Final Report

DEVELOPMENT AND EVALUATION OF A SIMPLIFIED SUPERPAVE IDT TESTING SYSTEM FOR IMPLEMENTATION IN MIX DESIGN AND CONTROL

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Submitted to:

Florida Department of Transportation
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DISCLAIMER

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in²	square inches	645.2	square millimeters	mm²
ft²	square feet	0.093	square meters	m²
yd²	square yards	0.836	square meters	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km²
VOLUME				
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft³	cubic feet	0.028	cubic meters	m³
yd³	cubic yards	0.765	cubic meters	m³

NOTE: Volumes greater than 1000 l shall be shown in m³.

Symbol	When You Know	Multiply By	To Find	Symbol
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
TEMPERATURE (exact)				
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	l
fl	foot-Lamberts	3.426	candela/m²	cd/m²
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
psi	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	yd²
ha	hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi²
VOLUME				
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m³	cubic meters	35.71	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lb)	T
TEMPERATURE (exact)				
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	psi

(Revised August 1992)

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16. Abstract

Asphalt mixtures designed using modern conventional methods, whether Marshall or Superpave methodologies, fail to address the cracking performance of these mixtures. Research previously conducted at the University of Florida for the Florida Department of Transportation has identified key mixture parameters that control cracking performance. These parameters can be obtained from a series of relatively simple tests performed using the Superpave indirect tension tests (IDT). Traditionally, this equipment is large, heavy, requires fixed utilities, and specialized training. A **Simple IDT** testing platform has been developed that removes these restrictions. This platform is small, and portable, incorporating all of the most important performance features of the heavier fixed systems. Evaluation of the **Simple IDT** was conducted, at three different testing temperatures, using a laboratory prepared mixture. The results show equivalent comparison of the key mixture parameters versus two different fixed IDT systems, one at UF and the other at the FDOT State Materials Office. Additionally, software has been developed to aid the operator in performing the tests on the **Simple IDT**, thereby reducing the need for specialized training. Work continues refining a sensor system to measure the on-specimen deformations, which would eliminate the need to glue targets or gage points on the specimen faces, reducing this additional specimen preparation.

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EXECUTIVE SUMMARY

Asphalt mixtures designed using modern conventional methods, whether Marshall or Superpave methodologies, fail to address the cracking performance of these mixtures. Research previously conducted at the University of Florida for the Florida Department of Transportation has identified key mixture parameters that control cracking performance. These parameters can be obtained from a series of relatively simple tests performed using the Superpave indirect tension tests (IDT). Traditionally, this equipment is large, heavy, requires fixed utilities, and specialized training. A **Simple IDT** testing platform has been developed that removes these restrictions. This platform is small, and portable, incorporating all of the most important performance features of the heavier fixed systems. Evaluation of the **Simple IDT** was conducted, at three different testing temperatures, using a laboratory prepared mixture. The results show equivalent comparison of the key mixture parameters versus two different fixed IDT systems, one at UF and the other at the FDOT State Materials Office. Additionally, software has been developed to aid the operator in performing the tests on the **Simple IDT**, thereby reducing the need for specialized training. Work continues refining a sensor system to measure the on-specimen deformations, which would eliminate the need to glue targets or gage points on the specimen faces, reducing this additional specimen preparation.

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

The University of Florida has been conducting research for many years focusing on the cracking performance of asphalt mixtures. Work performed by Roque, et al., has identified parameters that control the cracking performance of asphalt mixtures. Continuing research efforts have focused on the development of performance-based mixture specifications based on these parameters that are obtained from a series of relatively simple tests performed with the Superpave indirect tension test (IDT). These specifications will provide the Florida Department of Transportation, and any other agency, with the tools necessary to specify mixtures that will provide superior cracking performance.

The testing systems necessary to perform these tests have traditionally been very large, and heavy, requiring fixed utilities. Manufacturers such as MTS, Interlaken, Instron, and others, have been making these systems for years. Typically, these systems require a large amount of fixed space, three phase power, and a source of chilled water to cool the hydraulic pump necessary of these servo-hydraulic systems, and cost upwards of $100,000. Additionally, these systems require operators who are specifically trained in their operation, use, and maintenance. These machines are also infinitely flexible, having been designed to test many different products and materials, under a variety of conditions, and across many engineering disciplines or fields. These aspects of these systems make them excessively complex and expensive for routine use in mixture design or quality control. However, with this resource, FDOT now has the potential to achieve superior mixture performance through the implementation of Superpave IDT mixture parameters in their mixture specifications and in the mixture design and control process.

