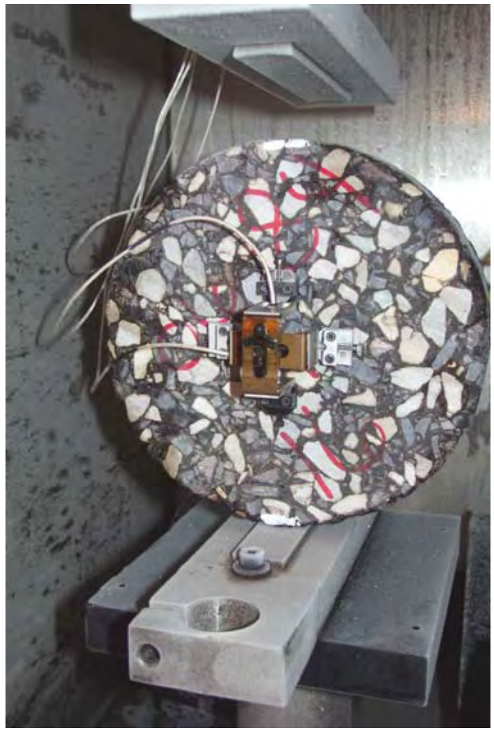

Figure 2: Instrumented IDT Specimen

Procedure

Prior to performing the creep testing, gauge points were attached to the IDT specimens using a gluing template and a cyanoacrylate adhesive (see Figures 3(a) through 3(g)). Just before testing a particular IDT specimen, specially modified MTS adapters were mounted onto the gauge points, aligned and secured in preparation for suspending the extensometers between each set of opposing adapters (black for vertical, gray for horizontal). Figures 3(h) and 3(i) show the mounting of the adapters.

Three replicate test specimens were inserted into the temperature chamber: one that was instrumented with the extensometers and placed on the lower loading strip (as shown in Figure 2), and two that were not. The chamber was turned on and the temperature control set to -21°C. Per recommendations in NCHRP Report 530, specimen temperature was monitored by using a dummy IDT specimen within the chamber that had a type K thermocouple embedded at its 3-dimensional center. Thus, the chamber temperature was necessarily set at the target test temperature ±1.0°C in order to obtain an internal specimen temperature that was within ±0.5°C of the target temperature (as indicated by the type K thermocouple) before any testing was performed. The basic procedure for creep testing was as follows:

1. Perform a 100 second IDT creep test at -20°C on specimen #1 of the set of three replicates that represent a particular treatment combination of mix type

and level of % air voids. Although not specified or even addressed in T 322-07, the static creep load should be applied as quickly as possible, with minimum overshoot, and then stabilized to ±2% of the creep load as quickly as possible. Figure 4 shows a typical load versus time plot. NOTE: Data was acquired at a rate of 10 Hz throughout the entire creep test.

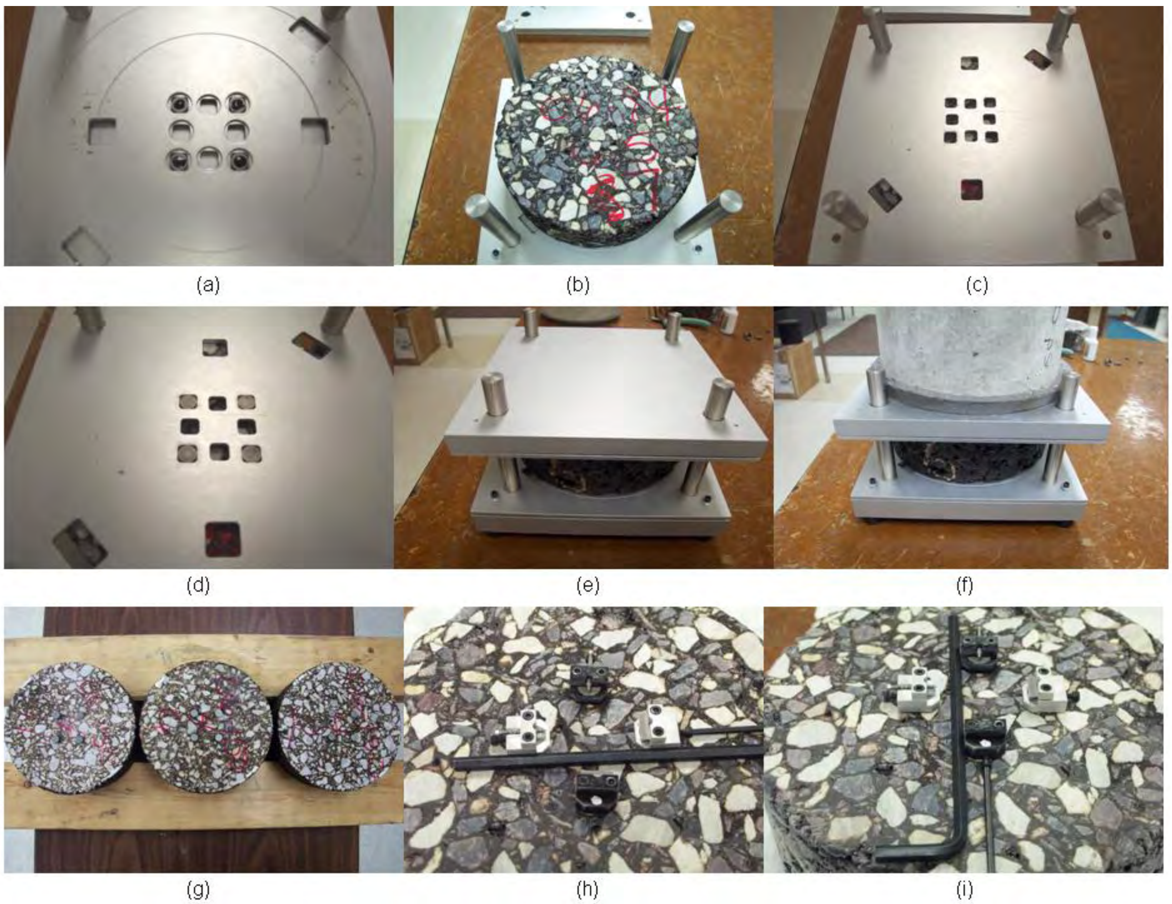

Figure 3: Pre-Instrumentation Preparation

2. After removal of the static load, continue to record deformations (rebound) of specimen #1 for at least an additional 100 seconds
3. Repeat steps 1 and 2 on specimens #2 and #3. NOTE: In between the testing of each specimen, the adapters/extensometers had to be moved from one specimen to the next, and this was done outside of the chamber. During this time, the door to the chamber was left open (thus shutting off the temperature chamber) so that the temperature of the dummy specimen (left inside the chamber) would more closely reflect the temperature of the specimen that was about to be tested. Once the next specimen was instrumented and aligned on the IDT test fixture lower loading strip, the door would be closed, the temperature chamber energized, and testing would not resume until the

dummy specimen temperature was again within ±0.5°C of the target temperature.

4. Once testing is completed at -20°C, repeat steps 1 through 3 at 0°C and then again at -10°C, all with the same three specimens.

Thus, the same three specimens were tested at all temperatures in the following order: 1, 2, 3 (at -20°C), 3, 2, 1 (at 0°C), then 1, 2, 3 (at -10°C). On average, it took about 12 hours to perform the creep testing for one set of replicates. Most of that time was spent waiting for the temperature of the dummy specimen (as indicated by the type K thermocouple) to stabilize at the desired test temperature, ±0.5°C.

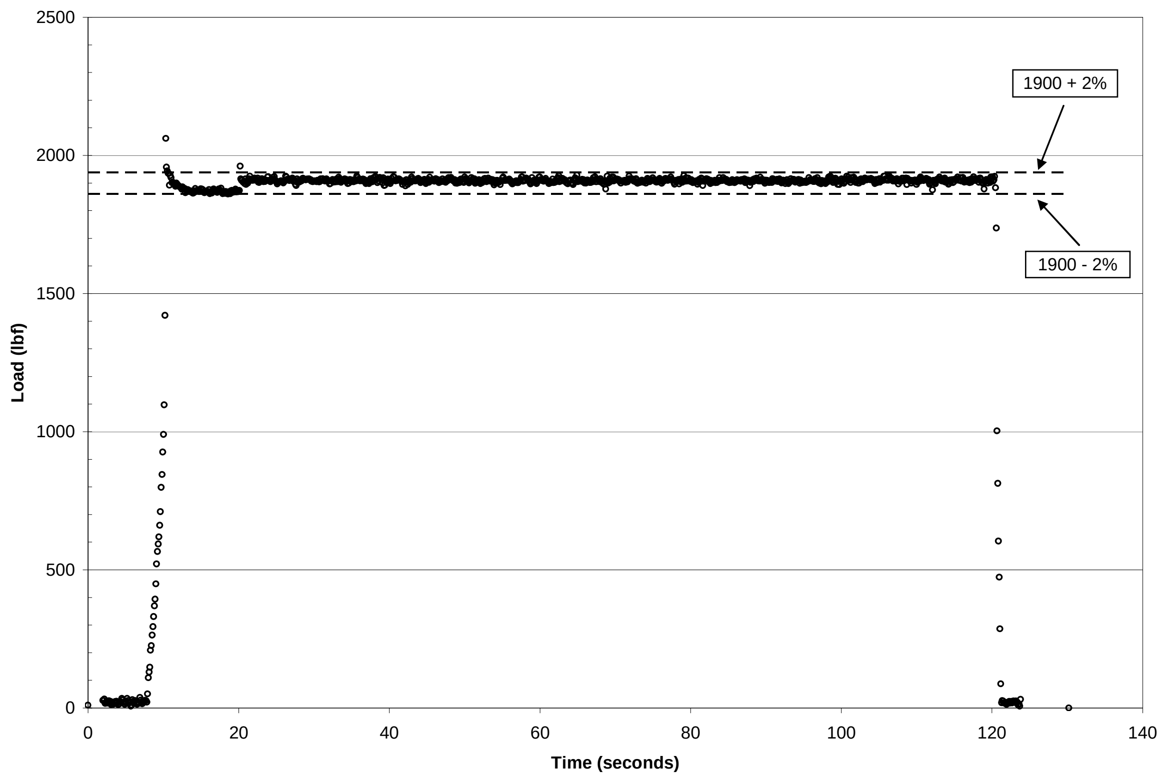

Figure 4: Typical Load vs Time Plot

The use of a thermocouple-instrumented dummy specimen to determine test specimen temperatures was a deviation from T 322-07. Section 11.3 states to "lower the temperature of the environmental chamber to the test temperature and, once the test temperature ±0.5°C is achieved, allow each specimen to remain at the test temperature from 3 ± 1 hours prior to testing." The problem with the method specified in T 322-07 is that the door to the chamber is open for approximately 5 minutes while the adapters/extensometers are being transferred to the next specimen, thus the chamber and the specimens warm up. Upon closing the door and turning the chamber back on, the chamber will come back to test temperature much faster than the specimens; i.e. there is no guarantee that the instrumented test specimen is actually at the test temperature unless internal specimen temperature is monitored, which was done during the testing in this study. As indicated earlier, creep testing of a set of three replicate specimens was accomplished, on average, in about 12 hours therefore no specimens were left at or below 0°C for more than 24 hours, per the restriction specified in T 322-07 Section 11.3.

Tensile Strength Testing

The tensile strength testing portion of T 322-07 is a destructive test; i.e. the specimen is loaded until tensile failure occurs and the specimen cannot be used again. The specimen temperature is first stabilized at the target temperature and then loaded at a rate of 12.5 mm of vertical ram movement per minute. Tensile failure has been defined to have taken place with the *first* occurrence of one of the following two conditions: 1) the maximum load is reached or 2) the difference between the vertical (y) and horizontal (x) deformations (on either face) reaches a peak. The load (and time) at which the y-x differential peaks was defined in T 322-03 as “first failure.” T 322-03 states, “This value [stress at first failure] is less than or equal to the ultimate stress realized by the specimen and is determined by analyzing deformations on both sides of each specimen.” However, T 322-07 has discontinued the use of the “first failure” definition and specifies the maximum load recorded during testing to be used in calculating tensile strength. Tensile strength is calculated as a function of the load at tensile failure and the specimen dimensions. Tensile failure strain is calculated as simply the horizontal strain at tensile failure; i.e. the horizontal deformation occurring between the initial application of load and tensile failure, divided by the gauge length (38 mm during this project).

MoDOT’s stated need for tensile failure strain data caused concern from the start of the project because it requires the recording of vertical and horizontal deformations during the IDT strength testing procedure which could lead to damage of the extensometers. The mode of tensile failure is temperature dependent; i.e. the lower the temperature, the higher the probability that the specimen will fail catastrophically and suddenly fracture in half, everything else remaining constant.

This issue of instrumented specimens during strength testing is one of the curiosities of T 322. T 322-07 Section 11.5 states, “After the creep tests have been completed at each temperature, determine the tensile strength by applying a load to the specimen at a rate of 12.5 mm of ram (vertical) movement per minute. *Record the vertical and horizontal deformations on both ends of the specimen and the load, until the load starts to decrease*.” The italicized sentence was also in T 322-03. However, the “first failure” definition has been removed from T 322-07 and determination of “first failure” was the only reason to record vertical and horizontal deformations during strength testing (i.e. monitor the y-x differential). Nowhere in T 322-07 are the deformations obtained during strength testing used for any calculation or analysis purposes.

Some experts assert that, provided the technician is very careful, tensile failure strain can be determined without damaging the equipment, even at very low temperatures. However, these same experts acknowledge that damage to deformation measurement devices has occurred. NCHRP Report 530 recommends not performing IDT strength testing while the specimen is instrumented. In that report, an equation was developed that transforms “uncorrected” IDT strength (i.e. strength calculated as a function of maximum load) into a “corrected” or true tensile strength (i.e. that strength calculated using the “first failure” definition). The relationship looks to have been developed using 16 data points and resulted in a R^2 value of 74%.

$$\text{Tensile Strength} = \left(0.78 \times \text{IDT Strength}\right) + 38 \tag{1}$$

where:

Tensile Strength = strength corrected to first failure
IDT Strength = strength calculated as a function of maximum load

The need for “first failure” tensile strength stems from the fact that the procedure outlined in T 322-03 was used during the national calibration of the thermal cracking distress model in the M-E PDG. Appendix HH of the M-E PDG documentation (*8*) goes into great detail about the IDT procedure and how “first failure” represents the true tensile strength of a HMA mixture at low temperatures better than simply using the maximum load. Thus, the argument is that any local calibration of the thermal cracking model should also be performed using the “first failure” concept.

Procedure

In light of the previous discussion about concerns over damaging or destroying the extensometers, the tensile strength and tensile failure strain data was collected in a sequence such that the probability of damage was minimum at the beginning and maximum at the end, thus ensuring the maximum amount of valid data across the entire testing program. The sequence was as follows:

1. Immediately following the creep compliance testing of a particular set of replicate specimens at -10°C, that same set of specimens was tested for tensile strength but they were not instrumented for deformation measurements. Because specimens were not instrumented, maximum load was used for calculation purposes.
2. Once all of the creep compliance and non-instrumented tensile strength testing was complete, another round of tensile strength testing was performed on the four mixes selected for testing at 21°C (70°F) but those specimens were instrumented with the extensometers. Due to instrumentation, the “first failure” concept was used for calculation purposes.
3. Following completion of the instrumented tensile strength testing at 21°C, another round of instrumented tensile strength testing was performed on the

same four mixes but at 4.4°C (40°F). Again, “first failure” was used during calculations.
4. Finally, instrumented tensile strength testing was performed on all six mixes at -10°C. Once again, “first failure” was used during calculations.

To try and minimize any shock or movement of the specimen during the instrumented, lower temperature tensile strength testing, a set of foam rubber “book ends” were constructed that were placed on either side of the specimen during testing. Figure 5 shows this configuration.

Figure 5: Low Temperature Tensile Strength Testing Configuration

The tensile strength testing was performed per T 322-07 in that the specimens were loaded at a rate of 12.5 mm of ram (vertical) movement per minute. The extensometers were configured for the larger range at which they had been calibrated such that deformations could be measured to a maximum of 2.000 mm vertically and 1.000 mm horizontally (±0.500 mm).

Data Reduction

Creep Compliance

Creep compliance is calculated as a function of the horizontal and vertical deformations, the gauge length over which these deformations are measured, the dimensions of the test specimen, and the magnitude of the static load. Creep compliance determination, as defined in T 322-07, is given as follows:

$$D(t) = \frac{\Delta X_{tm,t} \times D_{avg} \times b_{avg}}{P_{avg} \times GL} \times C_{cmpl} \tag{2}$$

where:

$D(t)$ = creep compliance at time t $(kPa)^{-1}$
GL = gauge length in meters (0.038 meters for 150 mm diameter specimens)
D_{avg} = average diameter of all specimens [typically 3] (nearest 0.001 meter)
b_{avg} = average thickness of all specimens [typically 3] (nearest 0.001 meter)
P_{avg} = average creep load (kN)
$\Delta X_{tm,t}$ = trimmed mean of the normalized, horizontal deformations (nearest 0.001 meter) of all specimen faces [typically 6] at time t

C_{cmpl} = correction factor = $0.6354 \times \left(\frac{X}{Y}\right)^{-1} - 0.332$ (3)

where:

$\frac{X}{Y}$ = absolute value of the ratio of the normalized, trimmed mean of the horizontal deformations (i.e. $\Delta X_{tm,t}$) to the normalized, trimmed mean of the vertical deformations (i.e. $\Delta Y_{tm,t}$) at a time corresponding to ½ the total creep test time [typically 50 seconds] for all specimen faces

Equation 3 gives a non-dimensional correction factor that accounts for horizontal and vertical stress correction factors, and horizontal specimen bulging during loading (*8, 9*). Equation 3 restrictions are given by Equation 4:

$$\left[0.704 - 0.213\left(\frac{b_{avg}}{D_{avg}}\right)\right] \le C_{cmpl} \le \left[1.566 - 0.195\left(\frac{b_{avg}}{D_{avg}}\right)\right] \tag{4}$$

Normalization of the measured vertical and horizontal deformations of a specific specimen face is accomplished by multiplying said deformations by a constant that is a function of specimen dimensions and the creep load:

$$\text{Normalization Constant} = \frac{b_n}{b_{avg}} \times \frac{D_n}{D_{avg}} \times \frac{P_{avg}}{P_n} \tag{5}$$

where:

b_n, D_n, and P_n = thickness, diameter, and creep load of specimen n, respectively.

The trimmed mean of the normalized deformations (i.e. $\Delta X_{tm,t}$ and $\Delta Y_{tm,t}$) is simply the average of the remaining values (usually 4) after the maximum and minimum values have been discarded.

Creep compliance values needed for input into the M-E PDG Thermal Cracking module are calculated at 1, 2, 5, 10, 20, 50, and 100 seconds of loading, at -20, -10, and 0°C. The first major step is to determine the deformations at these times during testing at each of the temperatures.

Upon inspection of the raw acquired data, one first identifies the points in time at which 1) the load is first applied to the specimen and 2) the load stabilizes to ± 2% of the target creep load. In viscoelastic theory, the load versus time profile for creep testing is a step function; i.e. the load is applied instantaneously, held constant for the desired length of time, and then removed instantaneously. However, instantaneous loading in the real world is impossible. Under ideal real-world conditions the elapsed time between the initial application of load and stabilization at the creep load (± 2%) would be 0.1 second or less, based on the opinions of experts. However due to equipment limitations, elapsed load “ramp” time (i.e. the elapsed time between initial application of the load and the stabilization of the load to ± 2% of the target creep load) during this study averaged 3 seconds.

Per recommendations by Harold Von Quintus, MoDOT’s consultant on calibration of the M-E PDG, creep compliance at 1 second, for example, would be calculated using deformations recorded 1 second *after* the load stabilized to ± 2% of the target creep load; i.e. the point in time at which the load stabilized to ± 2% of the target creep load would be considered t_{zero}. In essence, a true creep load profile was being assumed. All creep compliance values at different times, t, are calculated relative to t_{zero}. Designated as the “original” method throughout the remainder of this paper, the methodology described above is shown in Figure 6 using a time-abbreviated dataset. Deformations are designated as North or South (i.e. the face of the specimen the deformations are associated with), and Vertical or Horizontal.

Note that in this particular dataset, the load “drooped” to the lower limit (target creep load – 2%) immediately following the very brief overshoot, and stayed there for several seconds before fully stabilizing at the target creep load of 2000 pounds. This phenomenon occurred quite often but not all of the time, and seemed to result from a combination of the tuning of the T-O servo-hydraulic gains (i.e. Proportional, Integral, and Derivative gains or PID’s), the particular specimen and test temperature, and inherent peculiarities of the T-O system.

It should also be noted that although the indication is that deformations at the specified times are used for calculation of creep compliance, an average deformation value based on several deformations that straddle the specified time line was actually used for creep compliance calculations. This averaging of several values (a minimum of two and a maximum of nine) was done to account for noise in the data. For example, if the South Horizontal deformation value at 5 seconds was being determined, horizontal deformations on the south face of the specimen at 4.6, 4.7, 4.8, 4.9, 5.0, 5.1, 5.2, 5.3, and 5.4 seconds were averaged. However to determine the deformation at t_{zero}, a smaller number of values were averaged because the absolute value of the change in deformation per 0.1 second was usually greater than at later times.

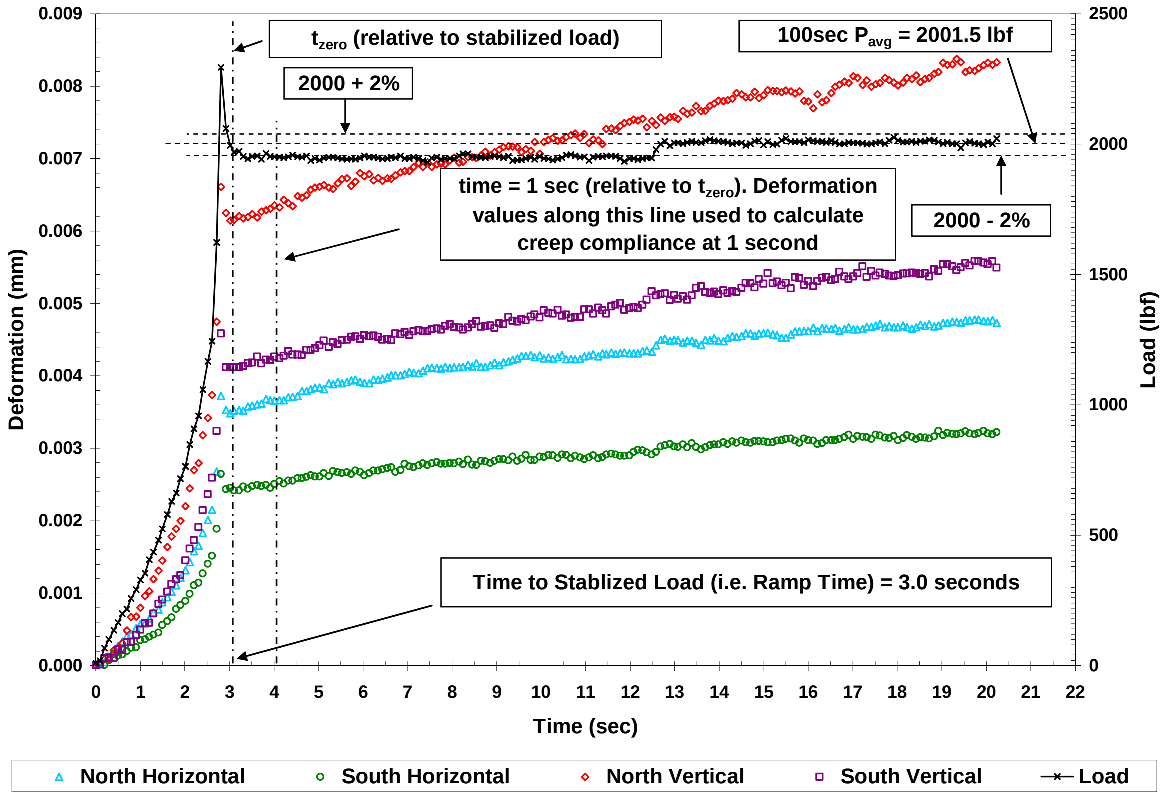

Figure 6: Deformation Determination for Creep Compliance Calculations

Poisson's Ratio

Poisson's ratio, ν, is calculated as follows:

$$\nu = -0.10 + 1.480\left(\frac{X}{Y}\right)^2 - 0.778\left(\frac{b_{avg}}{D_{avg}}\right)^2\left(\frac{X}{Y}\right)^2 \tag{6}$$

where:

$0.05 \le v \le 0.50$

Tensile Strength and Tensile Failure Strain

Calculation of tensile strength per T 322-07 is given by Equation 7.

$$S_{t,n} = \frac{2 \times P_{f,n}}{\pi \times b_n \times D_n} \tag{7}$$

where:

$S_{t,n}$ = tensile strength of specimen, n
$P_{f,n}$ = maximum load observed for specimen, n

As the “first failure” concept was utilized during IDT strength testing, calculation of tensile strength would be accomplished using Equation 7 but $P_{f,n}$ would be the load associated with the maximum y-x differential or the maximum load, whichever occurred first. The average tensile strength for a particular set of replicate specimens is also an input to the Thermal Cracking Module of the M-E PDG.

Tensile failure strain is calculated as follows:

$$\varepsilon_{tf} = \frac{\Delta X_f}{GL} \times 10^6 \tag{8}$$

where:

ε_{tf} = tensile failure strain (microstrain)
ΔX_f = the horizontal deformation (10^{-6} mm) at failure.
GL = gauge length in mm (38 for 150 mm diameter specimens)

RESULTS AND DISCUSSION

Creep Compliance

The creep compliance results are given in Tables 3 through 7. Creep compliance values are given in two different units: psi^{-1} (needed for input into the M-E PDG Thermal Cracking Module) and GPa^{-1}. Plots generated for comparison purposes are given in Figures 7 through 9 showing creep compliance results for mixes compacted to 6.5% voids. A complete set of plots are given in Appendix A.