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The following are key features which identify systems currently available for testing asphalt mixtures:

- The systems use servo-hydraulic loading frames which are overly complex and expensive

- Their testing software is too flexible, i.e., not application-specific

- Employ environmental testing chambers which require excessive amounts of time to achieve temperature stability or long soak times to equilibrate specimens

- Require an excessive amount of time or effort to prepare the specimens for testing, i.e., application or gluing of targets for mounting of displacement or strain gages

- Units are non-transportable, requiring large space and fixed heavy utilities

It has therefore been determined that a simplified version of the Superpave IDT testing equipment could prove valuable for routine use in mixture design and for quality control of asphalt mixtures.

1.2 Objectives

The Florida Department of Transportation has identified the need to implement a system which takes advantage of the mixture parameters which control cracking performance. This implementation is not realistic without the development of a tool which mix designers and contractors alike, can use to test mixtures quickly and easily. Therefore, the primary objective of this research effort is to design, develop, and evaluate a simplified Superpave IDT testing system that would be suitable for routine use in mixture design, optimization, specification and quality control. It was originally identified that the system should include the following key features:

- A temperature control system that is rapid and stable, and a method to quickly stabilize the specimens at the testing temperature

- A loading and measurement system requiring minimal specimen preparation

- A system using no servo-hydraulics

- A self-centering loading and measurement system

- A self-contained and portable testing platform

1.3 Scope

The scope of work was divided into tasks. These tasks would be: 1) system design, 2) prototype development, 3) preliminary testing and prototype modification, and 4) system evaluation, performance analysis, and comparison testing.

Task 1: System Design

It was initially determined that the ideal system would be self-contained and designed so that it could specifically perform the resilient modulus, creep and strength tests as required by the HMA fracture mechanics model developed for the FDOT based on the parameters obtained from the Superpave IDT. The testing system was further divided into subcomponents and identified as:

- A liquid-based (preferably water) temperature controlled tank, with a temperature range of 5 to 25°C, with an accuracy of ± 0.2° C.

- A pneumatic-based loading system, including an onboard compressor, to perform the resilient modulus and creep tests

- A screw driven loading system to perform the strength test

- A PC- based data acquisition and control system for both the pneumatic and screw driven loading systems

- Fully submersible on-specimen extensometers or strain gages which are spring-loaded and automatically positioned on specimens of variable thickness and diameter

- A loading frame with a capacity of 20,000 lbs.

Task 2: Prototype Development

Prototype design and development was to be accomplished in-house. All shop drawings of components and subassemblies were to be generated during prototype development. All raw materials, equipment, and instrumentation, was to be ordered so that a prototype could be built. The research team was to work closely with qualified machinists to produce the prototype within the time constraints.

Task 3: Preliminary Testing

A series of tests would be performed to evaluate all the sub-systems of the testing unit and determine whether there were any needs for modification. The sub-systems to be tested would include: the temperature control system, the on-specimen measuring system, the loading system, the data acquisition and control systems. Any modification to the subsystems would be made as necessary, until the entire unit was functioning properly. Preliminary testing of the prototype system would be performed on material(s) of known mechanical and physical properties, i.e., Delrin ^{TM}. The system noise and data quality would also be evaluated at this time.

Task 4: System Evaluation, etc.

Experiments will be performed with an asphalt mixture at three temperatures to evaluate the precision and accuracy of the new testing platform. All properties and parameters needed for cracking performance will be measured and evaluated. Any software modifications needed to reduce and analyze the data were to be made at this time.

These tasks were performed in cooperation with key personnel at the Florida Department of Transportation's State Materials Office. It was also anticipated that most of the machining and building required for this project would be done at the University of Florida. Finally, the

comparison testing of the prototype system, would take place using the existing Superpave IDT system at the University of Florida, as the benchmark for comparison.

CHAPTER 2

DEVELOPMENT HISTORY

2.1 Overview

The primary objective of this research effort was to design, develop and evaluate a simplified Superpave IDT system that was suitable for routine use in mixture design, optimization, specification, and quality control. It is expected that the performance of this simple system to be equivalent to that of the larger, more expensive, and more complex systems, like those found in State DOT or University material research laboratories. Initially, key features were identified to reduce the size, the cost and the complexity of these systems. These were:

1. A temperature control system that is rapid and stable

2. A loading and measurement system that requires minimal specimen preparation, e.g., specimen cutting, gauge application, and manual sensor mounting

3. No servo-hydraulics

4. A self-centering loading and measurement system

5. A small transportable package

In the past, researchers at the University of Florida and the Florida Department of Transportation had worked closely with Tom Brovold, the president of TestQuip, a Minnesota-based company. TestQuip had developed the Brovold Superpave Gyratory Compactor (SGC), now sold by Pine instruments, a well received, super-portable SGC. It was determined that Mr. Brovold's expertise in machine development and design would be very useful in this effort, therefore, Mr. Brovold was enlisted to join the University of Florida in this research effort.

The key features of this apparatus were discussed at length, generating many different ideas, directions and possible solutions. The following are excerpts or summaries of some of the discussions surrounding the key features:

1. It was originally intended that the specimens would be conditioned and tested in a fluid medium or bath. The high thermal conductivity of a fluid would rapidly condition the specimens to the testing temperature and would also tend to be more stable (more thermal mass), than conditioned air. Later discussions regarding testing of specimens in compression, within a fluid medium, revealed that testing in this manner could possibly affect the specimen response and result in a distortion of the data. This idea was abandoned in favor of placing the specimens in sealed bags, and conditioning the test specimens in a separate fluid bath. Upon reaching thermal equilibrium, the bagged specimens would be removed from this bath, transferred to the conditioned space within the **Simple IDT** and then removed from the bags. The testing of the specimens will therefore take place in a conditioned air environment.

2. It was also originally intended to test full height Superpave Gyratory Compactor pills to avoid cutting them into smaller segments, e.g., thereby reducing specimen preparation. Recent tests have shown that performance parameters generated from testing both whole or uncut SGC pills and cut SGC pills to be different. Research presented in past Transportation Research Board meetings have shown and identified density gradients, both axial and radial, through SGC pills, which could account for these results. Testing full height compacted specimens, at the lowest testing temperature, could require the built-in load frame and load cell of the **Simple IDT** to have a capacity greater than some laboratory or state research testing systems. In order to reduce the material and component costs of the **Simple IDT**, the upper load limit of the testing unit will be limited to 10,000 lbs force. This will require the cutting of the SGC pills to a maximum thickness, which will be determined, based on the testing temperature. Current specimen preparation requires the application or gluing of gage points or targets on the specimen faces, where sensors are attached to measure the on-specimen vertical and horizontal strains. This was identified as the key feature of the **Simple IDT** testing unit.

3. The original system design idea involved two separate loading systems, the first being servo-pneumatic, for use in the resilient modulus and creep tests, and an electro-mechanical system, to perform the strength test. The servo-pneumatic system would provide the quick response required for loading and unloading the specimen in 0.1 seconds, while the electro-mechanical system would provide the strength necessary to break the specimens at the coldest temperatures. During our discussions, Tom Brovold identified a manufacturer which had a portable servo-hydraulic test system which might be or could be, modified to meet our needs.

4. A self-centering loading and measurement system was determined to be the most important key feature of the **Simple IDT**. This would eliminate the need to glue or attach targets or gage points to both faces of the specimen on which to attach gages.

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This step in specimen preparation adds days and additional man hours to the performance testing of an asphalt mixture. It was hoped that a simple solution could be found where these addition additional steps would not be required. It was known that this feature would require the greatest attention and design effort. A balance would have to be struck between measuring the on surface strains and impacting or altering the behavior of the mixture under test.

5. As with all the key features, the ability to move or transport the testing system was deemed important. Currently, the fixed testing systems in use require hydraulic power supplies, chillers, and other ancillary equipment for their operation which preclude them from transportation or even movement within a structure or building. The design of this **Simple IDT** system will be self-contained and require only one power source, a standard 120 volt - 20 amp connection. It was expected that the total system weight would be less than 400 pounds, and capable of passing through standard 30 inch doorways, which would add to its portability.