Table 3: Creep Compliance: 06-125 (SP125C Limestone)

Temp	Time	06-125 (Voids = 4%)		06-125 (Voids = 6.5%)		06-125 (Voids = 9%)	
(deg C)	(sec)	D(t) (1/psi)	D(t) (1/Gpa)	D(t) (1/psi)	D(t) (1/Gpa)	D(t) (1/psi)	D(t) (1/Gpa)
-20	1	2.5035E-07	0.03631	3.0510E-07	0.04425	3.3867E-07	0.04912
	2	2.5648E-07	0.03720	3.0997E-07	0.04496	3.4573E-07	0.05014
	5	2.6933E-07	0.03906	3.2352E-07	0.04692	3.5754E-07	0.05186
	10	2.8235E-07	0.04095	3.4009E-07	0.04933	3.7427E-07	0.05428
	20	2.9128E-07	0.04225	3.6010E-07	0.05223	3.9264E-07	0.05695
	50	3.1535E-07	0.04574	3.8300E-07	0.05555	4.1835E-07	0.06068
	100	3.2748E-07	0.04750	4.1431E-07	0.06009	4.4649E-07	0.06476
-10	1	3.3791E-07	0.04901	3.6567E-07	0.05304	4.1683E-07	0.06046
	2	3.4928E-07	0.05066	3.8180E-07	0.05538	4.2892E-07	0.06221
	5	3.7034E-07	0.05371	4.0938E-07	0.05938	4.5714E-07	0.06630
	10	3.9875E-07	0.05783	4.4683E-07	0.06481	4.9356E-07	0.07159
	20	4.2747E-07	0.06200	4.8141E-07	0.06982	5.3069E-07	0.07697
	50	4.7736E-07	0.06924	5.4865E-07	0.07957	5.9145E-07	0.08578
	100	5.2629E-07	0.07633	6.0627E-07	0.08793	6.4465E-07	0.09350
0	1	5.3193E-07	0.07715	5.6385E-07	0.08178	6.7142E-07	0.09738
	2	5.6947E-07	0.08260	6.0557E-07	0.08783	7.1841E-07	0.10420
	5	6.3890E-07	0.09266	6.9872E-07	0.10134	8.1813E-07	0.11866
	10	7.1948E-07	0.10435	8.0840E-07	0.11725	9.3953E-07	0.13627
	20	8.2759E-07	0.12003	9.5273E-07	0.13818	1.0931E-06	0.15854
	50	1.0377E-06	0.15051	1.2298E-06	0.17837	1.3791E-06	0.20002
	100	1.2568E-06	0.18228	1.5379E-06	0.22305	1.6955E-06	0.24591

Table 4: Creep Compliance: 06-101 (SP125B Dolomite)

Temp	Time	06-101 (Voids = 4%)		06-101 (Voids = 6.5%)		06-101 (Voids = 9%)	
(deg C)	(sec)	D(t) (1/psi)	D(t) (1/Gpa)	D(t) (1/psi)	D(t) (1/Gpa)	D(t) (1/psi)	D(t) (1/Gpa)
-20	1	2.1272E-07	0.03085	2.4003E-07	0.03481	2.8444E-07	0.04125
	2	2.1606E-07	0.03134	2.4822E-07	0.03600	2.8698E-07	0.04162
	5	2.2259E-07	0.03228	2.5550E-07	0.03706	2.9960E-07	0.04345
	10	2.3511E-07	0.03410	2.6741E-07	0.03878	3.1585E-07	0.04581
	20	2.4617E-07	0.03570	2.7939E-07	0.04052	3.3516E-07	0.04861
	50	2.6328E-07	0.03819	2.9706E-07	0.04308	3.5140E-07	0.05097
	100	2.7380E-07	0.03971	3.1193E-07	0.04524	3.7558E-07	0.05447
-10	1	2.6071E-07	0.03781	3.0755E-07	0.04461	3.7287E-07	0.05408
	2	2.6953E-07	0.03909	3.2101E-07	0.04656	3.8817E-07	0.05630
	5	2.8765E-07	0.04172	3.4047E-07	0.04938	4.1282E-07	0.05987
	10	3.0762E-07	0.04462	3.6382E-07	0.05277	4.3411E-07	0.06296
	20	3.2653E-07	0.04736	3.9391E-07	0.05713	4.6853E-07	0.06795
	50	3.6785E-07	0.05335	4.3838E-07	0.06358	5.1935E-07	0.07533
	100	4.0278E-07	0.05842	4.7890E-07	0.06946	5.6973E-07	0.08263
0	1	3.8947E-07	0.05649	4.3942E-07	0.06373	4.8861E-07	0.07087
	2	4.1800E-07	0.06063	4.7132E-07	0.06836	5.2329E-07	0.07590
	5	4.7754E-07	0.06926	5.3036E-07	0.07692	5.9067E-07	0.08567
	10	5.4781E-07	0.07945	5.9919E-07	0.08690	6.7225E-07	0.09750
	20	6.3849E-07	0.09261	6.9474E-07	0.10076	7.7699E-07	0.11269
	50	8.0632E-07	0.11695	8.6604E-07	0.12561	9.5867E-07	0.13904
	100	9.8017E-07	0.14216	1.0474E-06	0.15192	1.1556E-06	0.16761

Table 5: Creep Compliance: 06-84 (SP125BSM Porphry)

Temp	Time	06-84 (Voids = 4%)		06-84 (Voids = 6.5%)		06-84 (Voids = 9%)	
(deg C)	(sec)	D(t) (1/psi)	D(t) (1/Gpa)	D(t) (1/psi)	D(t) (1/Gpa)	D(t) (1/psi)	D(t) (1/Gpa)
-20	1	2.5426E-07	0.03688	2.9047E-07	0.04213	3.6340E-07	0.05271
	2	2.6128E-07	0.03790	2.9604E-07	0.04294	3.6774E-07	0.05334
	5	2.7030E-07	0.03920	3.0591E-07	0.04437	3.8061E-07	0.05520
	10	2.8330E-07	0.04109	3.2202E-07	0.04670	3.9955E-07	0.05795
	20	2.9398E-07	0.04264	3.4097E-07	0.04945	4.2072E-07	0.06102
	50	3.1146E-07	0.04517	3.6314E-07	0.05267	4.4901E-07	0.06512
	100	3.2883E-07	0.04769	3.8628E-07	0.05603	4.7240E-07	0.06852
-10	1	3.5706E-07	0.05179	3.5774E-07	0.05189	5.0654E-07	0.07347
	2	3.6484E-07	0.05291	3.7019E-07	0.05369	5.1945E-07	0.07534
	5	3.8548E-07	0.05591	3.9085E-07	0.05669	5.4379E-07	0.07887
	10	4.0867E-07	0.05927	4.1908E-07	0.06078	5.8552E-07	0.08492
	20	4.4271E-07	0.06421	4.6059E-07	0.06680	6.3365E-07	0.09190
	50	4.8753E-07	0.07071	5.0960E-07	0.07391	7.1346E-07	0.10348
	100	5.4001E-07	0.07832	5.6664E-07	0.08218	7.9126E-07	0.11476
0	1	4.9589E-07	0.07192	4.9558E-07	0.07188	7.4524E-07	0.10809
	2	5.2990E-07	0.07686	5.2614E-07	0.07631	8.0206E-07	0.11633
	5	5.9431E-07	0.08620	5.9778E-07	0.08670	9.1754E-07	0.13308
	10	6.7615E-07	0.09807	6.8427E-07	0.09924	1.0566E-06	0.15324
	20	7.7898E-07	0.11298	8.0170E-07	0.11628	1.2460E-06	0.18072
	50	9.6964E-07	0.14063	1.0148E-06	0.14719	1.6149E-06	0.23423
	100	1.1634E-06	0.16874	1.2521E-06	0.18161	2.0361E-06	0.29531

Table 6: Creep Compliance: 06-150 (SP125C Limestone)

Temp	Time	06-150 (Voids = 4%)		06-150 (Voids = 6.5%)		06-150 (Voids = 9%)	
(deg C)	(sec)	D(t) (1/psi)	D(t) (1/Gpa)	D(t) (1/psi)	D(t) (1/Gpa)	D(t) (1/psi)	D(t) (1/Gpa)
-20	1	2.3270E-07	0.03375	2.7471E-07	0.03984	3.2558E-07	0.04722
	2	2.3364E-07	0.03389	2.7942E-07	0.04053	3.3127E-07	0.04805
	5	2.4020E-07	0.03484	2.8612E-07	0.04150	3.4147E-07	0.04953
	10	2.5333E-07	0.03674	2.9530E-07	0.04283	3.5699E-07	0.05178
	20	2.6562E-07	0.03853	3.0936E-07	0.04487	3.7511E-07	0.05441
	50	2.7686E-07	0.04016	3.2931E-07	0.04776	4.0184E-07	0.05828
	100	2.9248E-07	0.04242	3.4894E-07	0.05061	4.2234E-07	0.06126
-10	1	2.7076E-07	0.03927	3.4397E-07	0.04989	3.9128E-07	0.05675
	2	2.7845E-07	0.04039	3.5229E-07	0.05109	4.0149E-07	0.05823
	5	2.9297E-07	0.04249	3.7356E-07	0.05418	4.2930E-07	0.06227
	10	3.1444E-07	0.04560	4.0236E-07	0.05836	4.6357E-07	0.06724
	20	3.3663E-07	0.04882	4.2599E-07	0.06179	4.9991E-07	0.07251
	50	3.7557E-07	0.05447	4.7964E-07	0.06957	5.6571E-07	0.08205
	100	4.0644E-07	0.05895	5.2053E-07	0.07550	6.1993E-07	0.08991
0	1	3.6693E-07	0.05322	4.8603E-07	0.07049	6.5130E-07	0.09446
	2	3.8964E-07	0.05651	5.1387E-07	0.07453	6.9116E-07	0.10024
	5	4.2905E-07	0.06223	5.8161E-07	0.08436	7.8421E-07	0.11374
	10	4.7953E-07	0.06955	6.6901E-07	0.09703	8.9981E-07	0.13051
	20	5.4656E-07	0.07927	7.8147E-07	0.11334	1.0633E-06	0.15422
	50	6.6964E-07	0.09712	9.9636E-07	0.14451	1.3820E-06	0.20044
	100	8.0373E-07	0.11657	1.2394E-06	0.17976	1.7543E-06	0.25444

Table 7: Creep Compliance: 06-105 (SP125C Dolomite), 07-123 (BP-1 Dolomite)

Temp	Time	06-105 (Voids = 6.5%)		07-123 (Voids = 6.5%)	
(deg C)	(sec)	D(t) (1/psi)	D(t) (1/Gpa)	D(t) (1/psi)	D(t) (1/Gpa)
-20	1	2.7026E-07	0.03920	2.4423E-07	0.03542
	2	2.7292E-07	0.03958	2.5001E-07	0.03626
	5	2.8299E-07	0.04104	2.5685E-07	0.03725
	10	2.9788E-07	0.04320	2.6911E-07	0.03903
	20	3.0996E-07	0.04496	2.7338E-07	0.03965
	50	3.2931E-07	0.04776	2.9386E-07	0.04262
	100	3.4218E-07	0.04963	3.0554E-07	0.04431
-10	1	3.2643E-07	0.04734	3.0469E-07	0.04419
	2	3.4122E-07	0.04949	3.1069E-07	0.04506
	5	3.5722E-07	0.05181	3.2346E-07	0.04691
	10	3.7983E-07	0.05509	3.4429E-07	0.04994
	20	4.1038E-07	0.05952	3.6472E-07	0.05290
	50	4.4907E-07	0.06513	4.0189E-07	0.05829
	100	4.8786E-07	0.07076	4.2199E-07	0.06120
0	1	4.3592E-07	0.06323	4.0019E-07	0.05804
	2	4.5828E-07	0.06647	4.2175E-07	0.06117
	5	5.0714E-07	0.07355	4.6055E-07	0.06680
	10	5.6857E-07	0.08246	5.0619E-07	0.07342
	20	6.4142E-07	0.09303	5.6527E-07	0.08199
	50	7.7507E-07	0.11241	6.6626E-07	0.09663
	100	9.1212E-07	0.13229	7.7447E-07	0.11233

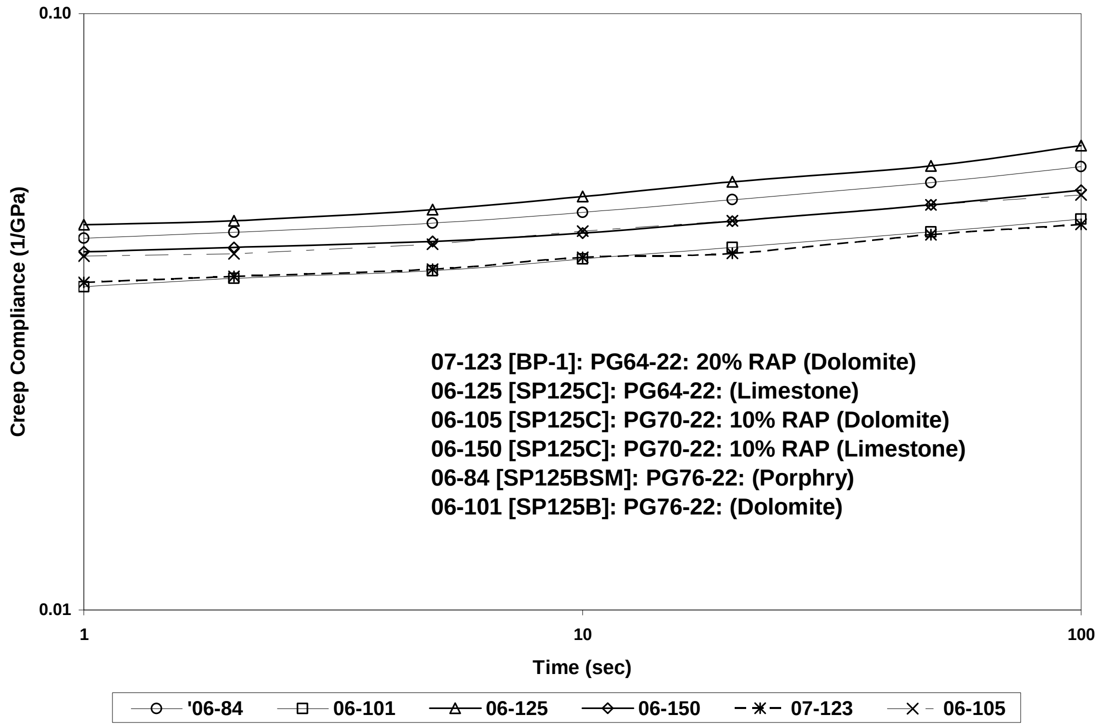

Figure 7: Creep Compliance Comparisons: 6.5% Voids, -20°C

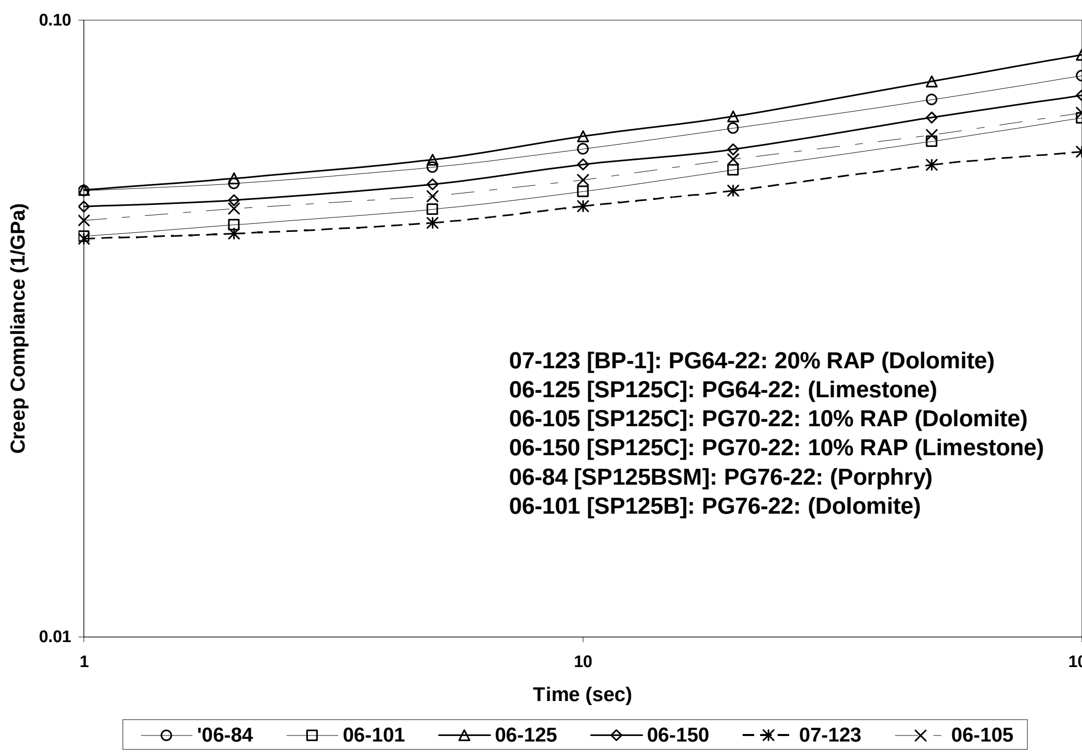

Figure 8: Creep Compliance Comparisons: 6.5% Voids, -10°C

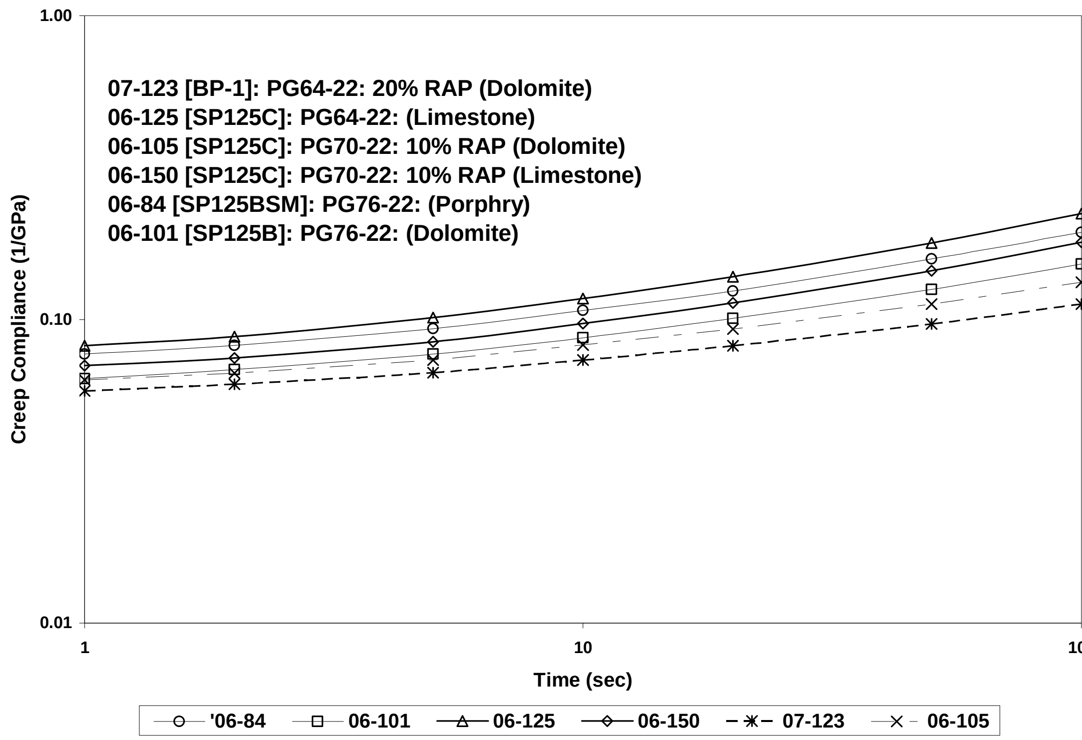

Figure 9: Creep Compliance Comparisons: 6.5% Voids, 0°C

Two rounds of IDT creep testing of the BP-1 (07-123) mix were performed because the first round of creep testing was performed with an insufficient load. The load during the first round of testing produced initial horizontal deformations that did not meet the lower limit of ~33 microstrain. So, although six replicate specimens were tested for tensile strength, only the last 3 replicate specimens (round 2) were used to calculate creep compliance.

There were also two rounds of IDT creep testing on 06-84, the SMA mix. The first round of testing resulted in creep compliance values for the 4% voids specimens that were greater than the 6.5% voids specimens, backward from the expected trend. The non-uniform void distribution in the SMA specimens resulted in one face of the sawn specimen sometimes possessing large exposed voids while the opposite face was much smoother. It is speculated that this difference in face texture could have been the cause of the unexpected trend. The second round of creep testing produced expected results and those values are the ones reported in Table 5. There was not a second round of tensile strength testing immediately following the second round of creep testing.

At 6.5% air voids and at all three test temperatures, 07-123 is the stiffest or least compliant of the six mixes investigated, whereas 06-125 is the most compliant. This result dramatically shows the effect that RAP has on creep compliance. Both 07-123 and 06-125 utilize PG64-22 as the virgin binder yet they are at the extremes, at least as it pertains to creep compliance, largely due to the fact that 07-123 has 20% RAP and 06-125 has none.

The usage of RAP in a mix is not directly addressed in the M-E PDG although some work has been done in this area (*10*). To properly account for its inclusion in a mix, a Level 1 analysis of the mix and binder should be performed; e.g. extracted RAP binder and the blended binder would need to be characterized. Estimations based on comparisons such as those shown in Figures 7 – 9 could be helpful in Level 2 and 3 designs. For example, at -20°C, 07-123 (PG64-22 virgin binder, 20% RAP) and 06-101 (PG76-22 binder, 0% RAP) have very similar creep compliance curves.

As a follow-up check on the creep compliance values listed in Tables 3 – 7, the M-E PDG software was utilized. An example new flexible pavement design (for the Dallas, Texas area) that is included in Version 1.0 of the software was used as the baseline design. Each set of creep compliance values and the associated average tensile strength from the present study were substituted into the Thermal Cracking Module of the software, they were identified as Level 1 inputs, and the analysis was performed. The purpose was to make sure that the creep compliance values as calculated would run in the software without any errors in the thermal cracking output. Only the 07-123 creep compliance values using the original calculation method produced errors in the thermal cracking output. Figure 10 shows the resultant thermal cracking plot.

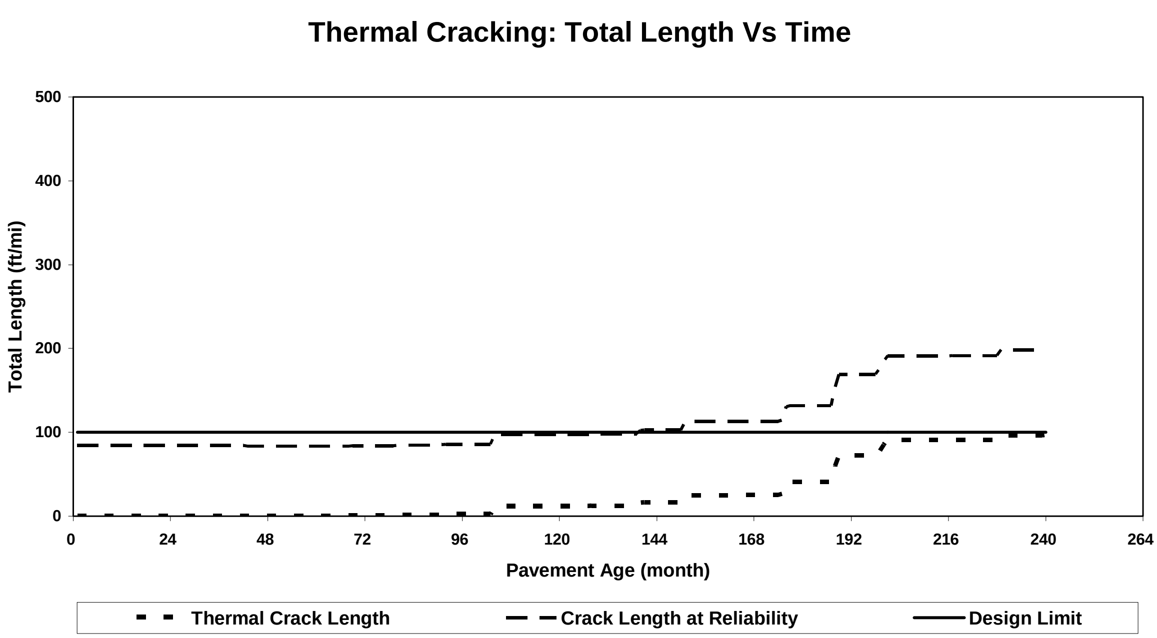

Figure 10: Irregular Thermal Cracking Output: Original Method: 07-123

An investigation into the reason for the error (extreme stair-step increases in thermal cracking beginning around 100 months) was undertaken. It seems that a relatively small range (the difference between the maximum and minimum values) of creep compliance per temperature can produce problems in the algorithm used to create the master creep compliance curve (the full explanation of which is beyond the scope of this paper) by limiting the amount of overlap created when the -10°C and the 0°C creep compliance – time curves are shifted to the right in time to extend the -20°C curve thereby creating one continuous, creep compliance – reduced time master curve. The general process is shown in Figure 11 using the 07-123 data calculated using the original method.

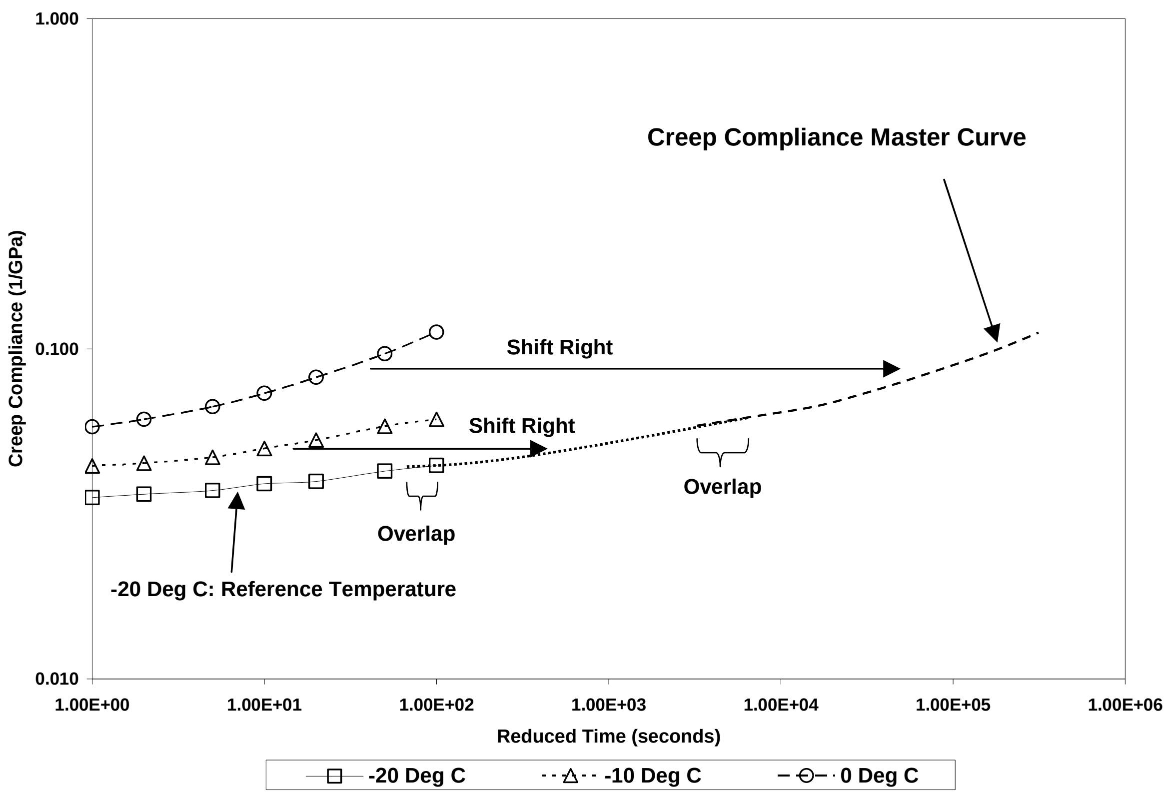

Figure 11: Creep Compliance Master Curve Creation

This conclusion was reached using two different types of analyses: one was based on creep compliance values calculated using a different method for determining t_{zero}, and the other was based on arbitrarily increasing the range of creep compliance values for the 07-123 mix at -10 and 0°C.

The alternative method for determining t_{zero} is based on an "equivalent area" concept where at some time, t, the area under the load versus time curve of a non-instantaneous ramp load is equal to the area under a true creep load profile at time, t′. This concept was first suggested to the authors by James Sherwood of the FHWA. Later, Harold Von Quintus verified that this concept has been used in the past, particularly in an earlier flexible pavement analysis program called VESYS.

However, published documentation of the equivalent area concept as applied specifically to non-instantaneous creep loading has yet to be found. Figure 12 shows this concept in calculating creep compliance at 1 second.