As originally conceived, the **Simple IDT** testing unit was envisioned to have two drive systems to accomplish the tests performed by the servo-hydraulic systems currently in use. Servo-hydraulic testing systems were known to be expensive, and it was intended that cost of the **Simple IDT** would be within the budget of most contractors, consultants, district material offices, and third-party HMA or Superpave mix design companies. Fortunately, Mr. Brovold had worked with a company, Shedworks, Inc., of College Station, TX, which was currently manufacturing a product called the FlexOLT, (http://www.shedworks.com/flexolt.html). The FlexOLT is a small horizontally mounted 10,000 lb load frame within an environmental chamber. This unit is used to test asphalt overlays in Texas and other states. Mr. Brovold thought that this device could be modified, with little effort, into a basis for the **Simple IDT**. This presented several advantages:

1. It consists of a load frame mounted within an environmental chamber whose temperature range closely matched our requirements.

2. The unit was designed around a National Instruments PXI system which has servo-hydraulic control capability, as well as inputs for data acquisition. The PXI system can be used as a stand-alone controller or can be connected to a PC to provide for human interface.

3. The unit featured a self-contained hydraulic pump, with an air cooled heat exchanger.

4. The loading system is a servo-hydraulically controlled 10,000 lb actuator, using PID control.

5. The unit is also portable, on wheels, whose narrowest dimension allows it to pass through standard doorways.

6. The only power utilities required for this unit was a standard 120 volt - 20 amp circuit.

The researchers agreed that the FlexOLT would be a good basis for the **Simple IDT**. A meeting was scheduled with Bill Crockford, president of Shedworks, Inc., and he agreed to modify one of his machines to meet most of our specifications. The original machine capacity specification of 20,000 lbs was reduced to 10,000 lbs, so that a redesign of Shedworks' built-in load frame would not be required. It was already anticipated that gyratory pills would have to be sliced or cut down; therefore, the specimen thickness will be limited by the temperature and the load limit of the actuator and load frame.

After the **Simple IDT** unit was received it was found that the current draw would trip the building circuit breaker. Testing and diagnosis determined that the machine drew considerably more than the 20 amps it was designed for, and a modification to the machine and electrical circuit was made. The machine's electrical specifications have been modified. The combination of the AC compressor, the addition of the new DAQ cards, and the heater strip has caused the machine to exceed the original electrical specs. This particular machine will require 120V at 30 amps, while newer units would use a solid state environmental conditioner system which draws much less current and should allow subsequent models to use the original electrical specifications of 120V at 20 amps.

2.2 On-Specimen displacement gages

The greatest challenge for this project would be the development of the on-specimen measurement system. Many ideas were offered in an effort to reduce the preparation required of the specimens.

Current practice requires the gluing or attachment of targets onto both faces of the specimen. These targets or gage points are either aluminum or steel depending on the measurement system that will be used. These targets are glued at a gage length determined by the specimen diameter. For the **Simple IDT** system, the gage length will be 1.500 inches.

An extensometer system developed by MTS Systems Corporation uses aluminum gauge points, which are glued onto the specimen surface. On these gage points, an attachment kit which holds knife edges is fixed by a set screw. The extensometer's are then clipped onto these knife edges, one over the other, to measure both the horizontal and vertical deformations. This is the system in use by the University of Florida. Another frequently encountered extensometer system is one which was developed by the Epsilon Corporation. This system requires that steel gauge points be glued to the specimen surface. Their extensometer's have built-in magnets in both legs for attachment to the steel gage points. Both systems have yielded similar results in comparison testing. It is expected that both of the systems will be tested in comparison to the final version being developed for the **Simple IDT**.

Of all the ideas presented for the **Simple IDT** on-specimen measurement system, the one which seemed to have the most merit incorporates the use of a spider or gage plate. The spider plate pre-positions the horizontal and vertical gages at the precise gage length prior to making contact with the specimen. Upon making contact with the specimen, the gages are released from the gage plate and are free to move and react to the stresses applied to the specimen. Upon

completion of the test, the gage plate is retracted from the specimen face and the extensometer's return to the correct gauge length. This action resets the gages for the next test or next specimen.

The development of the on-specimen extensometer system, any sensor conditioning, and interfacing with the National Instruments PXI controller (within the Shedworks testing platform) was subcontracted to TestQuip, Inc., through Shedworks, Inc. Mr. Brovold was to work closely with researchers at the University of Florida to develop, test, and complete this design.

The first prototype of the on-specimen displacement gages was very crude and rudimentary. The gages consisted of beryllium flexures, onto which the actual strain gauges are mounted, epoxied to two short aluminum cylindrical legs, whose opposite ends were tapered to fit a mating taper in the gage plate. On the flat bottom of the tapered end of the cylinder, two holes or pockets are back drilled up into the aluminum cylinder. Into these holes, steel pins with carbide tips are inserted (carbide tip down) and these provide the contact points between the specimen surface and the extensometers.