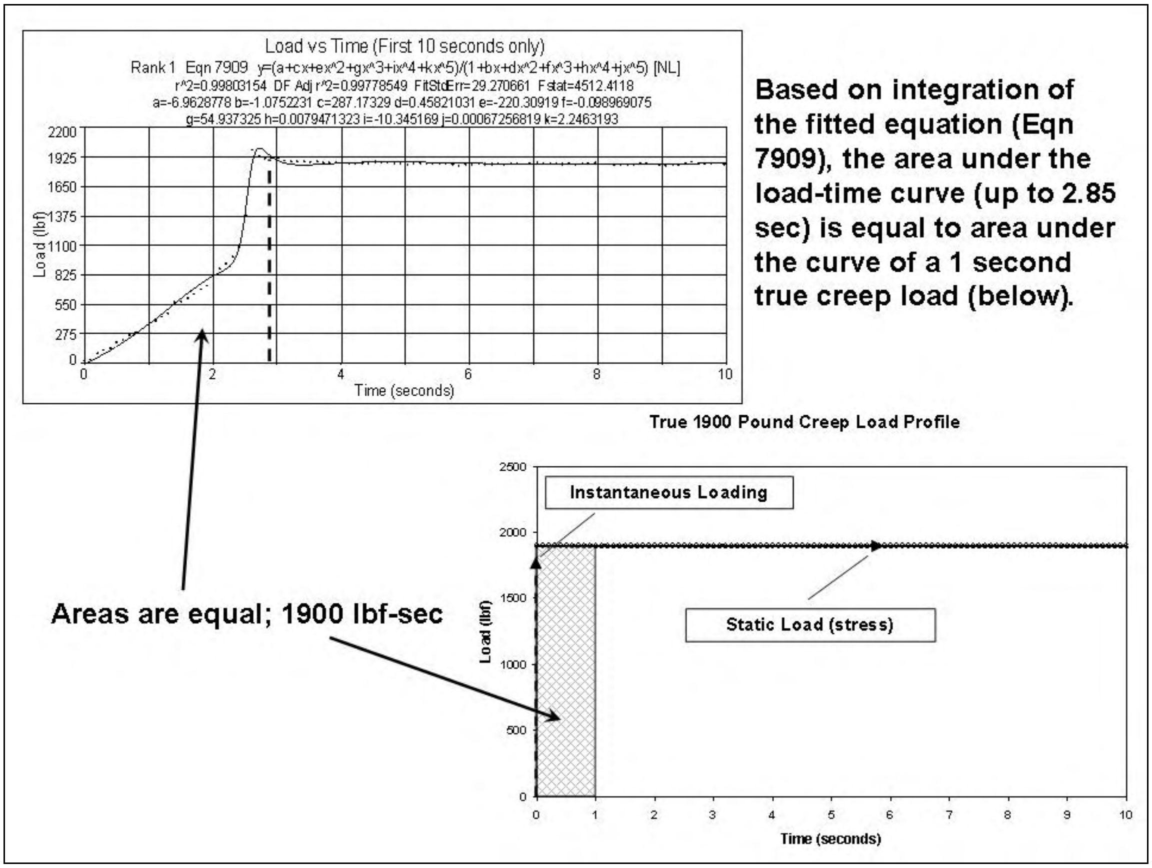

Figure 12: Equivalent Area Concept

Table 8 shows creep compliance values for 07-123 calculated using the equivalent area method and the “original” method described earlier.

Table 8: Equivalent Area vs. Original Method: 07-123

	Creep Compliance (1/psi)					
Time	Temp = -20degC		Temp = -10degC		Temp = 0degC	
(sec)	Equiv. Area	Original	Equiv. Area	Original	Equiv. Area	Original
1	2.4430E-07	2.4423E-07	2.9033E-07	3.0469E-07	3.5911E-07	4.0019E-07
2	2.4356E-07	2.5001E-07	3.0246E-07	3.1069E-07	3.9380E-07	4.2175E-07
5	2.5001E-07	2.5685E-07	3.2053E-07	3.2346E-07	4.4563E-07	4.6055E-07
10	2.5918E-07	2.6911E-07	3.3988E-07	3.4429E-07	4.9442E-07	5.0619E-07
20	2.7571E-07	2.7338E-07	3.6380E-07	3.6472E-07	5.5972E-07	5.6527E-07
50	2.9128E-07	2.9386E-07	4.0019E-07	4.0189E-07	6.6436E-07	6.6626E-07
100	3.0674E-07	3.0554E-07	4.2673E-07	4.2199E-07	7.7751E-07	7.7447E-07
Range	6.3187E-08	6.1304E-08	1.3641E-07	1.1730E-07	4.1840E-07	3.7427E-07
% of Equiv. Area Range		97.0%		86.0%		89.5%

The first item to point out in Table 8 is the anomalous values of creep compliance for the equivalent area method at -20°C and at 1 and 2 seconds; the value at 1 second is actually larger than that at 2 seconds which is contrary to the expected trend. Upon closer inspection of the data, this anomaly is due to the fact that deformations at 1 second using the equivalent area method more closely coincide with the “knee” of the load – time curve or that area where the overshoot occurs, not ~1 second after the overshoot as is the case when using the original method. Thus for this one particular anomaly, deformations at 1 second were actually larger than at 2 seconds simply because the load due to the very brief overshoot was greater than the load at 2 seconds.

A second observation in looking at Table 8 is the fact that the equivalent area method gives smaller creep compliance values, in general. This is due to the shifting of the time line by about 1 second. In the original method of calculating creep compliance, t = 1 second always occurred about 1 second *after the overshoot*. In the equivalent area method, t = 1 second generally *coincided with the overshoot*, thus there is about a 1 second difference between the two methods with the equivalent area method using smaller deformations and resulting in smaller creep compliance values, in general. Figure 13 graphically depicts the differences between the two methods. As can be seen, the lines essentially lay on top of one another, especially at the 100 second interval.

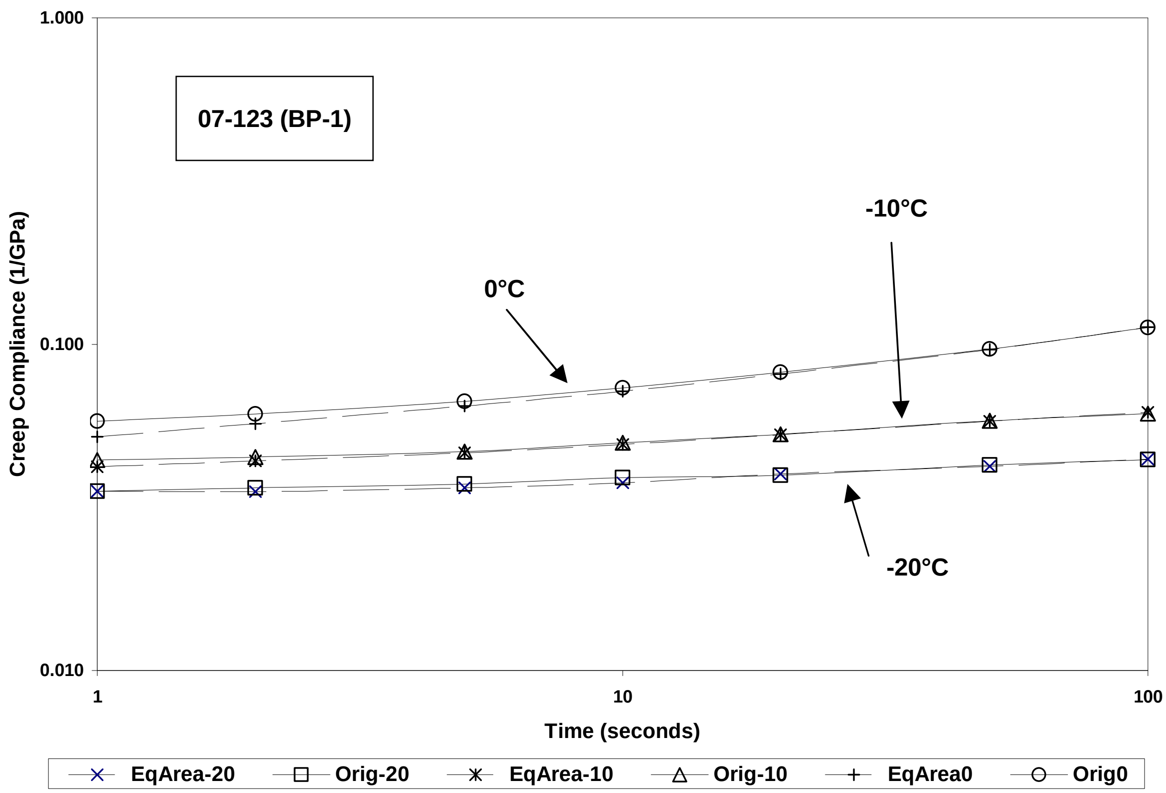

Figure 13: Equivalent Area vs. Original Method: 07-123

Getting back to the issue of the error in the thermal cracking output shown in Figure 10, the range of creep compliance values for the two calculation methods is shown in Table 8 and clearly indicates that the equivalent area method results in a greater range. The first clue that range had an impact on the algorithm in the Thermal Cracking Module came when the creep compliance values calculated using the equivalent area method (larger range) were input into the Thermal Cracking Module and ran error-free. Output from that analysis is shown in Figure 14. The “Thermal Crack Length” line is near zero and flat across the design period which is logical, as thermal cracking is probably not a major concern in Dallas, Texas due to its climate. It should be noted that the other 13 sets of creep compliance/IDT strength values produced thermal cracking output similar to Figure 14 when using the original method for calculating creep compliance.

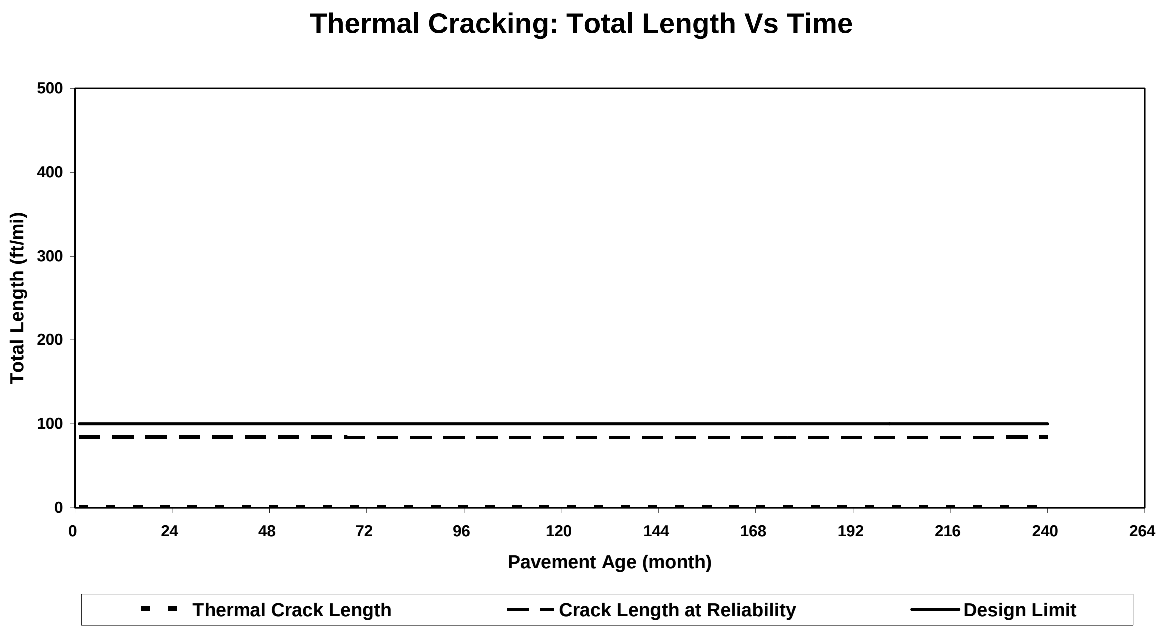

Figure 14: Thermal Cracking Output: Equivalent Area Method: 07-123

To double-check the theory that the creep compliance range could impact the Thermal Cracking Module algorithm, the creep compliance values calculated using the original method were modified by incrementally increasing the compliance values for -10 and 0°C resulting in a larger, “stretched” range for these two temperatures but having the original value at 1 second of creep. This stretching only increased the overlap (as depicted in Figure 11) of the -10 and 0°C curves and the upper limit of the 0°C curve. Table 9 shows this methodology.

Table 9: Original vs. Stretched Creep Compliance Ranges: 07-123

Time	Creep Compliance (1/psi)					
	Temp = -20degC		Temp = -10degC		Temp = 0degC	
(sec)	Original	Stretched*	Original	Stretched	Original	Stretched
1	2.4423E-07	2.4423E-07	3.0469E-07	3.0469E-07	4.0019E-07	4.0019E-07
2	2.5001E-07	2.5001E-07	3.1069E-07	3.1224E-07	4.2175E-07	4.2513E-07
5	2.5685E-07	2.5685E-07	3.2346E-07	3.2669E-07	4.6055E-07	4.6516E-07
10	2.6911E-07	2.6911E-07	3.4429E-07	3.4946E-07	5.0619E-07	5.1227E-07
20	2.7338E-07	2.7338E-07	3.6472E-07	3.7202E-07	5.6527E-07	5.7318E-07
50	2.9386E-07	2.9386E-07	4.0189E-07	4.1194E-07	6.6626E-07	6.7692E-07
100	3.0554E-07	3.0554E-07	4.2199E-07	4.3465E-07	7.7447E-07	7.8841E-07
Range	6.1304E-08	6.1304E-08	1.1730E-07	1.2996E-07	3.7427E-07	3.8821E-07
% of Original Range		100.0%		110.8%		103.7%

*This column is the same as the original

The stretched values (larger ranges for -10 and 0°C curves) were input into the Thermal Cracking Module and it also ran error-free thus confirming that the range of the creep compliance values per temperature has an impact on the proper operation of the Thermal Cracking Module algorithm.

Having determined that there is a problem running the M-E PDG thermal cracking analysis with the 07-123 creep compliance values calculated using the original method, it is recommended that the values determined using the equivalent area method (Table 8) be used when needed. A graph showing creep compliance values at 100 seconds, 6.5% voids, and at -10°C is given in Figure 15 for purposes of comparing mixes. Note that the 07-123 material (20% RAP) would still have the lowest creep compliance of all six mix types even though 07-123 creep compliance was calculated using the equivalent area method.

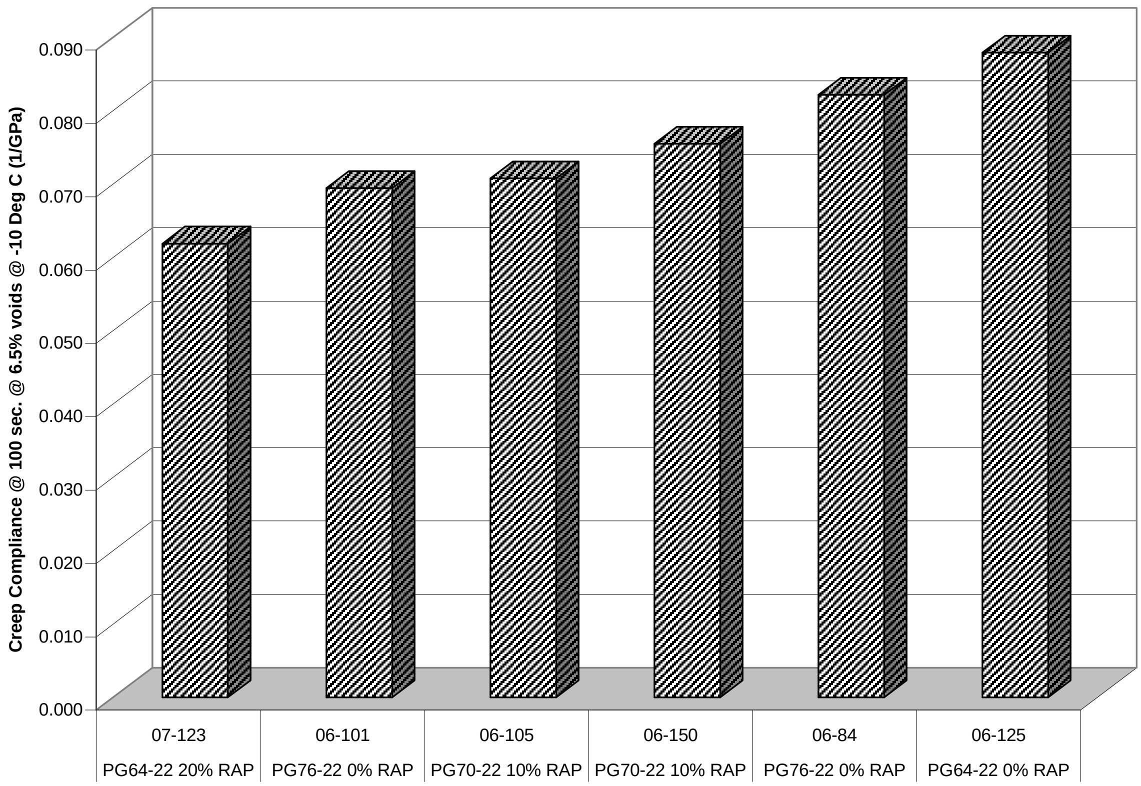

Figure 15: 100 Second Creep Compliance @ 6.5% Voids @ -10°C

Poisson's Ratio

Although not an input in the M-E PDG Thermal Cracking Module, Poisson's ratio is an Asphalt Materials Properties input in the M-E PDG and can be entered directly or estimated from other properties. Table 10 gives the Poisson's ratio values calculated using the procedure described in the Data Reduction section.

Table 10: Poisson's Ratio

Temp (Deg C)	07-123 6.5% voids	06-84 4% voids	06-84 6.5% voids	06-84 9% voids	06-101 4% voids	06-101 6.5% voids	06-101 9% voids
-20	0.210	0.279	0.245	0.224	0.242	0.240	0.178
-10	0.243	0.229	0.301	0.206	0.302	0.266	0.182
0	0.323	0.330	0.393	0.293	0.365	0.351	0.270
	06-105 6.5% voids	06-125 4% voids	06-125 6.5% voids	06-125 9% voids	06-150 4% voids	06-150 6.5% voids	06-150 9% voids
-20	0.246	0.306	0.223	0.212	0.295	0.243	0.216
-10	0.243	0.273	0.288	0.249	0.349	0.269	0.267
0	0.351	0.302	0.337	0.291	0.438	0.352	0.283

In general, the Poisson's ratio values in Table 10 increase with increasing temperature. However, there are four instances that do not follow this trend. Also, Poisson's ratio decreases with increasing % air voids at -20°C, but it does not always follow this trend at the higher temperatures.

Tensile Strength

All of the IDT strength testing as outlined in a previous section of this report was completed successfully. Summaries of the tensile strength results for the non-instrumented testing at -10°C, the instrumented testing at 21.1°C, the instrumented testing at 4.4°C, the instrumented testing at -10°C, and all testing at -10°C are given in Tables 11 – 15, respectively. More detailed tables are given in Appendix B.

Table 11: Non-instrumented Tensile Strength: -10°C

Mix ID	Number of Replicates	Average Air Voids (%)	S_t (psi)	SD* (psi)	CV** (%)	Equation 1 Correction (psi)
07-123	6	6.5	612	87.2	14.2	515
06-105	3	6.5	616	18.2	3.0	519
06-84	3	4.0	738	22.9	3.1	614
06-84	3	6.5	620	24.4	3.9	522
06-84	3	9.0	525	22.7	4.3	447
06-101	3	4.0	841	42.8	5.1	694
06-101	3	6.5	663	16.1	2.4	555
06-101	3	9.0	601	12.8	2.1	507
06-125	3	4.0	696	31.1	4.5	581
06-125	3	6.5	623	10.0	1.6	524
06-125	3	9.0	532	11.2	2.1	453
06-150	3	4.0	786	48.8	6.2	651
06-150	3	6.5	674	30.3	4.5	564
06-150	3	9.0	599	21.1	3.5	505

*Sample standard deviation
**Sample coefficient of variation

Table 11 shows the expected trend of tensile strength as a function of % air voids: the strength decreases with increasing voids. The strength values for mixes compacted to 6.5% voids are fairly consistent ranging from 612 to 674 psi. Mix 07-123 (BP1) shows a highly variable tensile strength which is not too surprising as it is the lowest quality mix with the highest percentage of RAP (20%). Also, remember that there were two rounds of creep testing on 07-123 which is why 6 specimens were tested for non-instrumented IDT strength. Also included in Table 11 are values calculated using Equation 1, the equation presented in the NCHRP 530 Report that purportedly corrects IDT strength test results to true tensile strength.

Table 12: Instrumented Tensile Strength: 21.1°C

Mix ID	No. Replicates	Average Air Voids (%)	S_t (psi)	SD (psi)	CV (%)
06-84	3	4.0	195	9.1	4.7
06-84	3	6.5	166	11.9	7.2
06-84	3	9.1	140	7.4	5.3
06-101	3	4.0	225	13.3	5.9
06-101	3	6.5	226	10.6	4.7
06-101	3	9.0	171	11.3	6.6
06-125	3	4.1	158	8.0	5.1
06-125	3	6.5	135	9.0	6.7
06-125	3	9.0	130	6.1	4.7
06-150	3	4.1	184	5.0	2.7
06-150	3	6.8	153	1.9	1.2
06-150	3	9.0	132	5.7	4.3

Table 12 shows one anomaly in that the 06-101 mix IDT strength did not vary between 4.0 and 6.5% air voids. This could be due to the fact that 06-101 uses a highly modified binder, PG76-22. However, this anomaly could also be due to variability among the replicates, as indicated by the statistics which show high CV values across all three levels of air voids.

Table 13: Instrumented Tensile Strength: 4.4°C

Mix ID	No. Replicates	Average Air Voids (%)	S_t (psi)	SD (psi)	CV (%)
06-84	3	4.0	460	18.8	4.1
06-84	3	6.5	419	23.2	5.5
06-84	3	9.0	341	3.0	0.9
06-101	3	4.0	543	27.0	5.0
06-101	3	6.4	492	22.6	4.6
06-101	3	9.0	401	28.5	7.1
06-125	3	4.1	465	5.8	1.2
06-125	3	6.4	380	18.0	4.7
06-125	3	9.0	335	3.9	1.2
06-150	3	4.1	520	21.9	4.2
06-150	3	6.8	438	16.5	3.8
06-150	3	9.0	388	17.0	4.4

Table 13 shows the expected trend of decreasing IDT strength with increasing voids. The 06-101 mix again shows consistently higher variability among the replicates of all mixes in Table 13 at all levels of air voids.

Table 14: Instrumented Tensile Strength: -10°C

Mix ID	No. Replicates	Average Air Voids (%)	S_t (psi)	SD (psi)	CV (%)
07-123	3	6.8	594*	59.6	10.0
06-105	3	6.5	571	35.2	6.2
06-84	3	4.1	697	19.2	2.8
06-84	3	6.5	618	46.7	7.6
06-84	3	9.0	551	58.0	10.5
06-101	3	4.0	773	15.4	2.0
06-101	3	6.5	625*	39.7	6.4
06-101	3	9.0	573	15.2	2.6
06-125	3	4.0	587*	36.1	6.1
06-125	3	6.5	509*	108.8	21.4
06-125	3	9.0	484*	37.1	7.7
06-150	3	4.0	780*	47.5	6.1
06-150	3	6.6	630*	20.0	3.2
06-150	3	9.0	550*	15.8	2.9

*Based on one or more instances of a maximum y-x differential occurring prior to the maximum load being reached

Of the instrumented IDT strength testing at three different temperatures, “first failure” as a result of maximum y-x differentials occurring prior to obtaining the maximum load was present only during the testing at -10°C. Of the 42 specimens represented in Table 14, 11 “failed” prior to the maximum load being reached. The amount of time that transpired between the maximum y-x differential and the maximum load ranged from 0.1 to 0.6 seconds. It should be noted that a data acquisition rate of ~20 Hz was depicted in the M-E PDG Appendix HH when describing the “first failure” due to a maximum y-x differential phenomenon. Therefore, while the data acquisition rate of 10 Hz as specified in T 322-07 for creep testing was used in this study, more accurate determinations of “first failure” may have been possible at higher acquisition rates.

Table 15: All Tensile Strength: -10°C

Mix ID	No. Replicates	Average Air Voids (%)	S_t (psi)	SD (psi)	CV (%)
07-123	9	6.6	606*	75.6	12.5
06-105	6	6.5	594	35.3	5.9
06-84	6	4.0	717	29.5	4.1
06-84	6	6.5	619	33.4	5.4
06-84	6	9.0	538	41.9	7.8
06-101	6	4.0	807	47.2	5.8
06-101	6	6.5	644*	34.3	5.3
06-101	6	9.0	587	19.6	3.3
06-125	6	4.0	641*	66.8	10.7
06-125	6	6.5	566*	93.4	16.5
06-125	6	9.0	508*	36.0	7.1
06-150	6	4.0	783*	43.2	5.5
06-150	6	6.5	652*	33.3	5.1
06-150	6	9.0	575*	31.3	5.4

*Based on one or more instances of a maximum y-x differential occurring prior to the maximum load being reached

Figures 16 through 21 graphically depict the results of the IDT strength testing performed in this study. Table 15 combines the results of all IDT strength testing performed at -10°C. The expected trend of decreasing strength with increasing voids is present. Statistically speaking, data in Table 15 is probably more accurate than Tables 11 and 14 due to the increased number of replicate specimens. For comparison purposes one could look at information reported in NCHRP 530 and ASTM D 6931-07 (*11*) where Anderson and McGennis (*12*) reported a CV value of 7% for IDT strength testing of 3 replicate 150 mm diameter specimens at -10°C using a load rate of 12.5 mm/min, and tested at two levels of % voids: 6.5 and 7.5%.

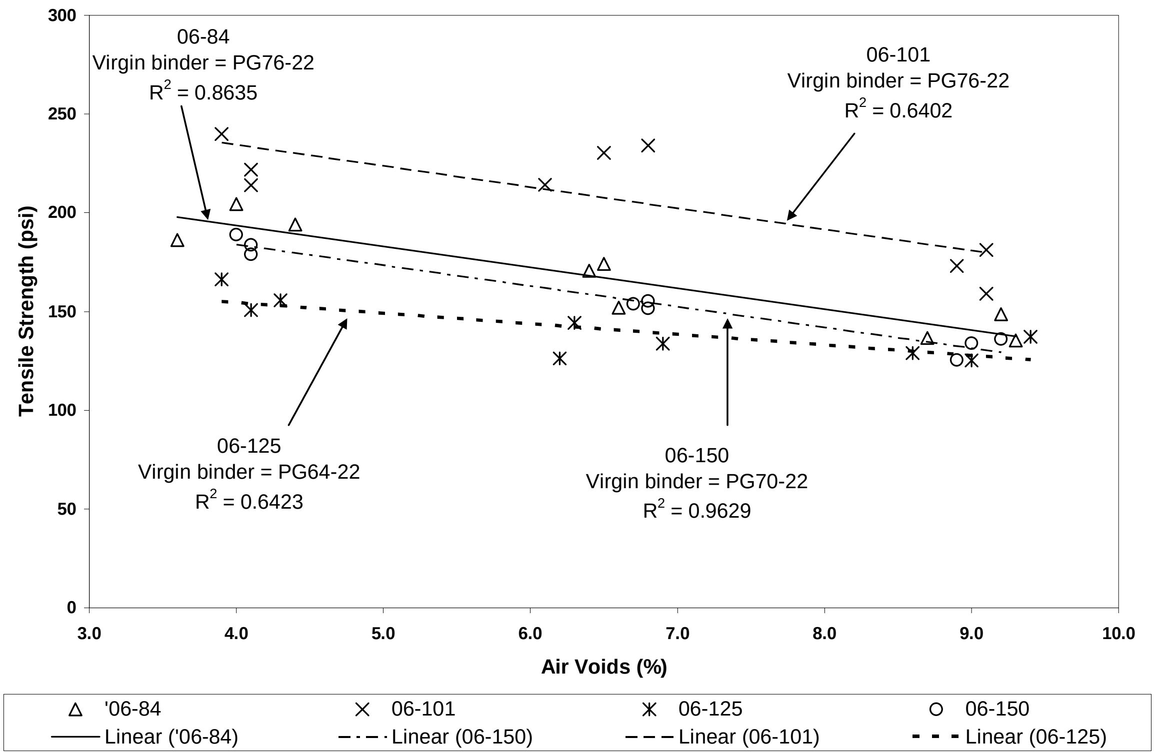

Figure 16: IDT Strength vs. % Air Voids: 4 Mixes: 21.1°C

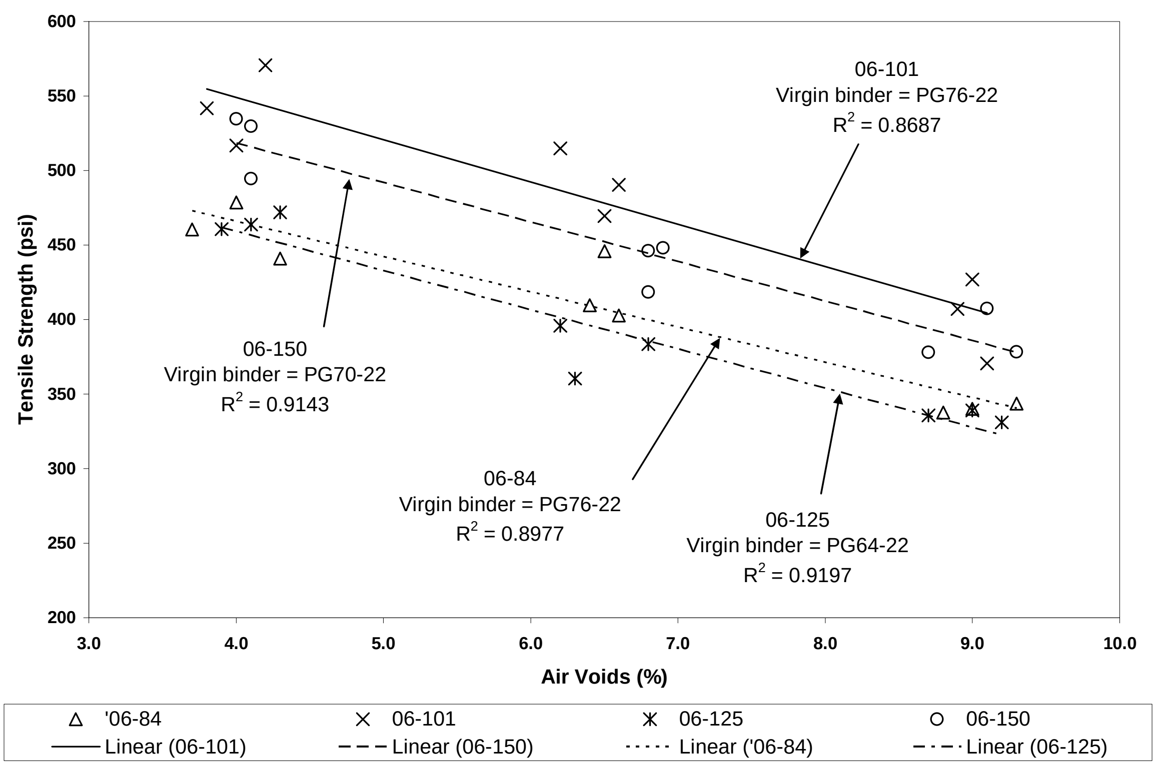

Figure 17: IDT Strength vs % Air Voids: 4 Mixes: 4.4°C

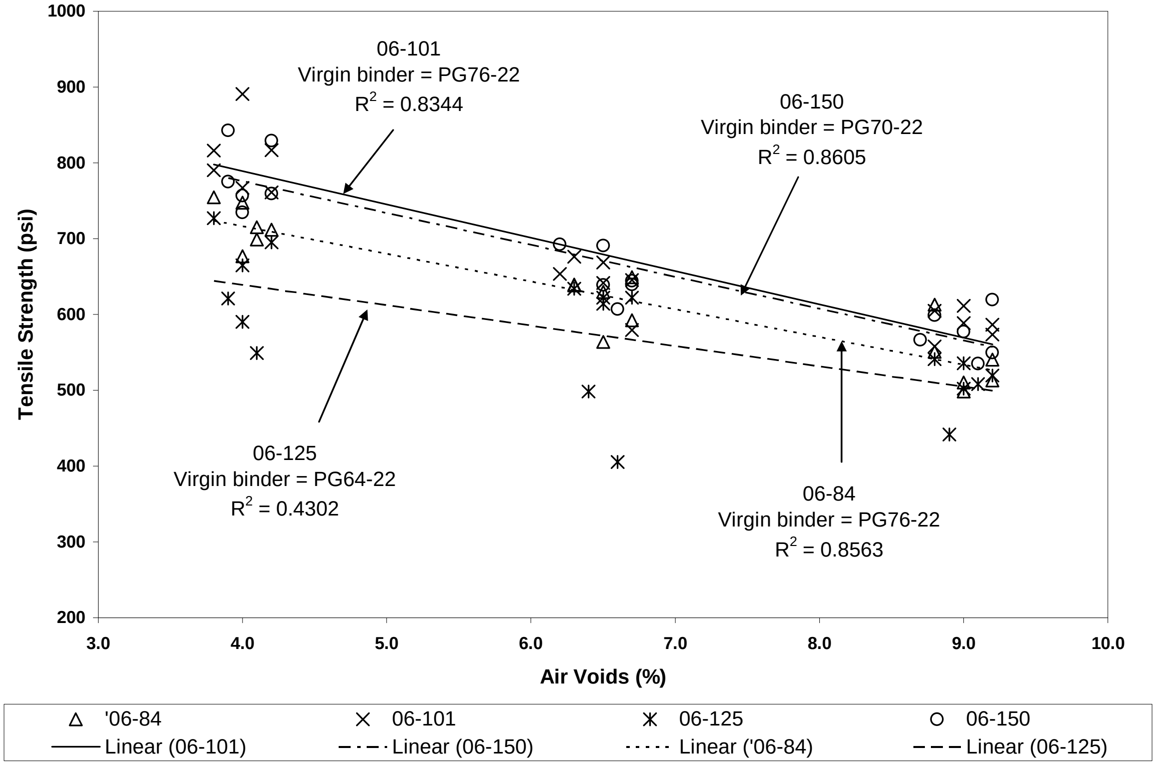

Figure 18: IDT Strength vs % Air Voids: 4 Mixes: -10°C

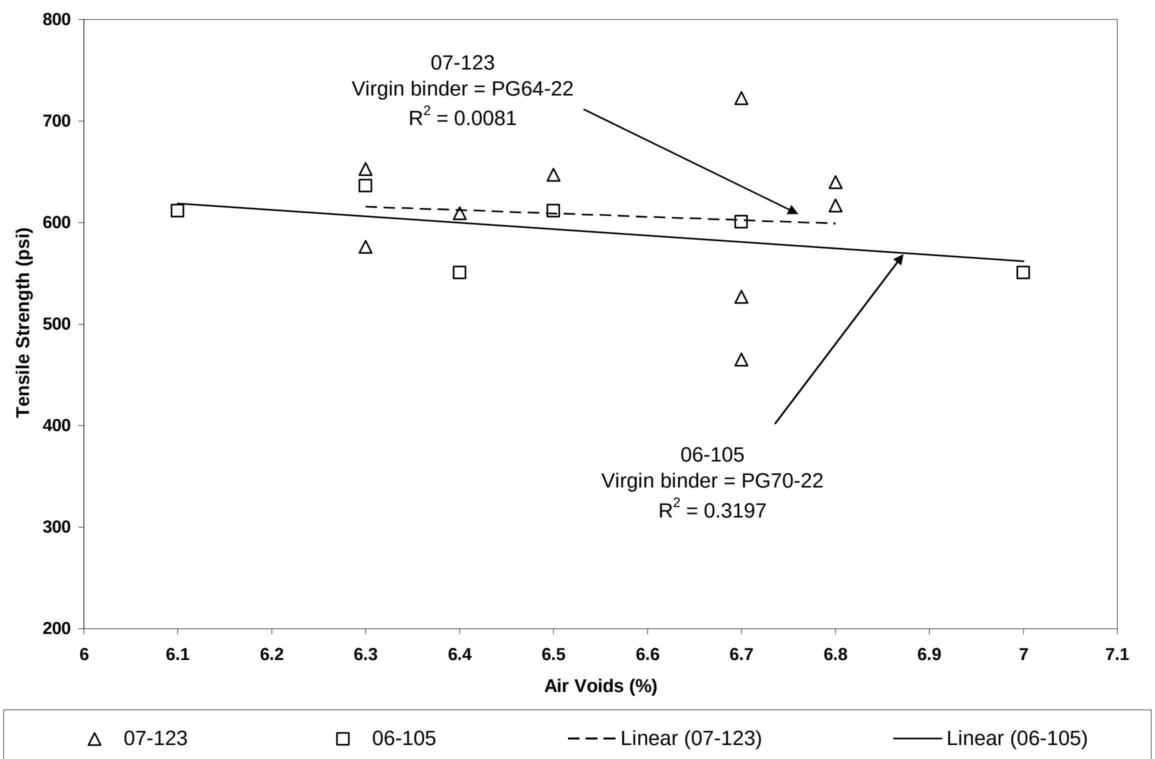

Figure 19: IDT Strength vs % Air Voids: 2 Mixes: -10°C

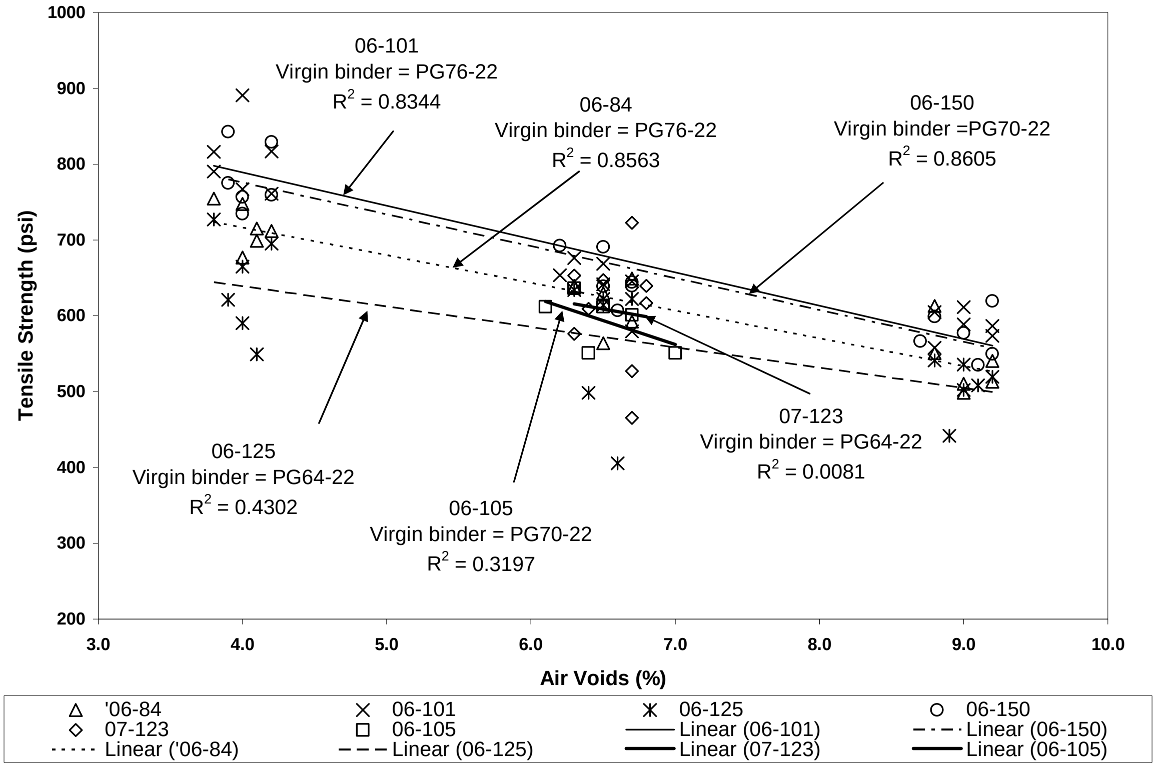

Figure 20: IDT Strength vs % Air Voids: All Mixes: -10°C

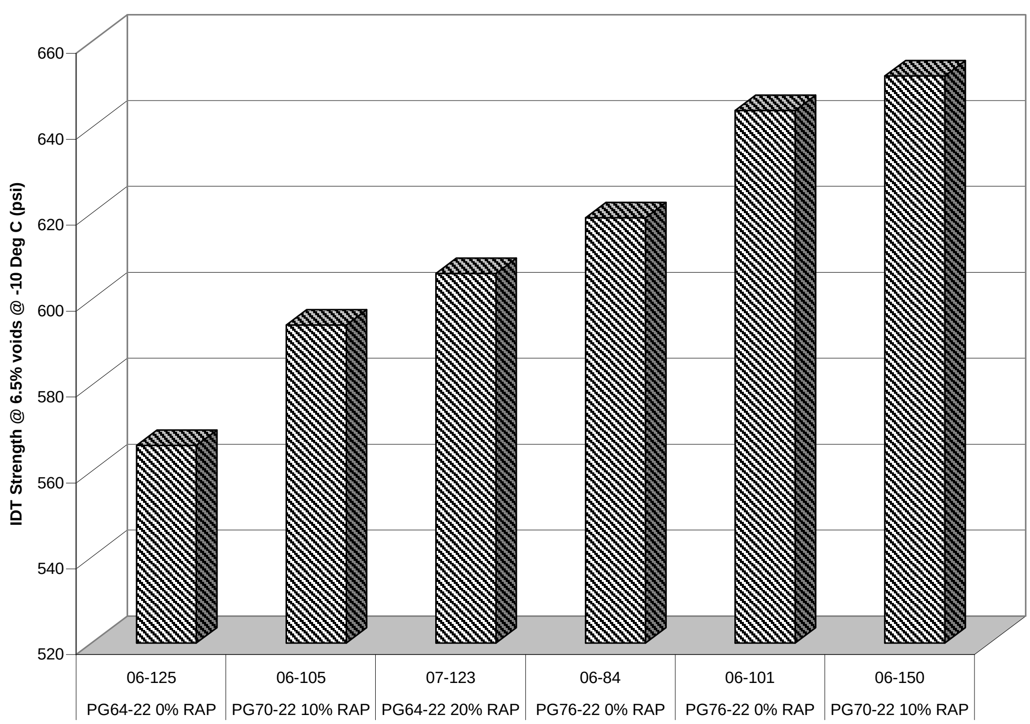

Figure 21: IDT Strength: All Mixes @ 6.5% Voids @ -10°C

Tensile Failure Strain

The tensile failure strain results determined using horizontal deformations recorded during the instrumented IDT strength testing are given in Tables 16 – 18. The results are expressed in microstrain based on a 38 mm gauge length.

Table 16: Tensile Failure Strain: 21.1°C

ID	Specimen No.	Voids (%)	Average Voids	Failure Strain (microstrain) North	South	Average
06-84	13	4.0		96	178	
06-84	20	4.4	4.0	172	163	180
06-84	21	3.6		267	203	
06-84	16	6.4		176	80	
06-84	19	6.5	6.5	105	211	153
06-84	20	6.6		142	203	
06-84	2	9.3		89	172	
06-84	13	9.2	9.1	247	228	180
06-84	28	8.7		130	211	
06-101	2	3.9		80	211	
06-101	6	4.1	4.0	189	133	150
06-101	22	4.1		118	170	
06-101	18	6.1		285	160	
06-101	20	6.8	6.5	90	92	129
06-101	27	6.5		52	95	
06-101	2	8.9		128	179	
06-101	21	9.1	9.0	145	268	183
06-101	28	9.1		222	154	
06-125	14	3.9		162	168	
06-125	25	4.1	4.1	181	258	193
06-125	26	4.3		151	238	
06-125	10	6.2		286	308	
06-125	19	6.9	6.5	185	199	227
06-125	29	6.3		168	213	
06-125	5	9.4		80	176	
06-125	16	9.0	9.0	287	195	180
06-125	28	8.6		197	149	
06-150	7	4.1		159	233	
06-150	14	4.1	4.1	157	213	179
06-150	17	4.0		179	133	
06-150	23	6.8		195	264	
06-150	8	6.8	6.8	213	240	228
06-150	21	6.7		177	283	
06-150	18	9.0		147	310	
06-150	25	8.9	9.0	225	346	266
06-150	24	9.2		225	343	

At 21.1°C (70°F), all failure strains coincided with the maximum load. Of particular interest is the lack of an obvious trend relating failure strain to % air voids for each mix.

Table 17: Tensile Failure Strain: 4.4°C

ID	Specimen No.	Voids (%)	Average Voids	Failure Strain (microstrain) North	South	Average
06-84	6	4.3		60	42	
06-84	8	3.7	4.0	79	46	63
06-84	24	4.0		104	50	
06-84	2	6.6		90	32	
06-84	9	6.4	6.5	29	65	54
06-84	18	6.5		39	69	
06-84	1	9.3		51	86	
06-84	23	9.0	9.0	37	104	66
06-84	25	8.8		78	37	
06-101	18	4.2		53	53	
06-101	20	4.0	4.0	108	45	69
06-101	23	3.8		22	131	
06-101	1	6.6		29	120	
06-101	14	6.2	6.4	79	66	64
06-101	25	6.5		14	77	
06-101	7	9.0		48	45	
06-101	22	8.9	9.0	31	78	52
06-101	25	9.1		19	91	
06-125	6	3.9		41	69	
06-125	10	4.1	4.1	49	39	51
06-125	13	4.3		64	47	
06-125	13	6.8		23	95	
06-125	26	6.3	6.4	30	65	50
06-125	28	6.2		66	22	
06-125	9	9.2		54	43	
06-125	11	9.0	9.0	53	40	48
06-125	20	8.7		65	32	
06-150	4	4.1		41	111	
06-150	19	4.1	4.1	64	105	85
06-150	20	4.0		43	146	
06-150	2	6.8		33	105	
06-150	7	6.8	6.8	85	43	61
06-150	12	6.9		32	70	
06-150	8	9.3		71	47	
06-150	9	9.1	9.0	65	38	58
06-150	13	8.7		89	35	

At 4.4°C (40°F), all failure strains again coincided with the maximum load. Again there is the lack of a definite trend relating failure strain to % air voids for each mix although for all except 06-84, the average failure strain for all six faces decreases with increasing % air voids. Once again the open-graded nature of 06-84, the SMA mix, may contribute to variability enough to cause the non-conformist trend.

Table 18: Tensile Failure Strain: -10°C

ID	Specimen No.	Voids (%)	Average Voids	Failure Strain (microstrain) At Maximum Load North	South	Average	At (Y - X) peak North	South	Average
07-123	16	6.8		15	14		15	14	
07-123	17	6.7	6.8	18	5	12	18	6*	12
07-123	18	6.8		6	15		6	15	
06-105	3	6.1		22	20				
06-105	8	7.0	6.5	10	15	18			
06-105	9	6.4		2	36				
06-84	4	4.0		15	24				
06-84	7	4.1	4.1	13	18	18			
06-84	23	4.1		8	28				
06-84	12	6.7		41	13				
06-84	15	6.5	6.5	17	22	27			
06-84	23	6.3		8	59				
06-84	11	9.2		30	13				
06-84	26	9.0	9.0	26	17	24			
06-84	27	8.8		11	47				
06-101	1	3.8		10	17				
06-101	3	4.2	4.0	9	25	16			
06-101	13	4.0		5	31				
06-101	8	6.7		1	52		4*	52	
06-101	16	6.5	6.5	11	16	17	11	16	18
06-101	26	6.2		7	17		7	17	
06-101	8	9.0		30	8				
06-101	11	9.2	9.0	11	37	22			
06-101	26	8.8		22	23				
06-125	4	3.9		25	20		25	20	
06-125	5	4.0	4.0	5	28	18	6*	28	18
06-125	8	4.1		4	25		4*	25	
06-125	2	6.4		1	42		2*	42	
06-125	5	6.6	6.5	1	35	19	3*	35	20
06-125	25	6.5		14	23		14	23	
06-125	2	9.1		8	26		8	26	
06-125	10	9.0	9.0	6	32	18	6*	32	18
06-125	12	8.9		2	31		2*	31	
06-150	10	4.2		13	22		13	22	
06-150	13	4.0	4.0	6	31	17	6*	31	17
06-150	26	3.9		12	18		12	18	
06-150	5	6.6		5	21		5	21	
06-150	13	6.5	6.6	6	28	15	6	28	15
06-150	14	6.7		20	11		20	11*	
06-150	5	9.1		6	33		7*	33	
06-150	6	8.7	9.0	21	16	19	21	16	19
06-150	17	9.2		4	31		4	31	

*Indicates an occurrence of first failure as a result of the peak y-x differential occurring prior to the maximum load being reached

At -10°C, only the 06-105 and the 06-84 mixes did not experience any peak y-x differential occurrences prior to the maximum load being reached. Mix 06-125 experienced the most "first failures" by peak y-x differential in that, for each level of air voids, two of the six observations were peak y-x differentials. Of the eight cases where means were calculated for both sets of failure strain (at the maximum load and at the peak y-x differential), only 06-101 at 6.5% voids and 06-125 at 6.5% voids resulted in slightly different mean values at the reporting precision selected. Once again, there is no apparent trend between failure strain and % air voids within a mix. More detailed tables are included in Appendix B.

Creep Compliance versus IDT Strength

Although extensive regression analyses could not be performed due to a lack of binder/mixture properties data, a simple correlation between creep compliance and IDT strength does exist and is shown in Figure 22.

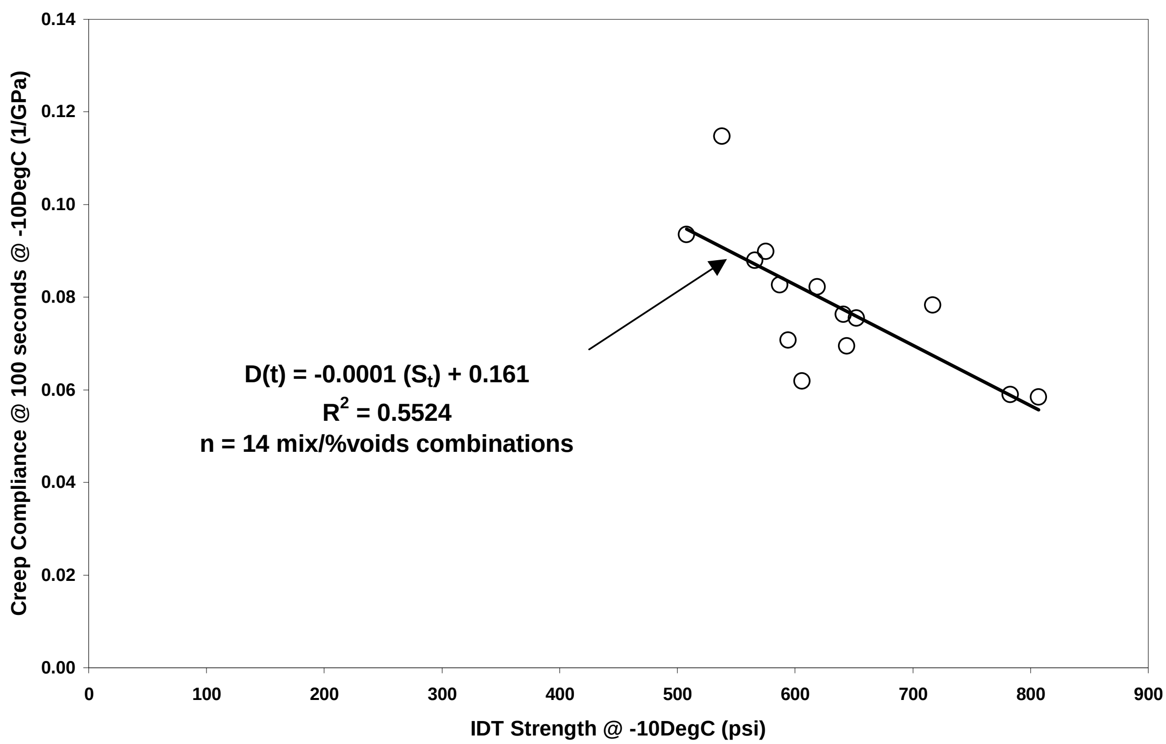

Figure 22: 100 Second Creep Compliance vs IDT Strength: -10°C

CONCLUSIONS

Expected trends such as increasing creep compliance and decreasing tensile strength with increasing % air voids and/or temperature were confirmed for all six mixes. And, there is an inverse relationship between creep compliance and IDT strength. However, Poisson's ratio did not always follow a definitive trend relative to % air voids or temperature. Also, tensile failure strain did not exhibit a consistent trend relative to % air voids but it did decrease with decreasing temperature in all cases.

One could conclude that the presence of recycled asphalt pavement (RAP) in a mix tends to decrease the creep compliance and increase the tensile strength compared to a mix without RAP but with the same virgin binder grade, everything else being somewhat equal. This is shown in Figures 15 and 21 by comparing 07-123 (PG64-22, 20% RAP) and 06-125 (PG64-22, 0% RAP). This conclusion is based on the assumption that the binder in the RAP is harder than the virgin binder, thereby increasing the viscosity of the blend. However, the conclusion may not hold if the RAP binder, although age-hardened, is actually softer than the virgin binder.

Figures 15 and 21 also indicate, though, that a clear trend cannot be determined due to the lack of mixes that could be compared in the same manner as 07-123 and 06-125. It does make sense that 06-125 (PG64-22 binder) had the lowest IDT and the greatest creep compliance. Beyond that, the combined influence of RAP and higher PG grades is indistinct because the effect of RAP on the blended binder viscosity characteristics is dependent on many factors.

The Marshall type mix, 07-123 (BP-1) and the Stone Matrix Asphalt (SMA) mix, 06-84, presented the most challenges in the IDT testing. 07-123 turned out to be the stiffest or least compliant mix of the six tested. It also produced highly variable tensile strength results. It is assumed that the non-uniform void distribution of the 06-84 mix played a part in producing a round of problematic creep compliance tests in which the specimens prepared at 4% air voids were more compliant or less stiff than the specimens prepared at 6.5%.

Although not related to the objectives of the work, it is clear that there still needs to be work done on the test method, T 322-07. More detail is required in regard to the IDT creep loading procedure and reducing the raw creep compliance data.

RECOMMENDATIONS

More work is needed to better understand the effects that recycled materials have on the binder/mix properties as they relate to creep compliance and tensile strength. MoDOT has recently increased the allowable percentage of RAP and also allows the usage of recycled asphalt shingles (RAS) in HMA. The binder in RAP and RAS is usually much stiffer than the virgin binder and this poses challenges not only to the mix designer but the pavement designer as well. A fuller understanding of the effects of RAP and RAS in HMA would require an experimental program to be performed in the laboratory so that the various factors could be controlled and/or monitored better than if the mixes were plant-produced.

In the draft final version of the Recommended Practice for Local Calibration of the M-E Pavement Design Guide (*13*), it is recommended that a minimum of 25 pavement test sections be analyzed for non-load related cracking; e.g. thermal cracking. It is also suggested that measured distress data for each pavement section cover at least 10 years of service. Thus, the combination of 25 pavement sections and 10 years of data per section may not correspond well with the plant-produced mixtures that were investigated in this study; i.e. RAP and SMA mixtures are relatively new and there may not be sufficient pavement sections available in Missouri to produce a reliable calibration – validation of the M-E PDG thermal cracking distress models. An alternative to using plant-produced mixes would be to obtain cores from the selected pavement sections and perform IDT creep/strength tests (along with other material characterization tests) on the cores, similar to the work that was done in the state of Montana (*14*).

IDT creep/strength test data is not only used for calibration – validation purposes, but becomes part of an “input library” for the M-E PDG. As new mix types are adopted by MoDOT, the thermal cracking parameters of creep compliance, tensile strength, and tensile failure strain should, at some point, be determined. MoDOT could perform a further refinement of the thermal cracking distress model parameters once a sufficient number of new mixes have accumulated.

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APPENDIX A: CREEP COMPLIANCE

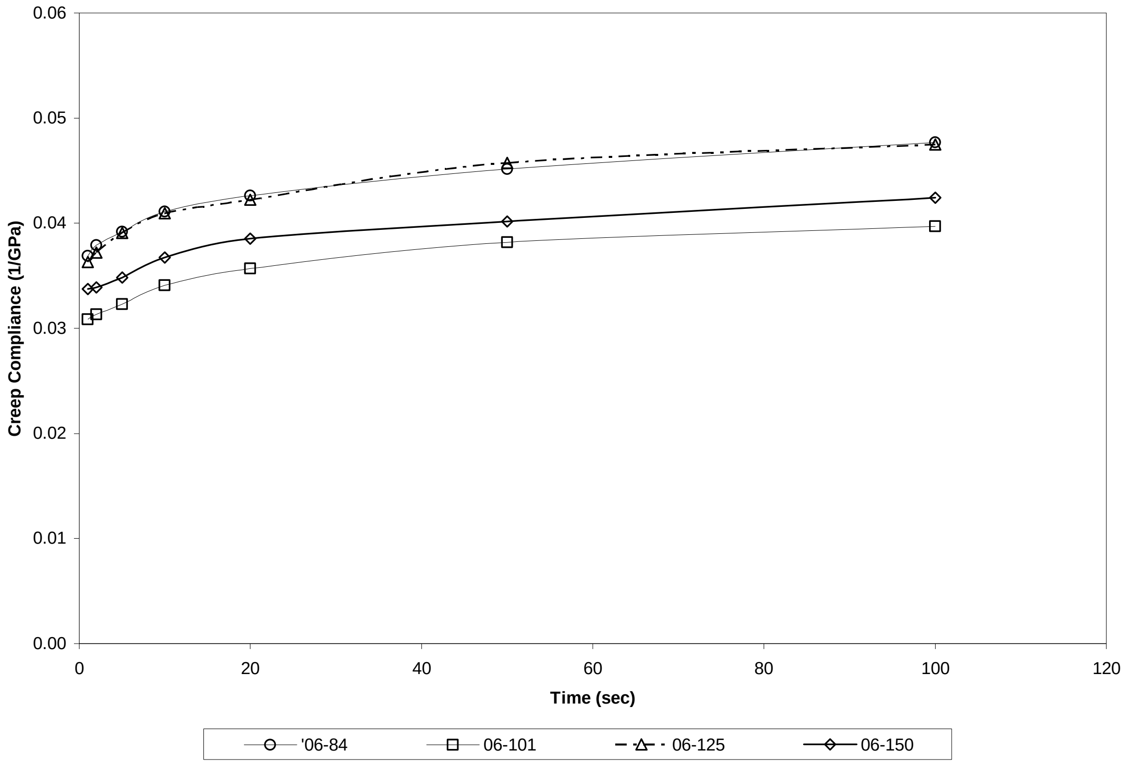

Figure A-23: 4 Mixes @ 4% Voids & -20°C

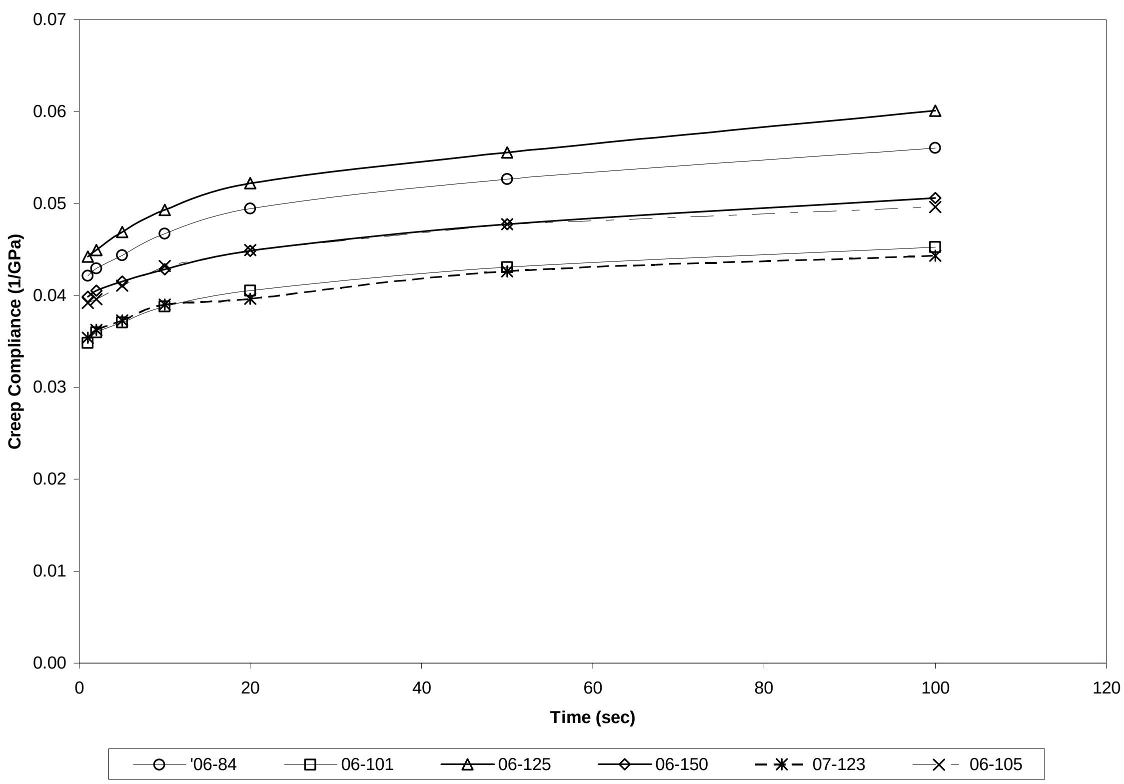

Figure A-24: 6 Mixes @ 6.5% Voids & -20°C

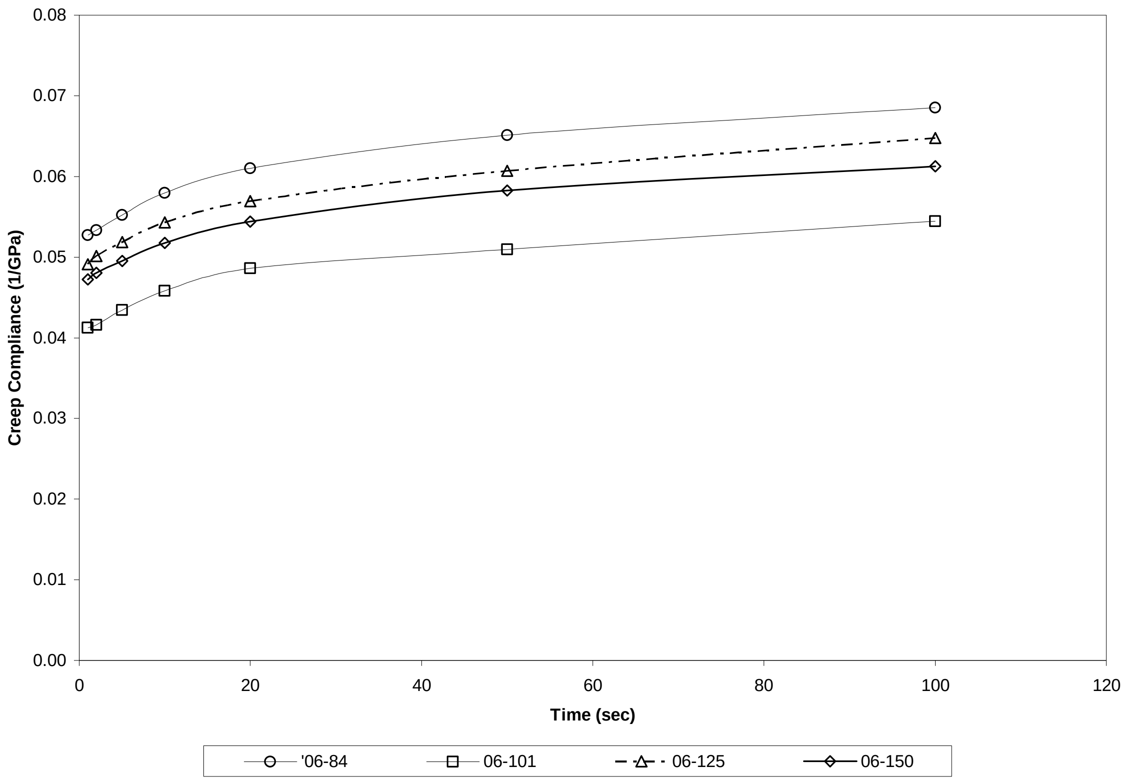

Figure A-25: 4 Mixes @ 9% Voids & -20°C

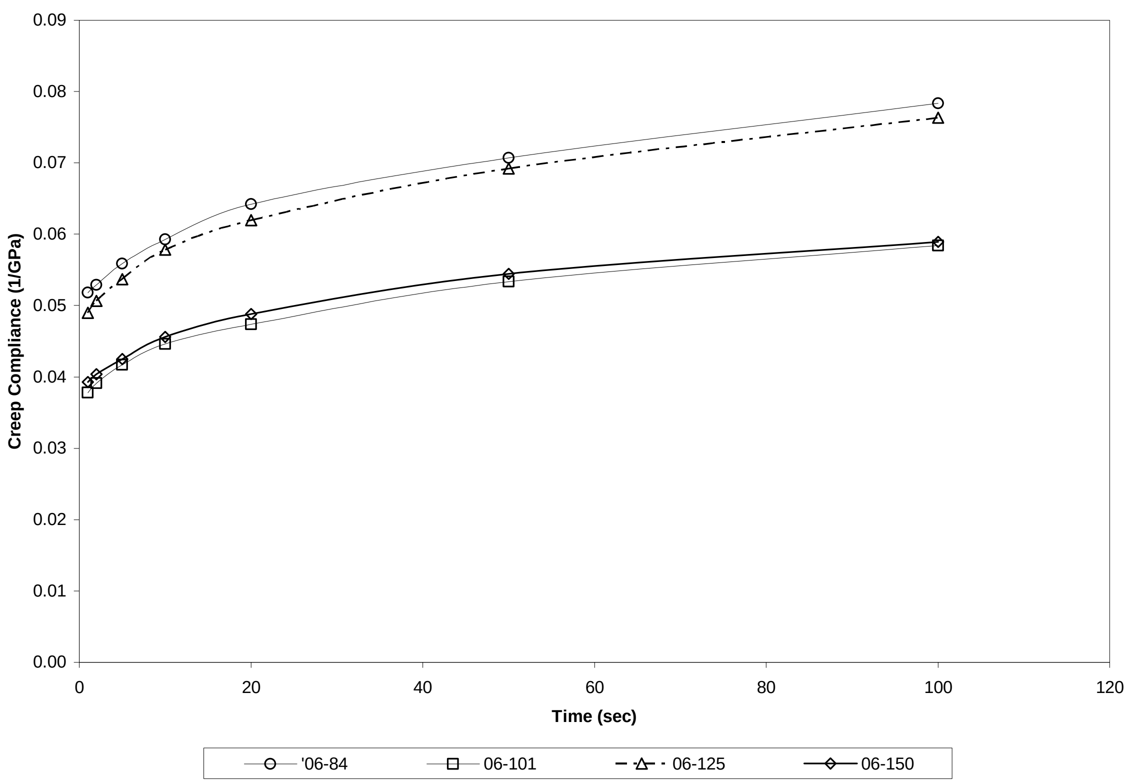

Figure A-26: 4 Mixes @ 4% Voids & -10°C

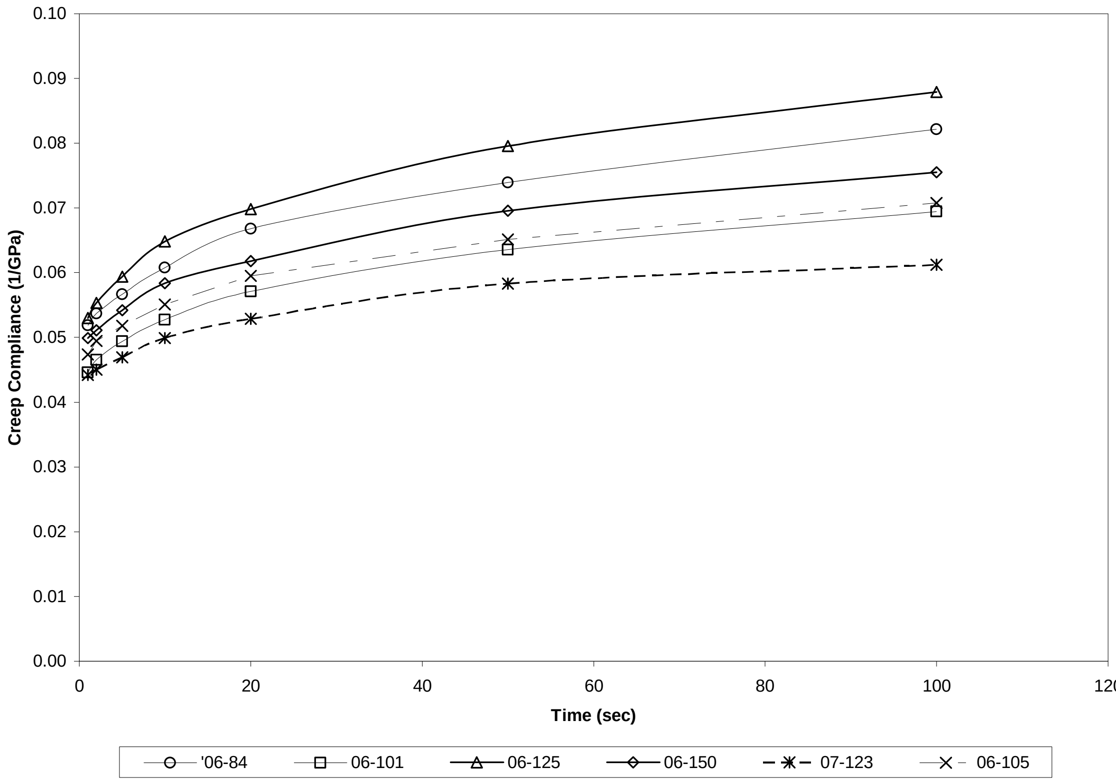

Figure A-27: 6 Mixes @ 6.5% Voids & -10°C

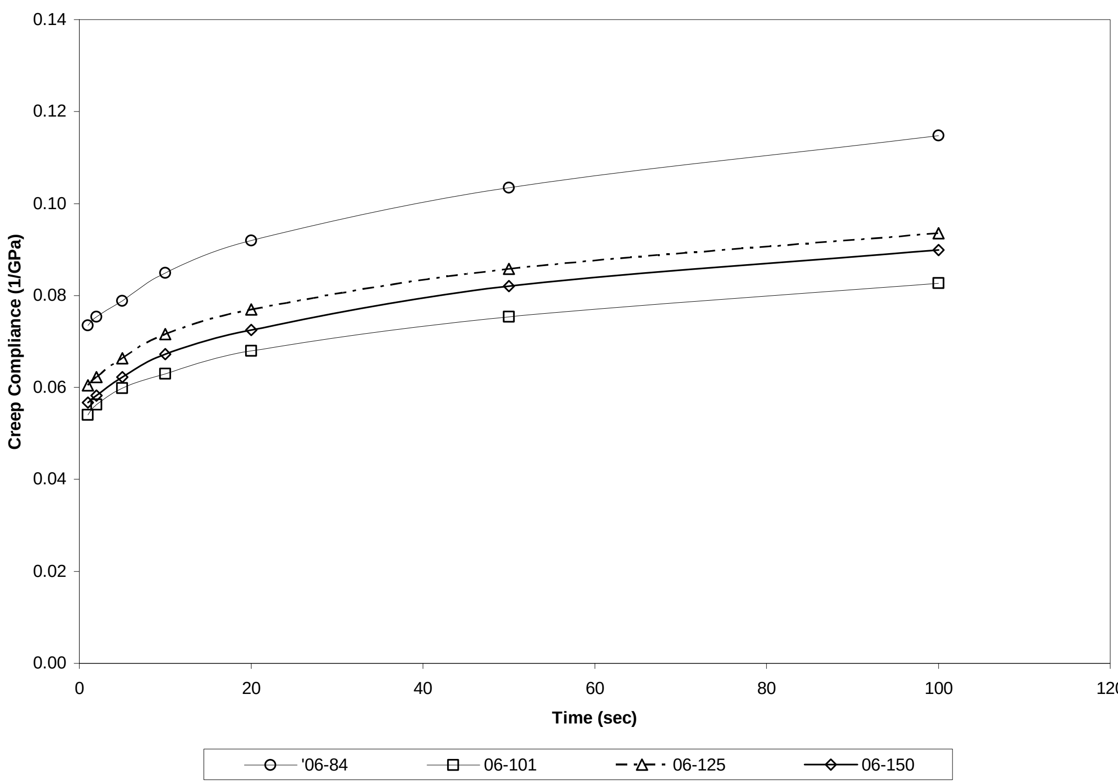

Figure A-28: 4 Mixes @ 9% Voids & -10°C

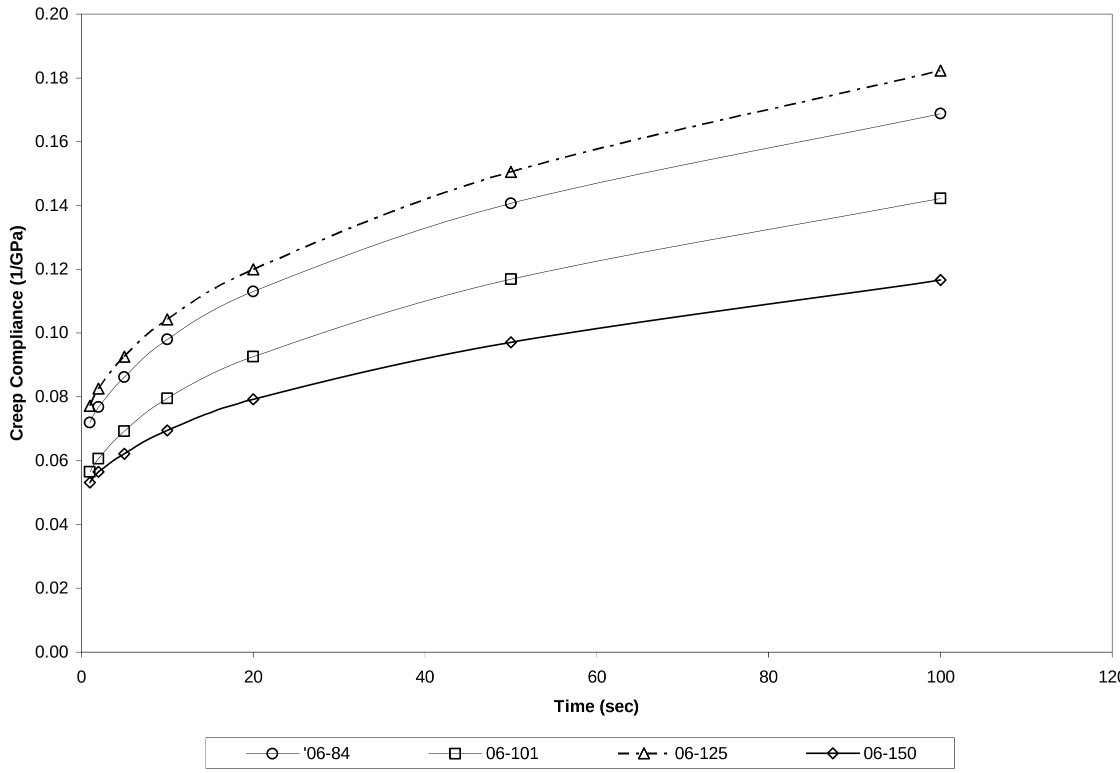

Figure A-29: 4 Mixes @ 4% Voids & 0°C

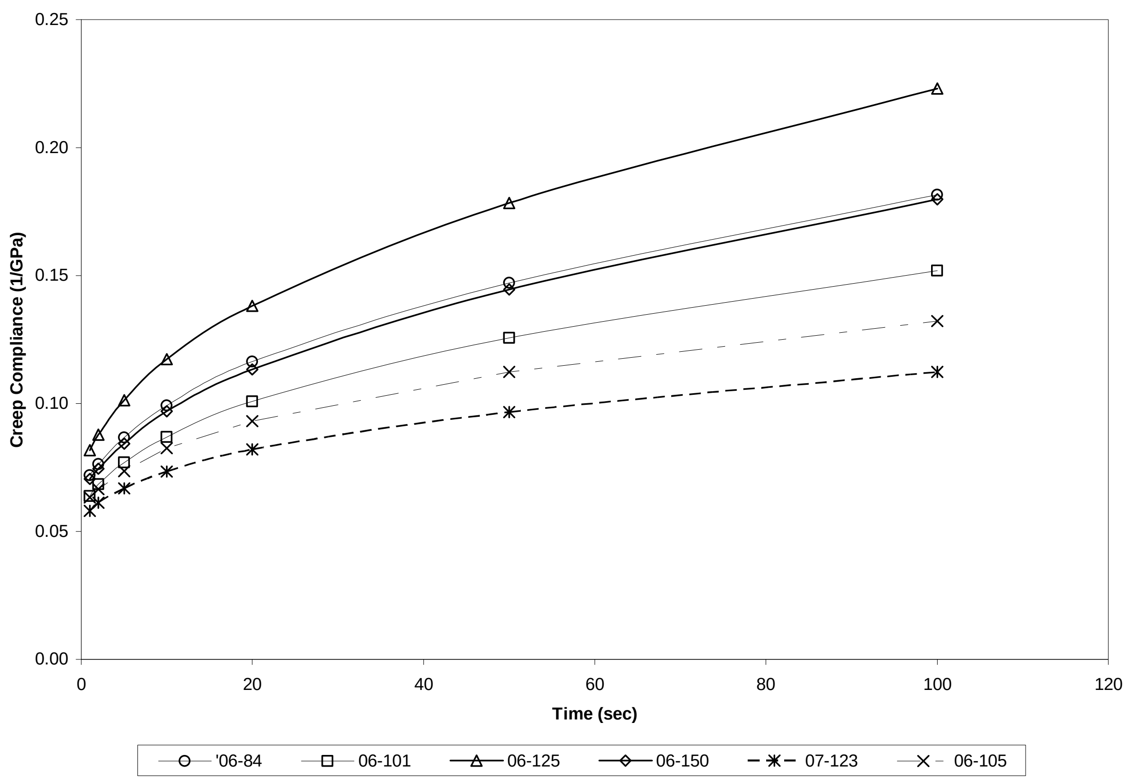

Figure A-30: 6 Mixes @ 6.5% Voids & 0°C

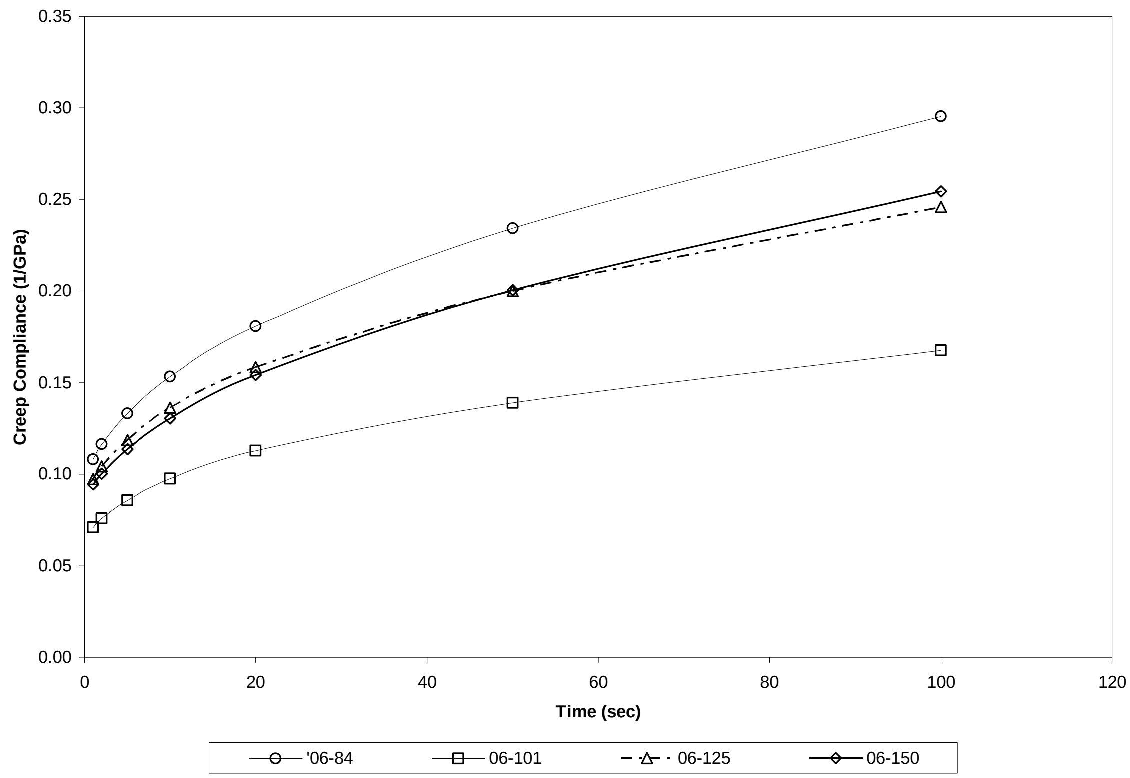

Figure A-31: 4 Mixes @ 9% Voids & 0°C

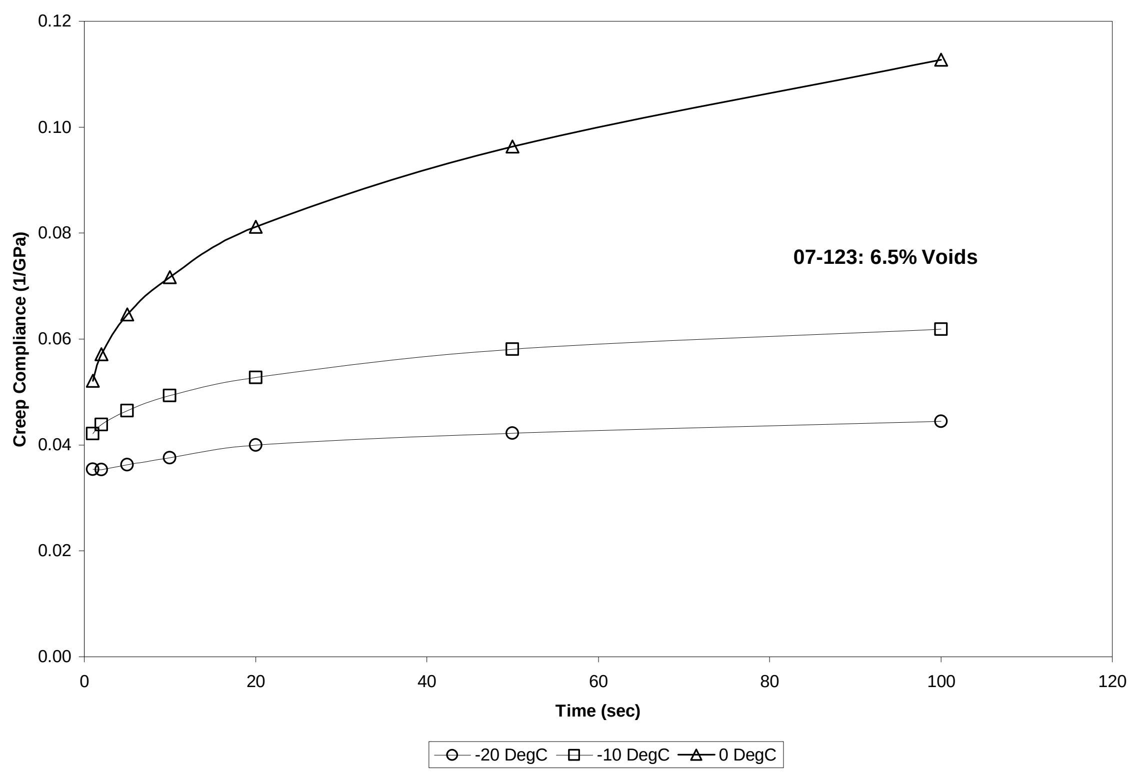

Figure A-32: 07-123 Using Equivalent Area Method

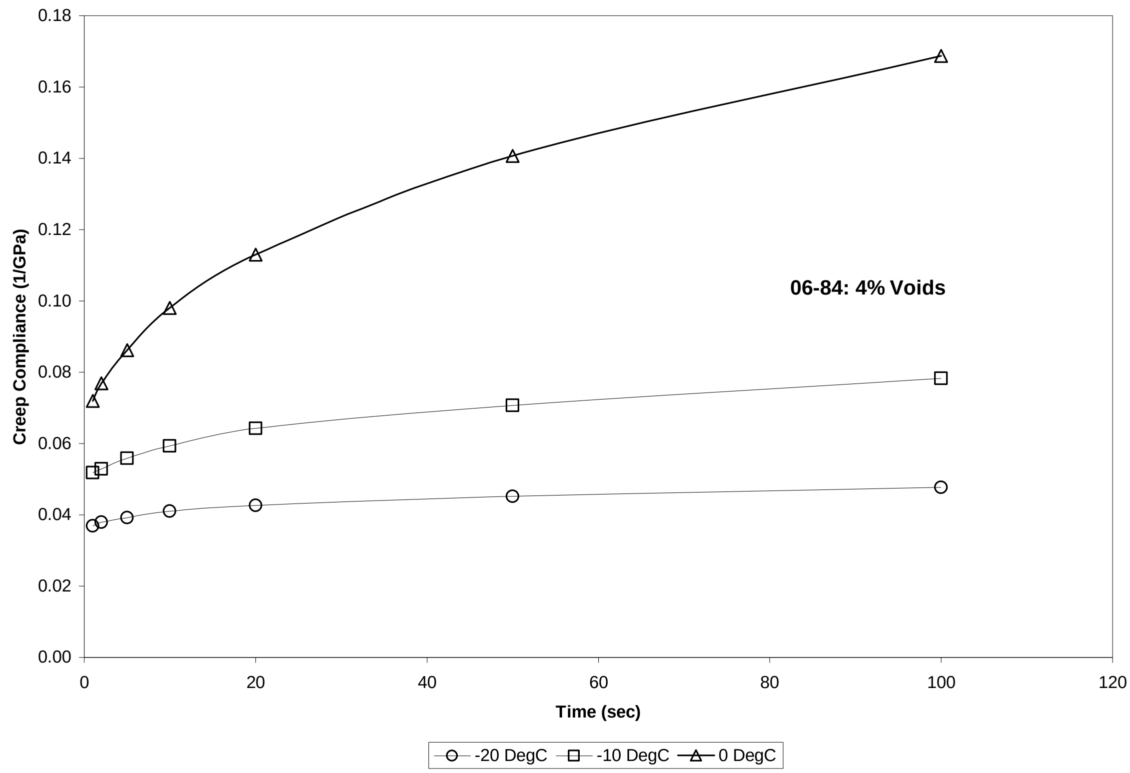

Figure A-33: 06-84 @ 4% Voids: Round 2

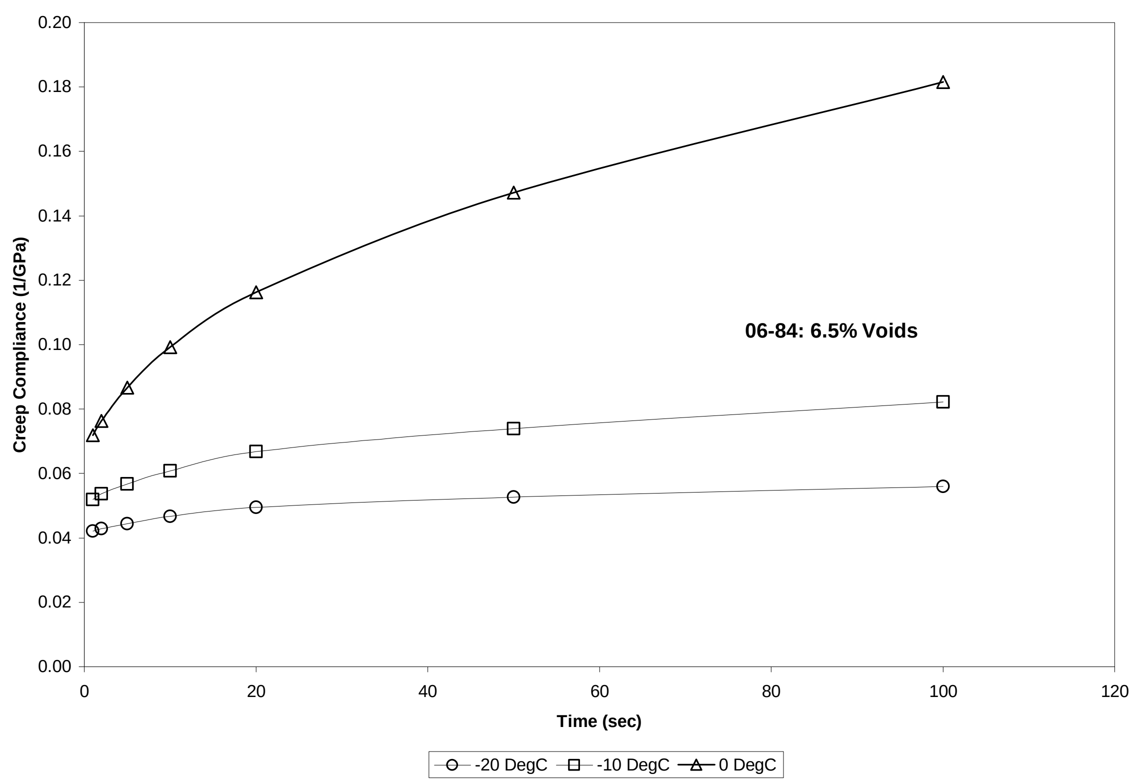

Figure A-34: 06-84 @ 6.5% Voids: Round 2

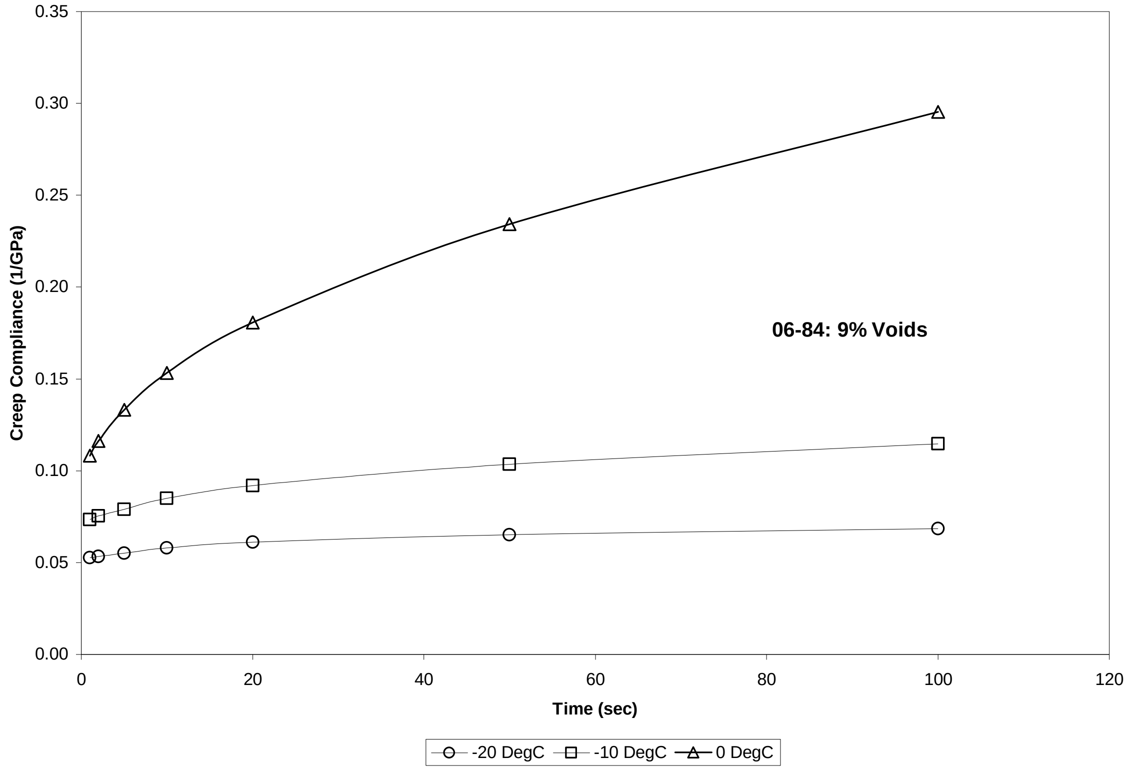

Figure A-35: 06-84 @ 9% Voids: Round 2

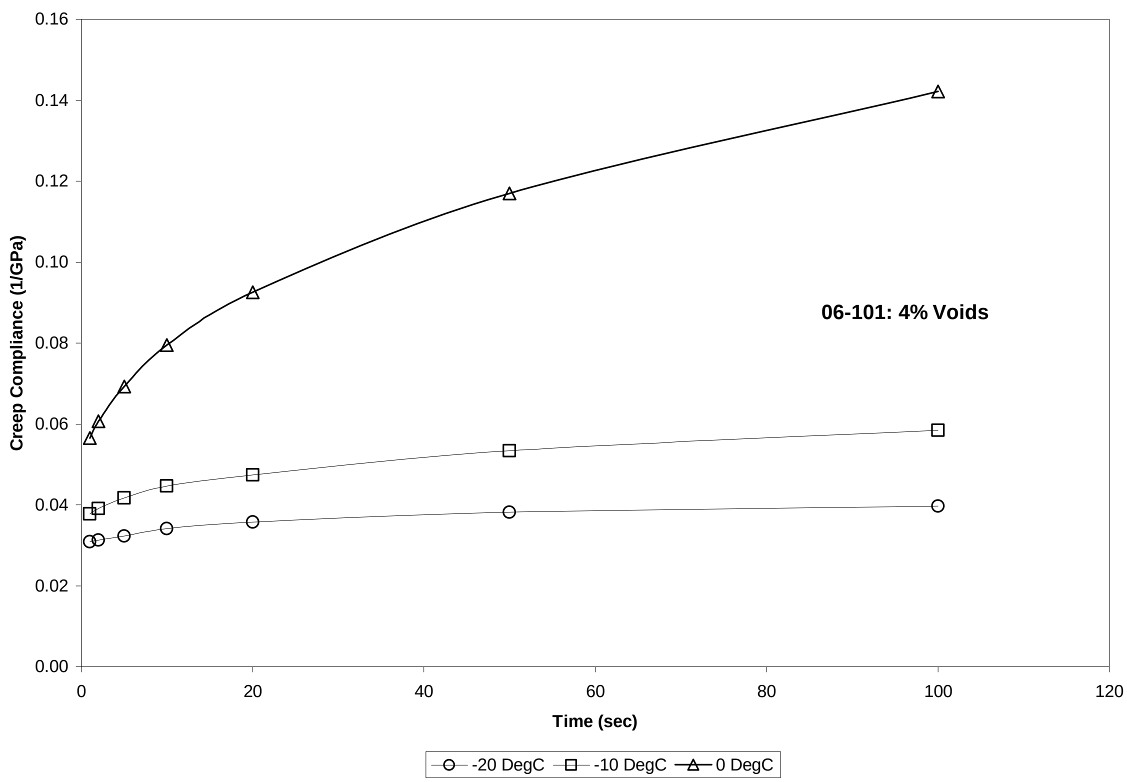

Figure A-36: 06-101 @ 4% Voids

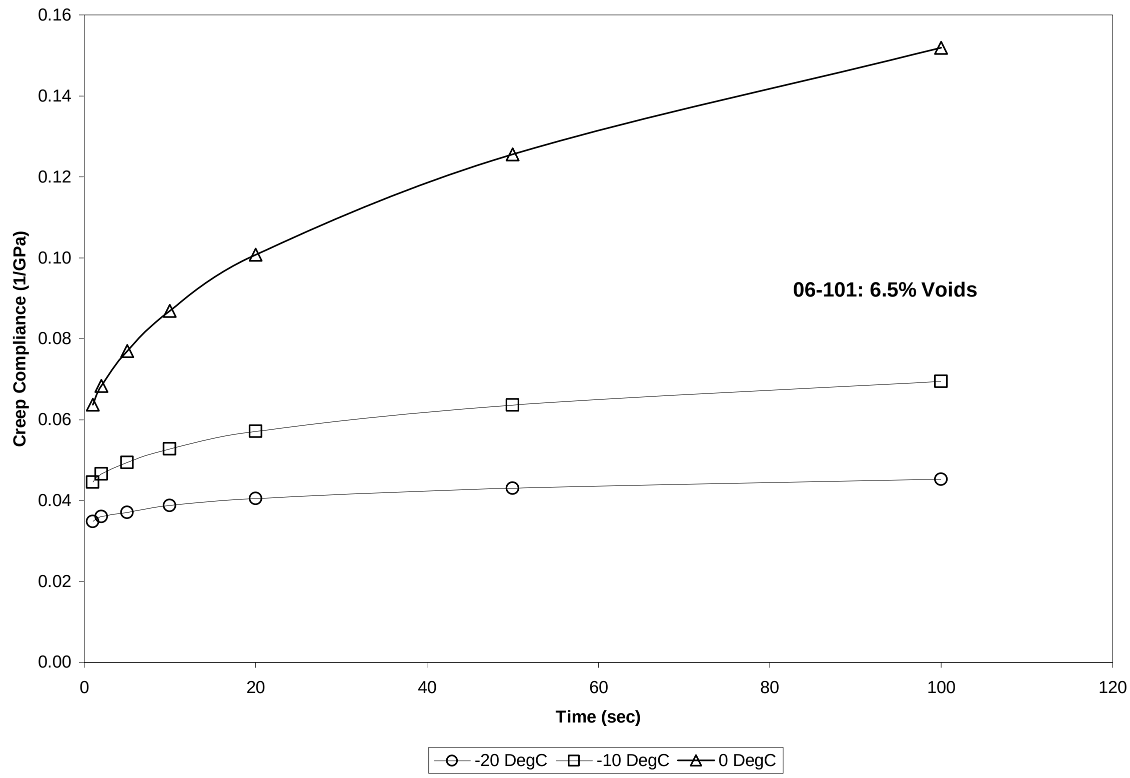

Figure A-37: 06-101 @ 6.5% Voids

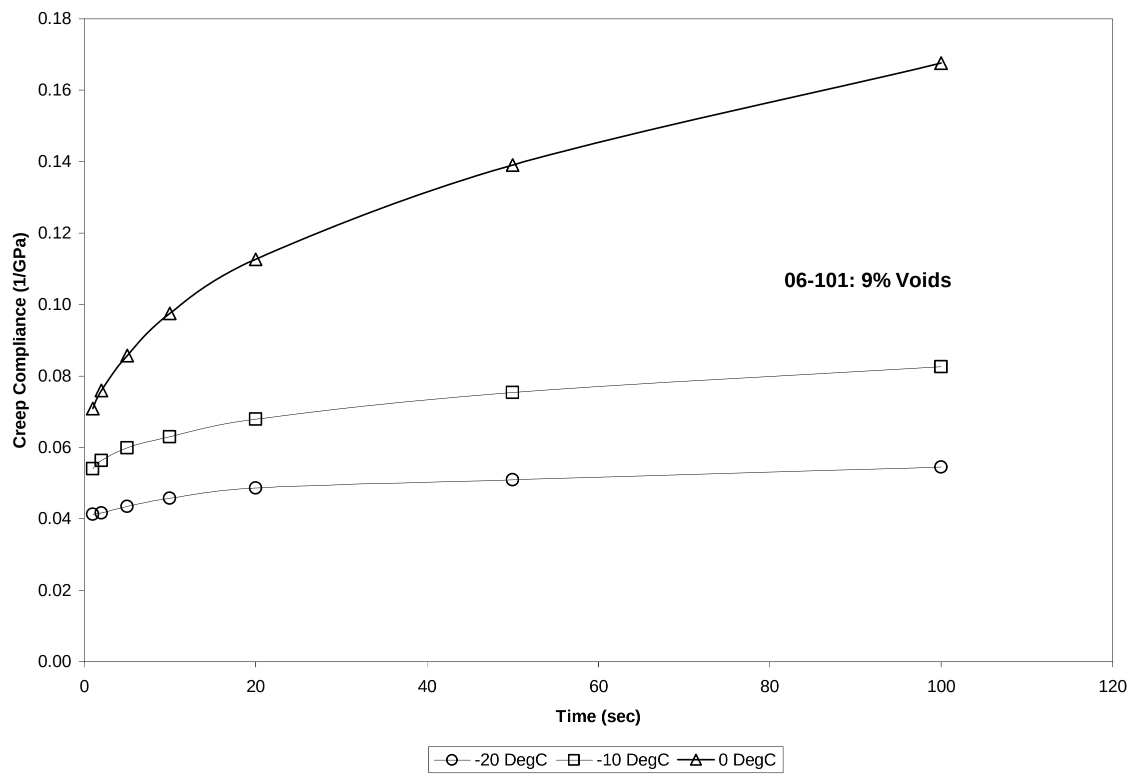

Figure A-38: 06-101 @ 9% Voids

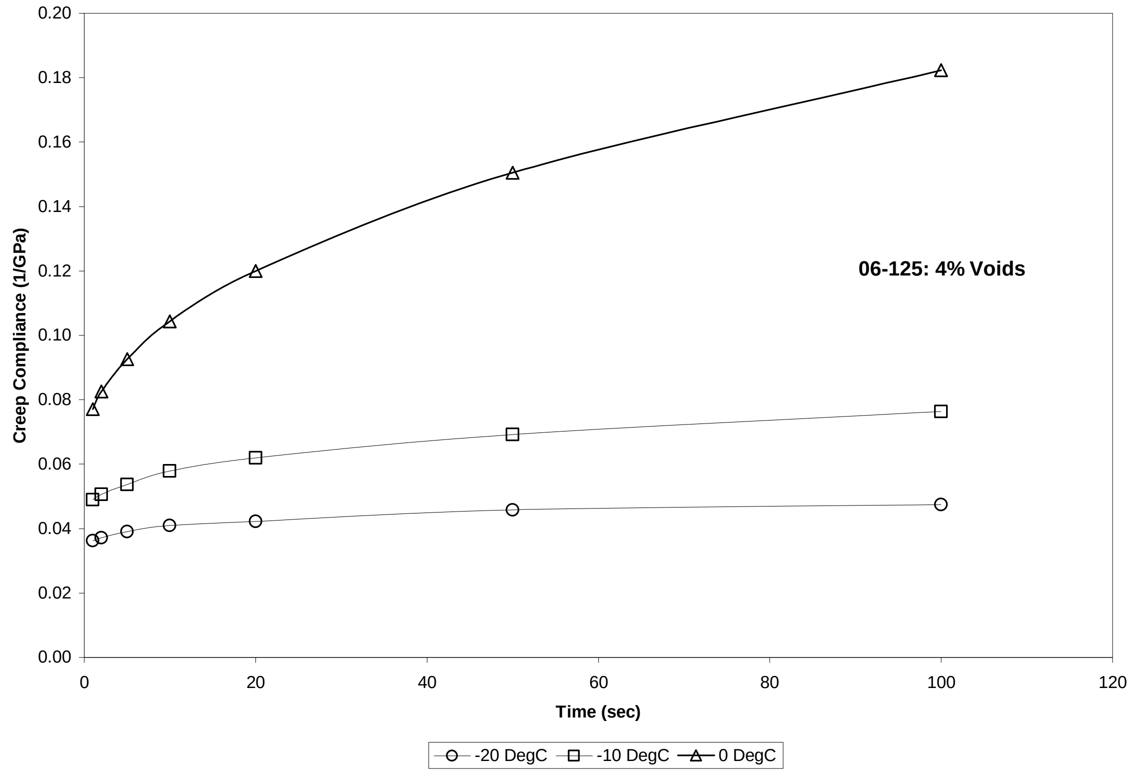

Figure A-39: 06-125 @ 4% Voids

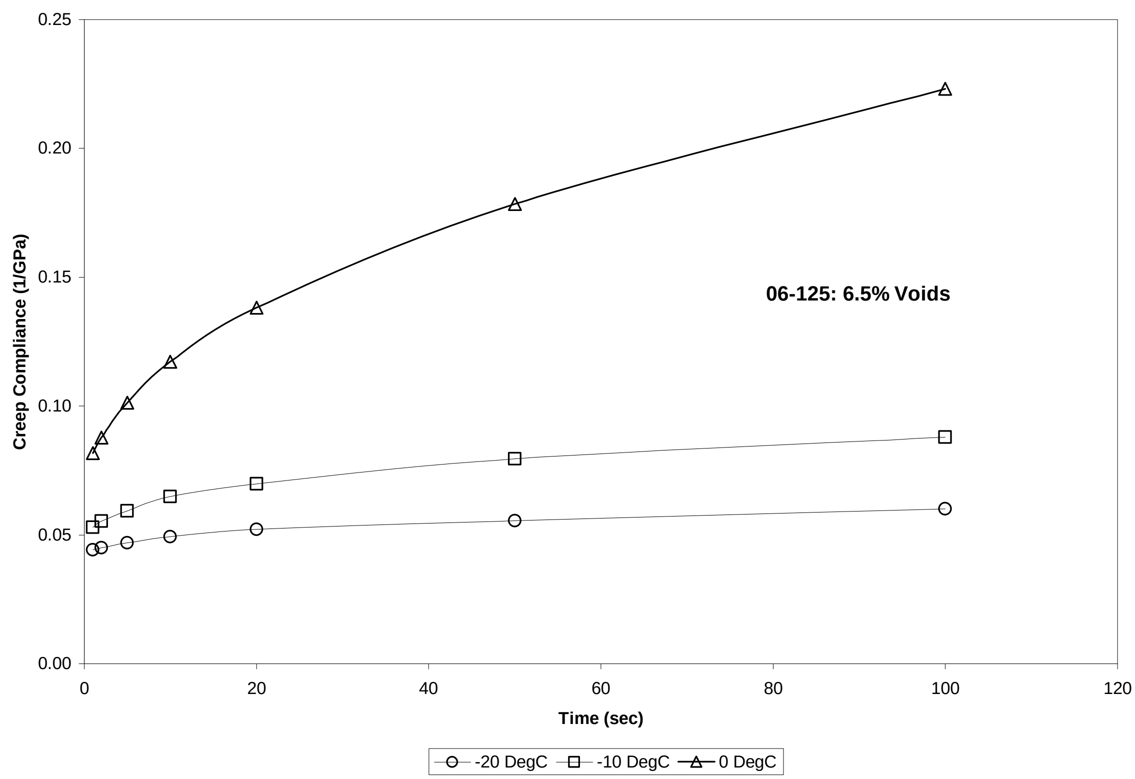

Figure A-40: 06-125 @ 6.5% Voids

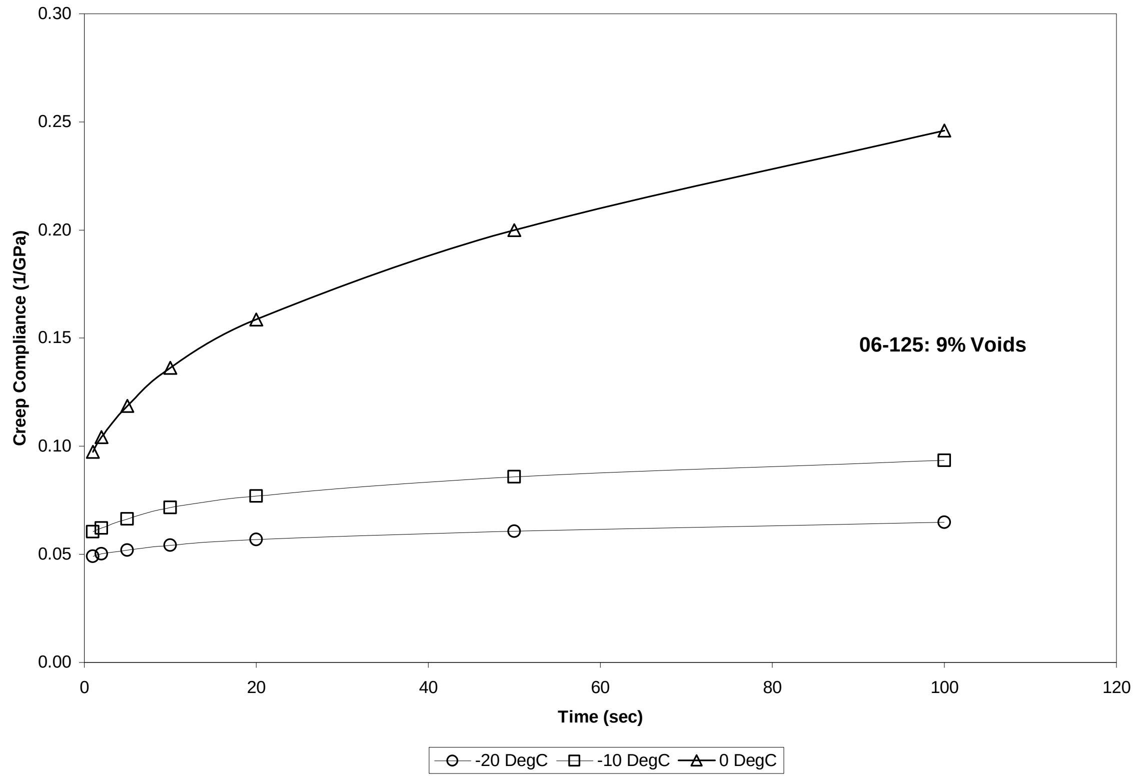

Figure A-41: 06-125 @ 9% Voids

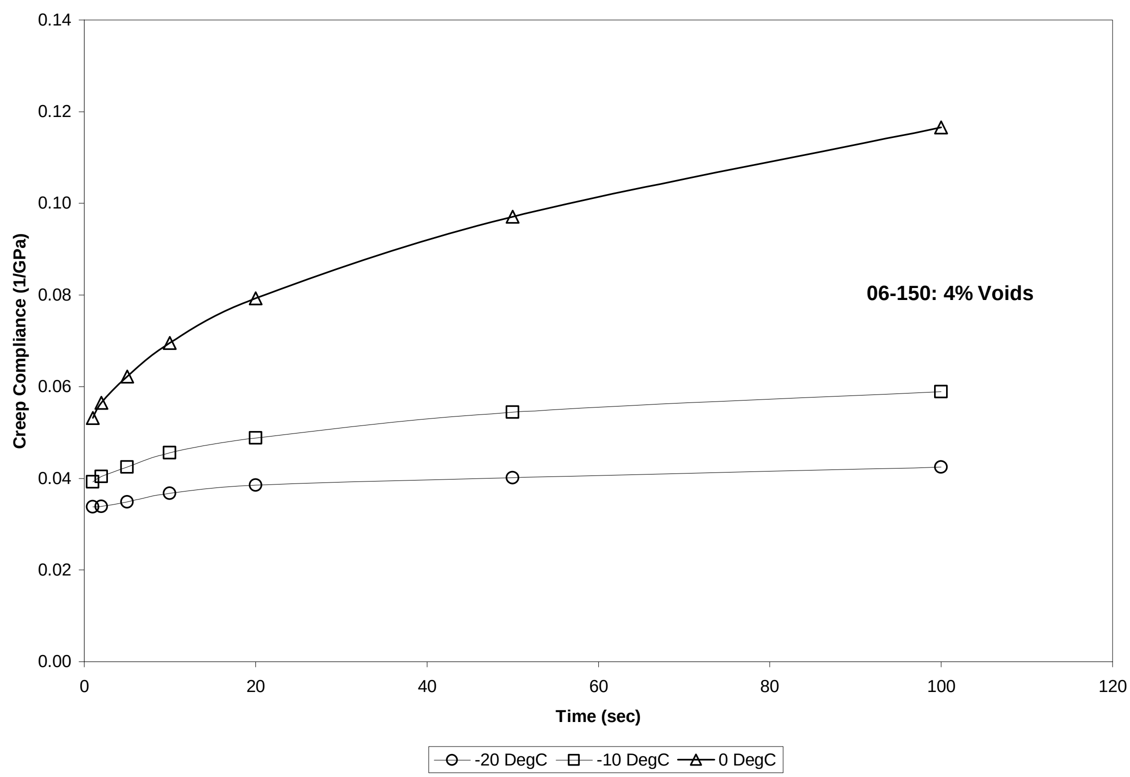

Figure A-42: 06-150 @ 4% Voids

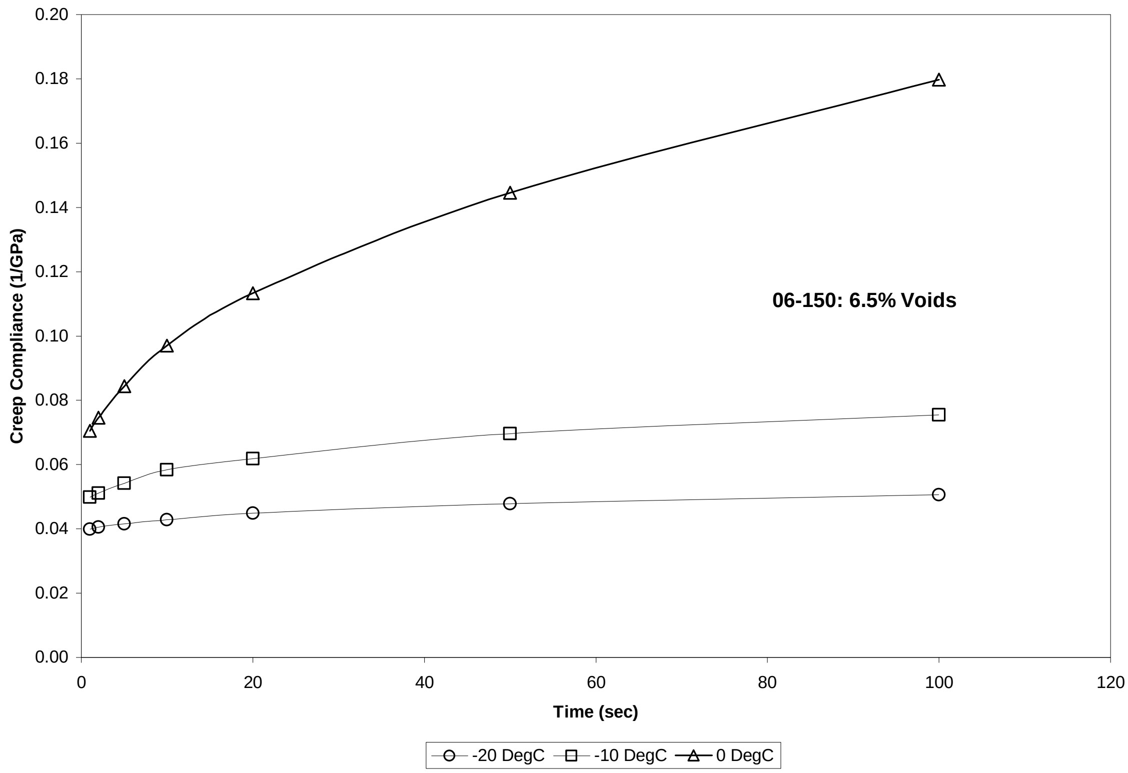

Figure A-43: 06-150 @ 6.5% Voids

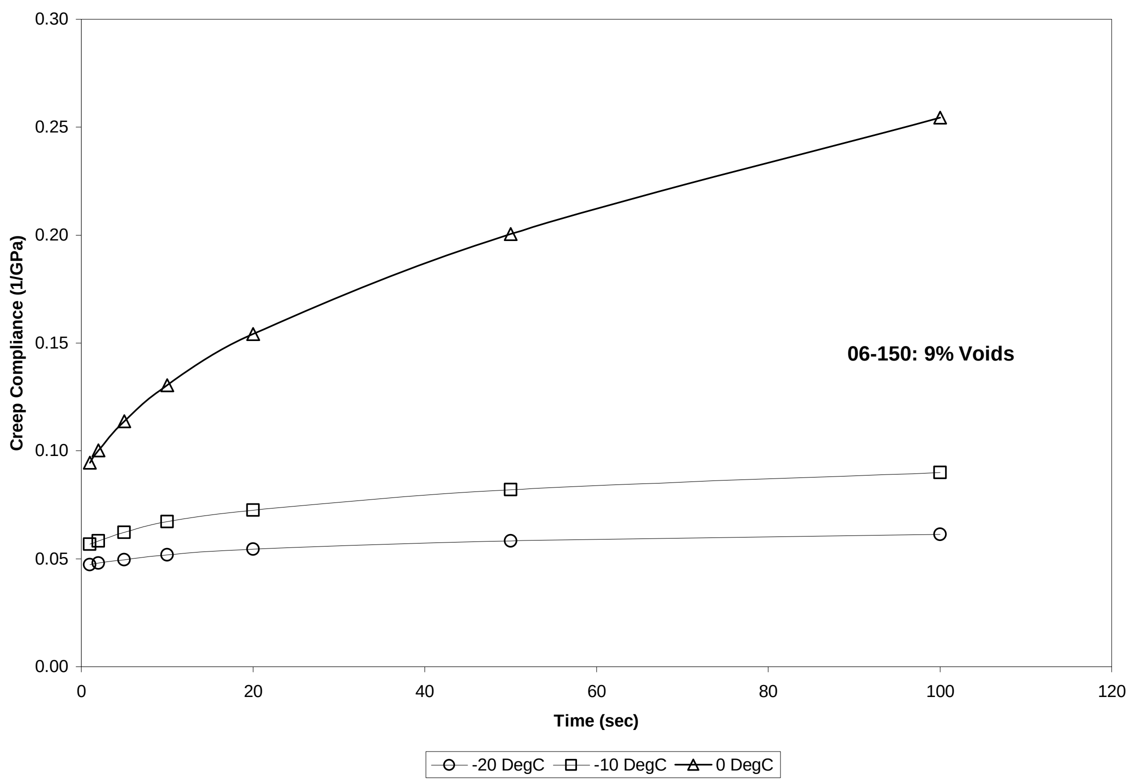

Figure A-44: 06-150 @ 9% Voids

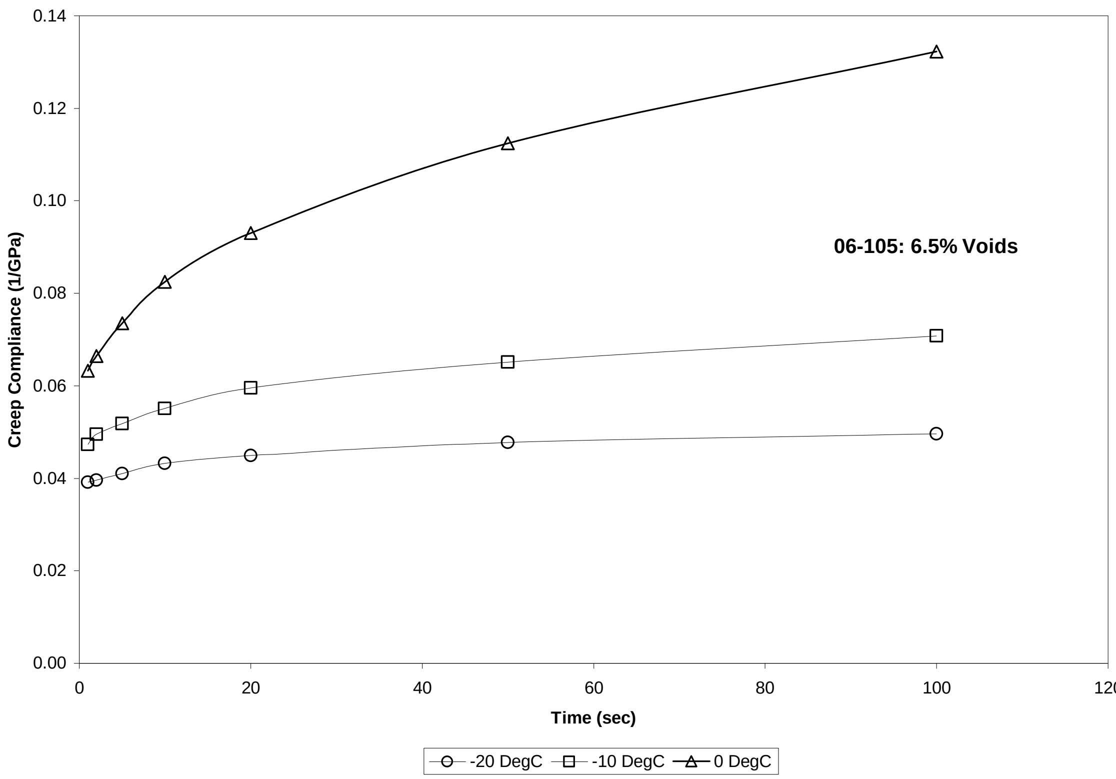

Figure A-45: 06-105 @ 6.5% Voids

APPENDIX B: TENSILE STRENGTH & TENSILE FAILURE STRAIN

Table B-19: Non-instrumented Data @ -10°C: Part A

Mix Designation	07-123	%RAP	20.0
Mix Type	BP1	RAP %AC	5.7
Virgin Binder Grade	PG64-22	Total %AC	5.3
%Virgin AC	4.2	%Fibers	0.0
Gmm	2.501		

Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Tensile Strength AASHTO T 322-07 Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	NCHRP 530 Correction St,n (psi)	Avg. St (psi)
2	2.333	6.7	1.991	50.6	5.895	149.7	-10.0	13322.8	723				602	
3	2.338	6.5	1.991	50.6	5.898	149.8	-9.7	11937.3	647	649	73.2	11.3%	543	544
14	2.342	6.3	1.994	50.6	5.899	149.8	-9.6	10645.8	576				487	
Average	2.338	6.5	1.992	50.6	5.897	149.8	-9.8							
5	2.334	6.7	1.994	50.6	5.901	149.9	-9.5	8598.6	465				401	
13	2.342	6.4	1.997	50.7	5.897	149.8	-9.6	11264.6	609	576	98.1	17.0%	513	487
15	2.344	6.3	2.001	50.8	5.898	149.8	-9.5	12101.4	653				547	
Average	2.340	6.5	1.997	50.7	5.899	149.8	-9.5	Statistics for All 6		612	87.2	14.2%		515

Mix Designation	06-105	%RAP	10.0
Mix Type	SP125C	RAP %AC	4.8
Virgin Binder Grade	PG70-22	Total %AC	5.6
%Virgin AC	5.1	%Fibers	0.0
Gmm	2.455		

Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Tensile Strength AASHTO T 322-07 Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	NCHRP 530 Correction St,n (psi)	Avg. St (psi)
2	2.290	6.7	1.72	43.7	5.92	150.4	-9.5	9610.6	601				507	
5	2.295	6.5	1.72	43.7	5.92	150.4	-9.5	9784.5	612	616	18.2	3.0%	515	519
11	2.301	6.3	1.72	43.7	5.92	150.4	-9.5	10178.2	636				534	
Average	2.295	6.5	1.72	43.7	5.92	150.4	-9.5							

Mix Designation	06-84	%RAP	0.0
Mix Type	SP125BSM	RAP %AC	0.0
Virgin Binder Grade	PG76-22	Total %AC	6.3
%Virgin AC	6.3	%Fibers	0.3
Gmm	2.436		

Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Tensile Strength AASHTO T 322-07 Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	NCHRP 530 Correction St,n (psi)	Avg. St (psi)
2	2.344	3.8	1.990	50.5	5.903	149.9	-9.7	13924.6	755				627	
3	2.339	4.0	1.997	50.7	5.905	150.0	-9.5	13849.5	748	738	22.9	3.1%	621	614
16	2.334	4.2	1.999	50.8	5.906	150.0	-9.6	13204.3	712				593	
Average	2.339	4.0	1.995	50.7	5.905	150.0	-9.6							
7	2.282	6.3	1.967	50.0	5.895	149.7	-9.5	11626.0	638				536	
11	2.272	6.7	1.985	50.4	5.896	149.8	-9.6	10888.7	592	620	24.4	3.9%	500	522
14	2.277	6.5	1.977	50.2	5.901	149.9	-9.7	11538.1	630				529	
Average	2.277	6.5	1.976	50.2	5.897	149.8	-9.6							
6	2.211	9.2	1.984	50.4	5.907	150.0	-9.8	9439.1	513				438	
14	2.222	8.8	1.991	50.6	5.905	150.0	-10.3	10172.1	551	525	22.7	4.3%	468	447
19	2.217	9.0	1.983	50.4	5.906	150.0	-9.8	9390.9	510				436	
Average	2.217	9.0	1.986	50.4	5.906	150.0	-10.0							

Table B-20: Non-instrumented Data @ -10°C: Part B

Mix Designation	06-101	%RAP	0.0
Mix Type	SP125B	RAP %AC	0.0
Virgin Binder Grade	PG76-22	Total %AC	5.7
%Virgin AC	5.7	%Fibers	0.0
Gmm	2.515		

								Tensile Strength						
								AASHTO T 322-07					NCHRP 530 Correction	
Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	St,n (psi)	Avg. St (psi)
4	2.421	3.8	1.985	50.4	5.895	149.7	-9.9	15002.8	816				675	
7	2.415	4.0	2.006	51.0	5.896	149.8	-10.0	16547.0	891	841	42.8	5.1%	733	694
11	2.410	4.2	2.003	50.9	5.897	149.8	-10.0	15153.9	817				675	
Average	2.415	4.0	1.998	50.7	5.896	149.8	-10.0	highlighted cells are Tinius-Olsen values						
2	2.352	6.5	1.988	50.5	5.898	149.8	-9.8	12315.1	669				560	
10	2.347	6.7	1.989	50.5	5.903	149.9	-9.7	11901.9	645	663	16.1	2.4%	541	555
17	2.357	6.3	1.999	50.8	5.904	150.0	-9.8	12535.4	676				565	
Average	2.352	6.5	1.992	50.6	5.902	149.9	-9.8							
4	2.284	9.2	1.992	50.6	5.903	149.9	-9.8	10836.2	587				496	
6	2.288	9.0	1.989	50.5	5.902	149.9	-9.6	11270.8	611	601	12.8	2.1%	515	507
18	2.294	8.8	1.994	50.6	5.908	150.1	-10.0	11196.9	605				510	
Average	2.289	9.0	1.992	50.6	5.904	150.0	-9.8							

Mix Designation	06-125	%RAP	0.0
Mix Type	SP125C	RAP %AC	0.0
Virgin Binder Grade	PG64-22	Total %AC	6.5
%Virgin AC	6.5	%Fibers	0.0
Gmm	2.412		

								Tensile Strength						
								AASHTO T 322-07					NCHRP 530 Correction	
Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	St,n (psi)	Avg. St (psi)
1	2.315	4.0	1.976	50.2	5.908	150.1	-9.6	12191.2	665				557	
20	2.321	3.8	2.001	50.8	5.904	150.0	-9.9	13492.4	727	696	31.1	4.5%	605	581
24	2.331	4.2	2.004	50.9	5.906	150.0	-9.9	12926.6	695				580	
Average	2.322	4.0	1.994	50.6	5.906	150.0	-9.8							
18	2.249	6.7	1.998	50.7	5.911	150.1	-9.7	11544.2	622				523	
23	2.260	6.3	1.991	50.6	5.903	149.9	-9.6	11703.5	634	623	10.0	1.6%	532	524
24	2.255	6.5	1.961	49.8	5.911	150.1	-9.7	11181.0	614				517	
Average	2.255	6.5	1.983	50.4	5.908	150.1	-9.7							
4	2.190	9.2	2.001	50.8	5.912	150.2	-9.6	9657.6	520				443	
6	2.196	9.0	1.989	50.5	5.908	150.1	-9.5	9892.0	536	532	11.2	2.1%	456	453
8	2.200	8.8	1.970	50.0	5.909	150.1	-9.6	9896.2	541				460	
Average	2.195	9.0	1.987	50.5	5.910	150.1	-9.6							

Mix Designation	06-150	%RAP	10.0
Mix Type	SP125C	RAP %AC	4.8
Virgin Binder Grade	PG70-22	Total %AC	5.5
%Virgin AC	5.0	%Fibers	0.0
Gmm	2.467		

								Tensile Strength						
								AASHTO T 322-07					NCHRP 530 Correction	
Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	St,n (psi)	Avg. St (psi)
2	2.364	4.2	1.980	50.3	5.904	150.0	-9.5	13949.6	760				631	
6	2.369	4.0	1.973	50.1	5.901	149.9	-9.6	13838.6	757	786	48.8	6.2%	628	651
11	2.370	3.9	1.987	50.5	5.900	149.9	-9.5	15516.3	843				695	
Average	2.368	4.0	1.980	50.3	5.902	149.9	-9.5	highlighted cells are Tinius-Olsen values						
4	2.301	6.7	1.985	50.4	5.906	150.0	-9.6	11771.2	639				537	
9	2.313	6.2	1.981	50.3	5.901	149.9	-9.6	12719.1	693	674	30.3	4.5%	578	564
11	2.307	6.5	1.978	50.2	5.907	150.0	-9.6	12675.2	691				577	
Average	2.307	6.5	1.981	50.3	5.905	150.0	-9.6							
1	2.240	9.2	1.971	50.1	5.911	150.1	-9.6	11340.9	620				521	
11	2.249	8.8	1.974	50.1	5.916	150.3	-10.3	10988.2	599	599	21.1	3.5%	505	505
19	2.245	9.0	1.970	50.0	5.918	150.3	-9.6	10575.6	577				488	
Average	2.245	9.0	1.972	50.1	5.915	150.2	-9.8							

Table B-21: Instrumented Data @ 21.1°C: Part A

Mix Designation	06-84	%RAP	0.0
Mix Type	SP125BSM	RAP %AC	0.0
Virgin Binder Grade	PG76-22	Total %AC	6.3
%Virgin AC	6.3	%Fibers	0.3
Gmm	2.436		

Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Tensile Strength AASHTO T 322-07 Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	Horizontal Deformations (mm) North	South	Average	Failure Strain (microstrain) North	South	Average
13	2.338	4.0	1.994	50.6	5.897	149.8	21.2	3774.6	204				3.6625E-03	6.7757E-03	5.2191E-03	96	178	137
20	2.328	4.4	1.994	50.6	5.897	149.8	21.0	3582.5	194	195	9.1	4.7%	6.5313E-03	6.1895E-03	6.3604E-03	172	163	167
21	2.349	3.6	1.989	50.5	5.898	149.8	20.9	3429.6	186				1.0135E-02	7.7151E-03	8.9251E-03	267	203	235
Average	2.338	4.0	1.992	50.6	5.897	149.8	21.0						Average		6.8349E-03			180
16	2.280	6.4	1.980	50.3	5.909	150.1	21.2	3135.9	171				6.6728E-03	3.0403E-03	4.8566E-03	176	80	128
19	2.278	6.5	1.995	50.7	5.898	149.8	21.2	3217.6	174	166	11.9	7.2%	3.9735E-03	8.0121E-03	5.9928E-03	105	211	158
20	2.276	6.6	1.981	50.3	5.900	149.9	21.2	2790.4	152				5.3776E-03	7.7265E-03	6.5521E-03	142	203	172
Average	2.278	6.5	1.985	50.4	5.902	149.9	21.2						Average		5.8005E-03			153
2	2.209	9.3	2.000	50.8	5.910	150.1	21.3	2513.2	135				3.3855E-03	6.5268E-03	4.9562E-03	89	172	130
13	2.212	9.2	2.005	50.9	5.903	149.9	21.2	2765.0	149	140	7.4	5.3%	9.3908E-03	8.6789E-03	9.0349E-03	247	228	238
28	2.223	8.7	1.976	50.2	5.906	150.0	21.2	2503.9	137				4.9517E-03	8.0014E-03	6.4765E-03	130	211	170
Average	2.215	9.1	1.994	50.6	5.906	150.0	21.2						Average		6.8225E-03			180

Mix Designation	06-101	%RAP	0.0
Mix Type	SP125B	RAP %AC	0.0
Virgin Binder Grade	PG76-22	Total %AC	5.7
%Virgin AC	5.7	%Fibers	0.0
Gmm	2.515		

Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Tensile Strength AASHTO T 322-07 Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	Horizontal Deformations (mm) North	South	Average	Failure Strain (microstrain) North	South	Average
2	2.417	3.9	1.977	50.2	5.892	149.7	21.4	4389.3	240				3.0530E-03	8.0117E-03	5.5324E-03	80	211	146
6	2.413	4.1	1.992	50.6	5.900	149.9	21.1	4095.9	222	225	13.3	5.9%	7.1782E-03	5.0474E-03	6.1128E-03	189	133	161
22	2.412	4.1	2.001	50.8	5.902	149.9	21.1	3967.8	214				4.4972E-03	6.4436E-03	5.4704E-03	118	170	144
Average	2.414	4.0	1.990	50.5	5.898	149.8	21.2						Average		5.7052E-03			150
18	2.361	6.1	1.991	50.6	5.901	149.9	21.2	3952.6	214				1.0839E-02	6.0714E-03	8.4552E-03	285	160	223
20	2.345	6.8	2.007	51.0	5.903	149.9	21.2	4355.9	234	226	10.6	4.7%	3.4217E-03	3.5048E-03	3.4632E-03	90	92	91
27	2.353	6.5	1.986	50.4	5.901	149.9	21.2	4241.4	230				1.9882E-03	3.6030E-03	2.7956E-03	52	95	74
Average	2.353	6.5	1.995	50.7	5.902	149.9	21.2						Average		4.9047E-03			129
2	2.290	8.9	1.991	50.6	5.905	150.0	21.2	3198.3	173				4.8725E-03	6.7855E-03	5.8290E-03	128	179	153
21	2.286	9.1	1.984	50.4	5.909	150.1	21.2	3338.3	181	171	11.3	6.6%	5.5179E-03	1.0167E-02	7.8423E-03	145	268	206
28	2.286	9.1	1.998	50.7	5.908	150.1	21.3	2948.6	159				8.4408E-03	5.8479E-03	7.1443E-03	222	154	188
Average	2.287	9.0	1.991	50.6	5.907	150.0	21.2						Average		6.9386E-03			183

Table B-22: Instrumented Data @ 21.1°C: Part B

Mix Designation	06-125	%RAP	0.0
Mix Type	SP125C	RAP %AC	0.0
Virgin Binder Grade	PG64-22	Total %AC	6.5
%Virgin AC	6.5	%Fibers	0.0
Gmm	2.412		

Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Tensile Strength AASHTO T 322-07 Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	Horizontal Deformations (mm) North	South	Average	Failure Strain (microstrain) North	South	Average
14	2.318	3.9	1.996	50.7	5.908	150.1	21.1	3081.8	166				6.1602E-03	6.4012E-03	6.2807E-03	162	168	165
25	2.314	4.1	1.962	49.8	5.900	149.9	21.2	2742.1	151	158	8.0	5.1%	6.8785E-03	9.7883E-03	8.3334E-03	181	258	219
26	2.308	4.3	1.918	48.7	5.902	149.9	21.3	2766.9	156				5.7384E-03	9.0398E-03	7.3891E-03	151	238	194
Average	2.313	4.1	1.959	49.8	5.903	149.9	21.2						Average		7.3344E-03			193
10	2.262	6.2	2.000	50.8	5.902	149.9	21.2	2342.7	126				1.0887E-02	1.1707E-02	1.1297E-02	286	308	297
19	2.245	6.9	1.976	50.2	5.915	150.2	21.3	2456.5	134	135	9.0	6.7%	7.0332E-03	7.5513E-03	7.2923E-03	185	199	192
29	2.261	6.3	1.993	50.6	5.911	150.1	21.0	2670.7	144				6.3868E-03	8.1031E-03	7.2450E-03	168	213	191
Average	2.256	6.5	1.990	50.5	5.909	150.1	21.2						Average		8.6114E-03			227
5	2.186	9.4	1.991	50.6	5.919	150.3	21.3	2539.2	137				3.0320E-03	6.6704E-03	4.8512E-03	80	176	128
16	2.195	9.0	2.002	50.9	5.913	150.2	21.3	2329.4	125	130	6.1	4.7%	1.0888E-02	7.4115E-03	9.1497E-03	287	195	241
28	2.206	8.6	1.990	50.5	5.909	150.1	21.1	2380.9	129				7.4711E-03	5.6799E-03	6.5755E-03	197	149	173
Average	2.196	9.0	1.994	50.7	5.914	150.2	21.2						Average		6.8588E-03			180

Mix Designation	06-150	%RAP	10.0
Mix Type	SP125C	RAP %AC	4.8
Virgin Binder Grade	PG70-22	Total %AC	5.5
%Virgin AC	5.0	%Fibers	0.0
Gmm	2.467		

Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Tensile Strength AASHTO T 322-07 Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	Horizontal Deformations (mm) North	South	Average	Failure Strain (microstrain) North	South	Average
7	2.365	4.1	1.998	50.7	5.901	149.9	21.3	3314.9	179				6.0567E-03	8.8484E-03	7.4526E-03	159	233	196
14	2.365	4.1	1.978	50.2	5.900	149.9	21.3	3366.5	184	184	5.0	2.7%	5.9546E-03	8.0853E-03	7.0199E-03	157	213	185
17	2.368	4.0	1.981	50.3	5.902	149.9	21.3	3470.5	189				6.8051E-03	5.0729E-03	5.9390E-03	179	133	156
Average	2.366	4.1	1.986	50.4	5.901	149.9	21.3						Average		6.8038E-03			179
23	2.300	6.8	1.993	50.6	5.906	150.0	21.5	2800.4	151				7.3935E-03	1.0033E-02	8.7131E-03	195	264	229
8	2.299	6.8	1.993	50.6	5.904	150.0	21.4	2868.6	155	153	1.9	1.2%	8.0818E-03	9.1102E-03	8.5960E-03	213	240	226
21	2.302	6.7	1.988	50.5	5.904	150.0	21.4	2835.1	154				6.7169E-03	1.0757E-02	8.7367E-03	177	283	230
Average	2.300	6.8	1.991	50.6	5.905	150.0	21.4						Average		8.6820E-03			228
18	2.245	9.0	1.975	50.2	5.913	150.2	21.2	2457.1	134				5.5853E-03	1.1797E-02	8.6911E-03	147	310	229
25	2.247	8.9	1.991	50.6	5.923	150.4	21.5	2322.1	125	132	5.7	4.3%	8.5425E-03	1.3138E-02	1.0840E-02	225	346	285
24	2.241	9.2	1.986	50.4	5.922	150.4	21.3	2513.8	136				8.5356E-03	1.3036E-02	1.0786E-02	225	343	284
Average	2.244	9.0	1.984	50.4	5.919	150.4	21.3						Average		1.0106E-02			266

Table B-23: Instrumented Data @ 4.4°C: Part A

Mix Designation	06-84	%RAP	0.0
Mix Type	SP125BSM	RAP %AC	0.0
Virgin Binder Grade	PG76-22	Total %AC	6.3
%Virgin AC	6.3	%Fibers	0.3
Gmm	2.436		

Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Tensile Strength AASHTO T 322-07 Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	Horizontal Deformations (mm) North	South	Average	Failure Strain (microstrain) North	South	Average
6	2.330	4.3	1.989	50.5	5.895	149.7	4.7	8119.5	441				2.2650E-03	1.6101E-03	1.9376E-03	60	42	51
8	2.346	3.7	2.004	50.9	5.901	149.9	4.7	8555.3	461	460	18.8	4.1%	3.0128E-03	1.7412E-03	2.3770E-03	79	46	63
24	2.339	4.0	1.997	50.7	5.900	149.9	4.7	8855.0	478				3.9349E-03	1.8839E-03	2.9094E-03	104	50	77
Average	2.338	4.0	1.997	50.7	5.899	149.8	4.7						Average		2.4080E-03			63
2	2.276	6.6	1.986	50.4	5.906	150.0	4.6	7418.0	403				3.4384E-03	1.2129E-03	2.3257E-03	90	32	61
9	2.281	6.4	1.994	50.6	5.903	149.9	4.7	7571.4	410	419	23.2	5.5%	1.1101E-03	2.4821E-03	1.7961E-03	29	65	47
18	2.277	6.5	1.973	50.1	5.895	149.7	4.7	8145.8	446				1.4662E-03	2.6228E-03	2.0445E-03	39	69	54
Average	2.278	6.5	1.984	50.4	5.901	149.9	4.7						Average		2.0554E-03			54
1	2.209	9.3	2.001	50.8	5.902	149.9	4.7	6376.5	344				1.9550E-03	3.2783E-03	2.6166E-03	51	86	69
23	2.216	9.0	1.988	50.5	5.907	150.0	4.6	6275.0	340	341	3.0	0.9%	1.4100E-03	3.9655E-03	2.6878E-03	37	104	71
25	2.223	8.8	1.995	50.7	5.911	150.1	4.7	6255.1	338				2.9748E-03	1.3945E-03	2.1846E-03	78	37	57
Average	2.216	9.0	1.995	50.7	5.907	150.0	4.7						Average		2.4963E-03			66

Mix Designation	06-101	%RAP	0.0
Mix Type	SP125B	RAP %AC	0.0
Virgin Binder Grade	PG76-22	Total %AC	5.7
%Virgin AC	5.7	%Fibers	0.0
Gmm	2.515		

Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Tensile Strength AASHTO T 322-07 Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	Horizontal Deformations (mm) North	South	Average	Failure Strain (microstrain) North	South	Average
18	2.410	4.2	1.995	50.7	5.900	149.9	4.5	10548.7	571				2.0025E-03	2.0213E-03	2.0119E-03	53	53	53
20	2.413	4.0	2.006	51.0	5.894	149.7	4.7	9595.3	517	543	27.0	5.0%	4.0944E-03	1.6964E-03	2.8954E-03	108	45	76
23	2.419	3.8	1.975	50.2	5.896	149.8	4.6	9908.4	542				8.3754E-04	4.9787E-03	2.9081E-03	22	131	77
Average	2.414	4.0	1.992	50.6	5.897	149.8	4.6						Average		2.6051E-03			69
1	2.350	6.6	1.986	50.4	5.902	149.9	4.7	9028.9	490				1.0861E-03	4.5516E-03	2.8188E-03	29	120	74
14	2.359	6.2	1.996	50.7	5.904	150.0	4.7	9528.2	515	492	22.6	4.6%	3.0026E-03	2.5218E-03	2.7622E-03	79	66	73
25	2.351	6.5	2.003	50.9	5.900	149.9	4.7	8716.4	470				5.3766E-04	2.9275E-03	1.7326E-03	14	77	46
Average	2.353	6.4	1.995	50.7	5.902	149.9	4.7						Average		2.4379E-03			64
7	2.289	9.0	1.978	50.2	5.903	149.9	4.6	7828.2	427				1.8130E-03	1.6972E-03	1.7551E-03	48	45	46
22	2.291	8.9	1.999	50.8	5.905	150.0	4.9	7547.2	407	401	28.5	7.1%	1.1722E-03	2.9698E-03	2.0710E-03	31	78	54
25	2.287	9.1	2.002	50.9	5.895	149.7	4.9	6871.1	371				7.0913E-04	3.4605E-03	2.0848E-03	19	91	55
Average	2.289	9.0	1.993	50.6	5.901	149.9	4.8						Average		1.9703E-03			52

Table B-24: Instrumented Data @ 4.4°C: Part B

Mix Designation	06-125	%RAP	0.0
Mix Type	SP125C	RAP %AC	0.0
Virgin Binder Grade	PG64-22	Total %AC	6.5
%Virgin AC	6.5	%Fibers	0.0
Gmm	2.412		

Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Tensile Strength AASHTO T 322-07 Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	Horizontal Deformations (mm) North	South	Average	Failure Strain (microstrain) North	South	Average
6	2.319	3.9	1.982	50.3	5.903	149.9	4.3	8466.2	461				1.5585E-03	2.6032E-03	2.0809E-03	41	69	55
10	2.312	4.1	2.085	53.0	5.905	150.0	4.6	8970.3	464	465	5.8	1.2%	1.8730E-03	1.4787E-03	1.6758E-03	49	39	44
13	2.308	4.3	2.015	51.2	5.906	150.0	4.6	8820.8	472				2.4177E-03	1.7993E-03	2.1085E-03	64	47	55
Average	2.313	4.1	2.027	51.5	5.905	150.0	4.5						Average		1.9551E-03			51
13	2.248	6.8	1.986	50.4	5.907	150.0	4.6	7068.2	384				8.7816E-04	3.5948E-03	2.2365E-03	23	95	59
26	2.259	6.3	2.009	51.0	5.906	150.0	4.6	6719.7	361	380	18.0	4.7%	1.1535E-03	2.4524E-03	1.8029E-03	30	65	47
28	2.263	6.2	1.989	50.5	5.904	150.0	4.6	7304.1	396				2.5214E-03	8.4765E-04	1.6845E-03	66	22	44
Average	2.257	6.4	1.995	50.7	5.906	150.0	4.6						Average		1.9080E-03			50
9	2.190	9.2	1.997	50.7	5.918	150.3	4.3	6147.1	331				2.0454E-03	1.6390E-03	1.8422E-03	54	43	48
11	2.194	9.0	1.993	50.6	5.915	150.2	4.4	6276.8	339	335	3.9	1.2%	2.0037E-03	1.5196E-03	1.7616E-03	53	40	46
20	2.203	8.7	1.994	50.6	5.911	150.1	4.6	6214.6	336				2.4821E-03	1.2316E-03	1.8569E-03	65	32	49
Average	2.196	9.0	1.995	50.7	5.915	150.2	4.4						Average		1.8202E-03			48

Mix Designation	06-150	%RAP	10.0
Mix Type	SP125C	RAP %AC	4.8
Virgin Binder Grade	PG70-22	Total %AC	5.5
%Virgin AC	5.0	%Fibers	0.0
Gmm	2.467		

Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Tensile Strength AASHTO T 322-07 Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	Horizontal Deformations (mm) North	South	Average	Failure Strain (microstrain) North	South	Average
4	2.365	4.1	1.981	50.3	5.900	149.9	4.4	9078.4	494				1.5633E-03	4.2285E-03	2.8959E-03	41	111	76
19	2.367	4.1	1.994	50.6	5.899	149.8	4.6	9788.8	530	520	21.9	4.2%	2.4197E-03	3.9886E-03	3.2041E-03	64	105	84
20	2.370	4.0	1.967	50.0	5.897	149.8	4.7	9741.2	535				1.6263E-03	5.5593E-03	3.5928E-03	43	146	95
Average	2.367	4.1	1.981	50.3	5.899	149.8	4.6						Average		3.2309E-03			85
2	2.299	6.8	1.978	50.2	5.904	150.0	4.7	8182.4	446				1.2578E-03	3.9871E-03	2.6224E-03	33	105	69
7	2.298	6.8	1.973	50.1	5.913	150.2	4.7	7669.9	419	438	16.5	3.8%	3.2145E-03	1.6358E-03	2.4252E-03	85	43	64
12	2.296	6.9	1.984	50.4	5.904	150.0	4.8	8243.4	448				1.2256E-03	2.6478E-03	1.9367E-03	32	70	51
Average	2.298	6.8	1.978	50.2	5.907	150.0	4.7						Average		2.3281E-03			61
8	2.237	9.3	1.956	49.7	5.915	150.2	4.4	6873.0	378				2.6945E-03	1.7769E-03	2.2357E-03	71	47	59
9	2.244	9.1	1.991	50.6	5.908	150.1	4.7	7528.1	407	388	17.0	4.4%	2.4755E-03	1.4490E-03	1.9622E-03	65	38	52
13	2.252	8.7	1.979	50.3	5.909	150.1	4.7	6941.6	378				3.3920E-03	1.3244E-03	2.3582E-03	89	35	62
Average	2.244	9.0	1.975	50.2	5.911	150.1	4.6						Average		2.1854E-03			58

Table B-25: Instrumented Data @ -10°C: 07-123 & 06-105

Mix Designation	07-123	%RAP	20.0
Mix Type	BP1	RAP %AC	5.7
Virgin Binder Grade	PG64-22	Total %AC	5.3
%Virgin AC	4.2	%Fibers	0.0
Gmm	2.501		

Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Tensile Strength: AASHTO T 322-07 Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	NCHRP 530 Correction St,n (psi)	Avg. St (psi)	AASHTO T 322-03 Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)
16	2.331	6.8	1.995	50.7	5.901	149.9	-9.9	11828.6	640				537		11828.6	640			
17	2.333	6.7	1.997	50.7	5.901	149.9	-9.7	10024.4	542	599	51.3	8.6%	460	505	9754	527	594	59.6	10.0%
18	2.331	6.8	1.983	50.4	5.905	150.0	-10.0	11345.8	617				519		11345.8	617			
Average	2.332	6.8	1.992	50.6	5.902	149.9	-9.9												

Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Horizontal Deformations (mm): At Maximum Load North	South	Average	At (Y - X) peak North	South	Average	Failure Strain (microstrain): At Maximum Load North	South	Average	At (Y - X) peak North	South	Average
16	2.331	6.8	1.995	50.7	5.901	149.9	-9.9	5.8338E-04	5.5008E-04	5.6673E-04	5.8338E-04	5.5008E-04	5.6673E-04	15	14	15	15	14	15
17	2.333	6.7	1.997	50.7	5.901	149.9	-9.7	6.9512E-04	1.7837E-04	4.3674E-04	6.9512E-04	2.1715E-04	4.5613E-04	18	5	11	18	6	12
18	2.331	6.8	1.983	50.4	5.905	150.0	-10.0	2.1927E-04	5.8208E-04	4.0067E-04	2.1927E-04	5.8208E-04	4.0067E-04	6	15	11	6	15	11
Average	2.332	6.8	1.992	50.6	5.902	149.9	-9.9	Average		4.6805E-04	Average		4.7451E-04	Average		12	Average		12

Mix Designation	06-105	%RAP	10.0
Mix Type	SP125C	RAP %AC	4.8
Virgin Binder Grade	PG70-22	Total %AC	5.6
%Virgin AC	5.1	%Fibers	0.0
Gmm	2.455		

Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Tensile Strength: AASHTO T 322-07 Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	NCHRP 530 Correction St,n (psi)	Avg. St (psi)	AASHTO T 322-03 Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)
3	2.306	6.1	1.73	43.9	5.92	150.4	-9.7	9839.5	612				515			0			
8	2.282	7.0	1.72	43.7	5.91	150.1	-9.7	8791.5	551	571	35.2	6.2%	467	483		0	0	0.0	#DIV/0!
9	2.297	6.4	1.73	43.9	5.92	150.4	-10.0	8860.5	551				468			0			
Average	2.295	6.5	1.73	43.9	5.92	150.3	-9.8												

Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Horizontal Deformations (mm): At Maximum Load North	South	Average	At (Y - X) peak North	South	Average	Failure Strain (microstrain): At Maximum Load North	South	Average	At (Y - X) peak North	South	Average
3	2.306	6.1	1.73	43.9	5.92	150.4	-9.7	8.1733E-04	7.7491E-04	7.9612E-04				22	20	21			
8	2.282	7.0	1.72	43.7	5.91	150.1	-9.7	3.8602E-04	5.6931E-04	4.7766E-04				10	15	13			
9	2.297	6.4	1.73	43.9	5.92	150.4	-10.0	6.6730E-05	1.3777E-03	7.2223E-04				2	36	19			
Average	2.295	6.5	1.73	43.9	5.92	150.3	-9.8	Average		6.6534E-04	Average		#DIV/0!	Average		18	Average		#DIV/0!

indicates an instance of first failure

Ending horizontal deformation taken as the reading on the same line as t maximum difference between vertical and horizontal deformation

Table B-26: Instrumented Data @ -10°C: 06-84

Mix Designation	06-84	%RAP	0.0
Mix Type	SP125BSM	RAP %AC	0.0
Virgin Binder Grade	PG76-22	Total %AC	6.3
%Virgin AC	6.3	%Fibers	0.3
Gmm	2.436		

								Tensile Strength											
								AASHTO T 322-07					NCHRP 530 Correction		AASHTO T 322-03				
Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	St,n (psi)	Avg. St (psi)	Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)
4	2.340	4.0	1.979	50.3	5.898	149.8	-10.0	12406.6	677				566			0			
7	2.336	4.1	2.000	50.8	5.897	149.8	-10.0	13244.0	715	697	19.2	2.8%	596	581		0	0	0.0	#DIV/0!
23	2.337	4.1	1.956	49.7	5.899	149.8	-10.0	12665.4	699				583			0			
Average	2.338	4.1	1.978	50.2	5.898	149.8	-10.0												
12	2.274	6.7	1.995	50.7	5.912	150.2	-10.0	12029.4	649				544			0			
15	2.278	6.5	1.999	50.8	5.899	149.8	-10.1	10446.8	564	618	46.7	7.6%	478	520		0	0	0.0	#DIV/0!
23	2.282	6.3	1.988	50.5	5.899	149.8	-10.0	11782.8	640				537			0			
Average	2.278	6.5	1.994	50.6	5.903	149.9	-10.0												
11	2.211	9.2	1.994	50.6	5.906	150.0	-10.2	9998.2	540				460			0			
26	2.217	9.0	1.983	50.4	5.905	150.0	-9.7	9164.4	498	551	58.0	10.5%	427	467		0	0	0.0	#DIV/0!
27	2.223	8.8	1.997	50.7	5.905	150.0	-9.9	11355.0	613				516			0			
Average	2.217	9.0	1.991	50.6	5.905	150.0	-9.9												

								Horizontal Deformations (mm)						Failure Strain (microstrain)					
								At Maximum Load			At (Y - X) peak			At Maximum Load			At (Y - X) peak		
Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	North	South	Average	North	South	Average	North	South	Average	North	South	Average
4	2.340	4.0	1.979	50.3	5.898	149.8	-10.0	5.6494E-04	9.0662E-04	7.3578E-04				15	24	19			
7	2.336	4.1	2.000	50.8	5.897	149.8	-10.0	5.0361E-04	6.7086E-04	5.8724E-04				13	18	15			
23	2.337	4.1	1.956	49.7	5.899	149.8	-10.0	3.2247E-04	1.0770E-03	6.9973E-04				8	28	18			
Average	2.338	4.1	1.978	50.2	5.898	149.8	-10.0	Average		6.7425E-04	Average		#DIV/0!	Average		18	Average		#DIV/0!
12	2.274	6.7	1.995	50.7	5.912	150.2	-10.0	1.5408E-03	4.9095E-04	1.0159E-03				41	13	27			
15	2.278	6.5	1.999	50.8	5.899	149.8	-10.1	6.2882E-04	8.5322E-04	7.4102E-04				17	22	20			
23	2.282	6.3	1.988	50.5	5.899	149.8	-10.0	3.0918E-04	2.2304E-03	1.2698E-03				8	59	33			
Average	2.278	6.5	1.994	50.6	5.903	149.9	-10.0	Average		1.0089E-03	Average		#DIV/0!	Average		27	Average		#DIV/0!
11	2.211	9.2	1.994	50.6	5.906	150.0	-10.2	1.1227E-03	5.0068E-04	8.1171E-04				30	13	21			
26	2.217	9.0	1.983	50.4	5.905	150.0	-9.7	9.9439E-04	6.3455E-04	8.1447E-04				26	17	21			
27	2.223	8.8	1.997	50.7	5.905	150.0	-9.9	4.3575E-04	1.7759E-03	1.1058E-03				11	47	29			
Average	2.217	9.0	1.991	50.6	5.905	150.0	-9.9	Average		9.1067E-04	Average		#DIV/0!	Average		24	Average		#DIV/0!

indicates an instance of first failure

Ending horizontal deformation taken as the reading on the same line as t maximum difference between vertical and horizontal deformation

Table B-27: Instrumented Data @ -10°C: 06-101

Mix Designation	06-101	%RAP	0.0
Mix Type	SP125B	RAP %AC	0.0
Virgin Binder Grade	PG76-22	Total %AC	5.7
%Virgin AC	5.7	%Fibers	0.0
Gmm	2.515		

Specimen	Gmb	Voids	Thickness		Diameter		Temp	Tensile Strength											
								AASHTO T 322-07					NCHRP 530 Correction		AASHTO T 322-03				
No.		(%)	(in)	(mm)	(in)	(mm)	(deg C)	Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	St,n (psi)	Avg. St (psi)	Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)
1	2.421	3.8	1.993	50.6	5.894	149.7	-9.9	14584.4	790				655			0			
3	2.409	4.2	2.001	50.8	5.898	149.8	-9.8	14113.2	761	773	15.4	2.0%	632	641		0	0	0.0	#DIV/0!
13	2.414	4.0	2.000	50.8	5.896	149.8	-9.9	14212.0	767				636			0			
Average	2.415	4.0	1.998	50.7	5.896	149.8	-9.9												
8	2.347	6.7	2.007	51.0	5.906	150.0	-10.3	11481.9	617				519		10792.8	580			
16	2.350	6.5	2.000	50.8	5.906	150.0	-10.0	11903.1	642	637	18.9	3.0%	538	535	11903.1	642	625	39.7	6.4%
26	2.358	6.2	2.002	50.9	5.896	149.8	-9.9	12119.8	654				548		12119.8	654			
Average	2.352	6.5	2.003	50.9	5.903	149.9	-10.1												
8	2.289	9.0	1.993	50.6	5.904	150.0	-10.0	10875.9	588				497			0			
11	2.283	9.2	1.977	50.2	5.897	149.8	-10.0	10505.4	574	573	15.2	2.6%	485	485		0	0	0.0	#DIV/0!
26	2.293	8.8	1.987	50.5	5.903	149.9	-9.9	10282.0	558				473			0			
Average	2.288	9.0	1.986	50.4	5.901	149.9	-10.0												

Specimen	Gmb	Voids	Thickness		Diameter		Temp	Horizontal Deformations (mm)						Failure Strain (microstrain)					
								At Maximum Load			At (Y - X) peak			At Maximum Load			At (Y - X) peak		
No.		(%)	(in)	(mm)	(in)	(mm)	(deg C)	North	South	Average	North	South	Average	North	South	Average	North	South	Average
1	2.421	3.8	1.993	50.6	5.894	149.7	-9.9	3.6580E-04	6.6074E-04	5.1327E-04				10	17	14			
3	2.409	4.2	2.001	50.8	5.898	149.8	-9.8	3.3648E-04	9.4584E-04	6.4116E-04				9	25	17			
13	2.414	4.0	2.000	50.8	5.896	149.8	-9.9	2.0830E-04	1.1824E-03	6.9534E-04				5	31	18			
Average	2.415	4.0	1.998	50.7	5.896	149.8	-9.9	Average		6.1659E-04	Average		#DIV/0!	Average		16	Average		#DIV/0!
8	2.347	6.7	2.007	51.0	5.906	150.0	-10.3	2.3756E-05	1.9705E-03	9.9712E-04	1.5470E-04	1.9705E-03	1.0626E-03	1	52	26	4	52	28
16	2.350	6.5	2.000	50.8	5.906	150.0	-10.0	4.2096E-04	6.1440E-04	5.1768E-04	4.2096E-04	6.1440E-04	5.1768E-04	11	16	14	11	16	14
26	2.358	6.2	2.002	50.9	5.896	149.8	-9.9	2.5428E-04	6.3165E-04	4.4297E-04	2.5428E-04	6.3165E-04	4.4297E-04	7	17	12	7	17	12
Average	2.352	6.5	2.003	50.9	5.903	149.9	-10.1	Average		6.5259E-04	Average		6.7441E-04	Average		17	Average		18
8	2.289	9.0	1.993	50.6	5.904	150.0	-10.0	1.1259E-03	2.9886E-04	7.1238E-04				30	8	19			
11	2.283	9.2	1.977	50.2	5.897	149.8	-10.0	4.1363E-04	1.4178E-03	9.1571E-04				11	37	24			
26	2.293	8.8	1.987	50.5	5.903	149.9	-9.9	8.3473E-04	8.5893E-04	8.4683E-04				22	23	22			
Average	2.288	9.0	1.986	50.4	5.901	149.9	-10.0	Average		8.2497E-04	Average		#DIV/0!	Average		22	Average		#DIV/0!

indicates an instance of first failure

Ending horizontal deformation taken as the reading on the same line as t maximum difference between vertical and horizontal deformation

X

Table B-28: Instrumented Data @ -10°C: 06-125

Mix Designation	06-125	%RAP	0.0
Mix Type	SP125C	RAP %AC	0.0
Virgin Binder Grade	PG64-22	Total %AC	6.5
%Virgin AC	6.5	%Fibers	0.0
Gmm	2.412		

								Tensile Strength											
								AASHTO T 322-07					NCHRP 530 Correction		AASHTO T 322-03				
Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	St,n (psi)	Avg. St (psi)	Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)
4	2.317	3.9	2.002	50.9	5.910	150.1	-9.9	11541.1	621				522		11541.1	621			
5	2.315	4.0	1.986	50.4	5.903	149.9	-10.0	11042.5	600	593	32.0	5.4%	506	500	10870.4	590	587	36.1	6.1%
8	2.314	4.1	1.974	50.1	5.907	150.0	-10.1	10220.9	558				473		10057.4	549			
Average	2.315	4.0	1.987	50.5	5.907	150.0	-10.0												
2	2.257	6.4	2.002	50.9	5.912	150.2	-10.0	9655.2	519				443		9270.6	499			
5	2.254	6.6	1.998	50.7	5.919	150.3	-9.9	8515.0	458	533	82.8	15.5%	396	454	7528.8	405	509	108.8	21.4%
25	2.254	6.5	1.967	50.0	5.905	150.0	-10.1	11350.7	622				523		11350.7	622			
Average	2.255	6.5	1.989	50.5	5.912	150.2	-10.0												
2	2.192	9.1	2.000	50.8	5.917	150.3	-10.0	9449.5	508				435		9449.5	508			
10	2.196	9.0	1.990	50.5	5.906	150.0	-10.0	9393.9	509	487	36.5	7.5%	435	418	9273.7	502	484	37.1	7.7%
12	2.197	8.9	2.005	50.9	5.932	150.7	-10.1	8319.1	445				385		8245.8	441			
Average	2.195	9.0	1.998	50.8	5.918	150.3	-10.0												

								Horizontal Deformations (mm)						Failure Strain (microstrain)					
								At Maximum Load			At (Y - X) peak			At Maximum Load			At (Y - X) peak		
Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	North	South	Average	North	South	Average	North	South	Average	North	South	Average
4	2.317	3.9	2.002	50.9	5.910	150.1	-9.9	9.3901E-04	7.4703E-04	8.4302E-04	9.3901E-04	7.4703E-04	8.4302E-04	25	20	22	25	20	22
5	2.315	4.0	1.986	50.4	5.903	149.9	-10.0	1.9826E-04	1.0819E-03	6.4009E-04	2.1738E-04	1.0819E-03	6.4965E-04	5	28	17	6	28	17
8	2.314	4.1	1.974	50.1	5.907	150.0	-10.1	1.4188E-04	9.4319E-04	5.4254E-04	1.6601E-04	9.4319E-04	5.5460E-04	4	25	14	4	25	15
Average	2.315	4.0	1.987	50.5	5.907	150.0	-10.0	Average		6.7522E-04	Average		6.8242E-04	Average		18	Average		18
2	2.257	6.4	2.002	50.9	5.912	150.2	-10.0	2.5085E-05	1.5809E-03	8.0297E-04	8.9861E-05	1.5809E-03	8.3536E-04	1	42	21	2	42	22
5	2.254	6.6	1.998	50.7	5.919	150.3	-9.9	3.6860E-05	1.3453E-03	6.9106E-04	1.3262E-04	1.3453E-03	7.3894E-04	1	35	18	3	35	19
25	2.254	6.5	1.967	50.0	5.905	150.0	-10.1	5.2556E-04	8.5754E-04	6.9155E-04	5.2556E-04	8.5754E-04	6.9155E-04	14	23	18	14	23	18
Average	2.255	6.5	1.989	50.5	5.912	150.2	-10.0	Average		7.2853E-04	Average		7.5528E-04	Average		19	Average		20
2	2.192	9.1	2.000	50.8	5.917	150.3	-10.0	3.0568E-04	1.0037E-03	6.5470E-04	3.0568E-04	1.0037E-03	6.5470E-04	8	26	17	8	26	17
10	2.196	9.0	1.990	50.5	5.906	150.0	-10.0	2.2111E-04	1.2297E-03	7.2540E-04	2.3520E-04	1.2297E-03	7.3245E-04	6	32	19	6	32	19
12	2.197	8.9	2.005	50.9	5.932	150.7	-10.1	5.9978E-05	1.1773E-03	6.1865E-04	8.9952E-05	1.1773E-03	6.3364E-04	2	31	16	2	31	17
Average	2.195	9.0	1.998	50.8	5.918	150.3	-10.0	Average		6.6625E-04	Average		6.7360E-04	Average		18	Average		18

indicates an instance of first failure

Ending horizontal deformation taken as the reading on the same line as t
maximum difference between vertical and horizontal deformation

Table B-29: Instrumented Data @ -10°C: 06-150

Mix Designation	06-150	%RAP	10.0
Mix Type	SP125C	RAP %AC	4.8
Virgin Binder Grade	PG70-22	Total %AC	5.5
%Virgin AC	5.0	%Fibers	0.0
Gmm	2.467		

								Tensile Strength												
								AASHTO T 322-07					NCHRP 530 Correction		AASHTO T 322-03					
Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)	St,n (psi)	Avg. St (psi)	Pf,n (lbf)	St,n (psi)	Avg. St (psi)	St SD (psi)	St CV (%)
10	2.363	4.2	1.973	50.1	5.900	149.9	-10.0	15159.9	829				685		15159.9	829			
13	2.369	4.0	1.999	50.8	5.898	149.8	-10.1	13757.3	743	782	43.6	5.6%	617	648	13601.7	734	780	47.5	6.1%
26	2.371	3.9	1.993	50.6	5.899	149.8	-9.9	14315.2	775				643		14315.2	775			
Average	2.368	4.0	1.988	50.5	5.899	149.8	-10.0												
5	2.303	6.6	1.985	50.4	5.908	150.1	-9.8	11184.7	607				512		11184.7	607			
13	2.307	6.5	1.983	50.4	5.905	150.0	-9.8	11751.7	639	632	22.0	3.5%	536	531	11751.7	639	630	20.0	3.2%
14	2.302	6.7	1.975	50.2	5.901	149.9	-9.7	11887.8	649				545		11793.2	644			
Average	2.304	6.6	1.981	50.3	5.905	150.0	-9.8												
5	2.244	9.1	1.965	49.9	5.923	150.4	-10.3	9789.4	535				456		9779.1	535			
6	2.251	8.7	1.983	50.4	5.906	150.0	-9.9	10421.8	567	551	15.5	2.8%	480	467	10421.8	567	550	15.8	2.9%
17	2.240	9.2	1.996	50.7	5.915	150.2	-9.9	10193.5	550				467		10193.5	550			
Average	2.245	9.0	1.981	50.3	5.915	150.2	-10.0												

								Horizontal Deformations (mm)						Failure Strain (microstrain)					
								At Maximum Load			At (Y - X) peak			At Maximum Load			At (Y - X) peak		
Specimen No.	Gmb	Voids (%)	Thickness (in)	Thickness (mm)	Diameter (in)	Diameter (mm)	Temp (deg C)	North	South	Average	North	South	Average	North	South	Average	North	South	Average
10	2.363	4.2	1.973	50.1	5.900	149.9	-10.0	4.8545E-04	8.2024E-04	6.5284E-04	4.8545E-04	8.2024E-04	6.5284E-04	13	22	17	13	22	17
13	2.369	4.0	1.999	50.8	5.898	149.8	-10.1	2.1924E-04	1.1759E-03	6.9754E-04	2.4096E-04	1.1759E-03	7.0841E-04	6	31	18	6	31	19
26	2.371	3.9	1.993	50.6	5.899	149.8	-9.9	4.6333E-04	6.9265E-04	5.7799E-04	4.6333E-04	6.9265E-04	5.7799E-04	12	18	15	12	18	15
Average	2.368	4.0	1.988	50.5	5.899	149.8	-10.0	Average		6.4279E-04	Average		6.4641E-04	Average		17	Average		17
5	2.303	6.6	1.985	50.4	5.908	150.1	-9.8	1.8824E-04	7.9069E-04	4.8946E-04	1.8824E-04	7.9069E-04	4.8946E-04	5	21	13	5	21	13
13	2.307	6.5	1.983	50.4	5.905	150.0	-9.8	2.3198E-04	1.0721E-03	6.5204E-04	2.3198E-04	1.0721E-03	6.5204E-04	6	28	17	6	28	17
14	2.302	6.7	1.975	50.2	5.901	149.9	-9.7	7.6259E-04	4.0355E-04	5.8307E-04	7.6259E-04	4.1198E-04	5.8729E-04	20	11	15	20	11	15
Average	2.304	6.6	1.981	50.3	5.905	150.0	-9.8	Average		5.7486E-04	Average		5.7626E-04	Average		15	Average		15
5	2.244	9.1	1.965	49.9	5.923	150.4	-10.3	2.3487E-04	1.2611E-03	7.4798E-04	2.6786E-04	1.2611E-03	7.6447E-04	6	33	20	7	33	20
6	2.251	8.7	1.983	50.4	5.906	150.0	-9.9	8.1478E-04	6.1273E-04	7.1375E-04	8.1478E-04	6.1273E-04	7.1375E-04	21	16	19	21	16	19
17	2.240	9.2	1.996	50.7	5.915	150.2	-9.9	1.4092E-04	1.1786E-03	6.5976E-04	1.4092E-04	1.1786E-03	6.5976E-04	4	31	17	4	31	17
Average	2.245	9.0	1.981	50.3	5.915	150.2	-10.0	Average		7.0717E-04	Average		7.1266E-04	Average		19	Average		19

indicates an instance of first failure

Ending horizontal deformation taken as the reading on the same line as t
maximum difference between vertical and horizontal deformation

Missouri Department of Transportation
Organizational Results
P. O. Box 270
Jefferson City, MO 65102

573.526.4335
1 888 ASK MODOT
innovation@modot.mo.gov