Immediately, it was noticed that these extensometers were very heavy, and called into question their ability to react with the specimen without damping the specimen response. In addition, elastic or rubber bands are used to provide the downward force to keep the gage is in contact with the specimen surface. Depending on how they were stretched, to each side of the cylinder, they provided an uneven force and had a tendency to tip the gage to one side or the other. These prototype gages were tested on a polymer puck simulating an asphalt specimen. For comparison, the opposite side of the polymer puck was instrumented with MTS extenso-meters. These would provide our benchmark for the specimen response. The prototype gages were carefully pushed onto the polymer specimen surface and the elastic bands were adjusted to make even the normal or downward force. A repeated load haversine waveform was applied to

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the specimen and unfortunately, the specimen response was as expected, and it exhibited a dampened response by about 40% versus the opposite side of the specimen. This was repeated many times with similar results. It was therefore determined that this system would require a redesign, taking into consideration that total weight of the extensometers was extremely important, and should be kept at a minimum.

A second prototype system was developed, designed, manufactured, and assembled by TestQuip. This version reduced the weight of the extensometers significantly. It replaced the aluminum cylindrical legs with thin rectangular legs reducing the weight by approximately 60%. It also incorporated a redesign of the beryllium flexure, which made the extensometer easier to assemble. The weak link in this system seemed to be the elastic bands, threaded through the aluminum legs, used to provide the normal or downward force (see Figure 2.2.3). An evaluation of this system, using real asphalt specimens, would reveal any weaknesses or flaws in the design.

This new on-specimen sensor system was again tested side-by-side versus the MTS gages with the glue-on gage points. The bottom side of the test specimens was instrumented using this newer gage plate and extensometer design, while the top side was instrumented with the MTS gages with the glue-on gage points. The testing results were mixed. Analyses of some tests show that both sets of gages measured approximately equal material response, while other test responses exhibit skipping or excessive vibration (see Figures 2.2.1 and 2.2.2).
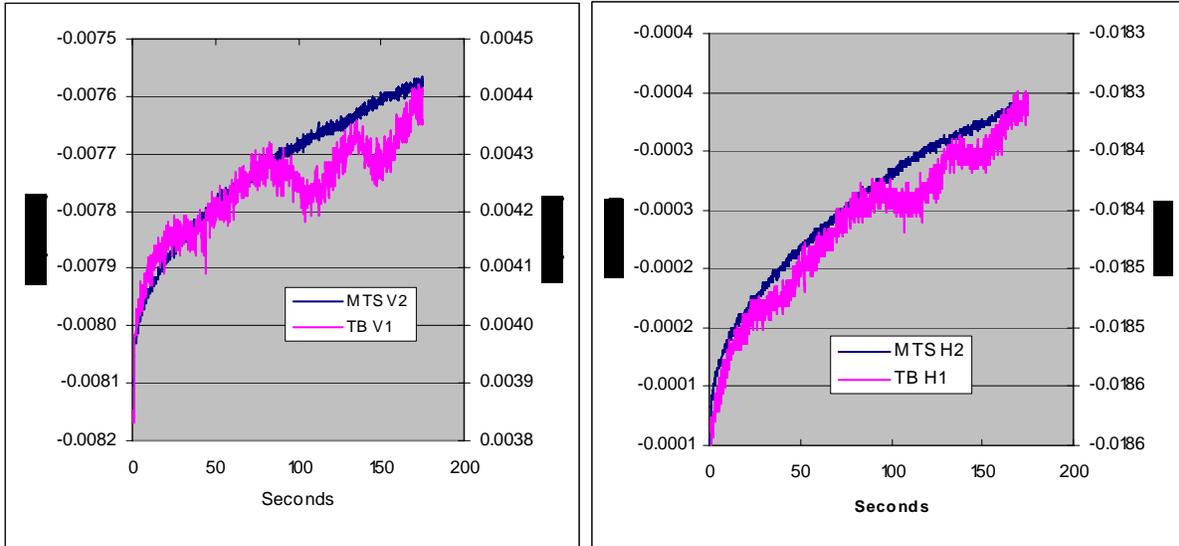
Figures 2.2.1 - Examples of good test responses – Creep Test (with some vibration)
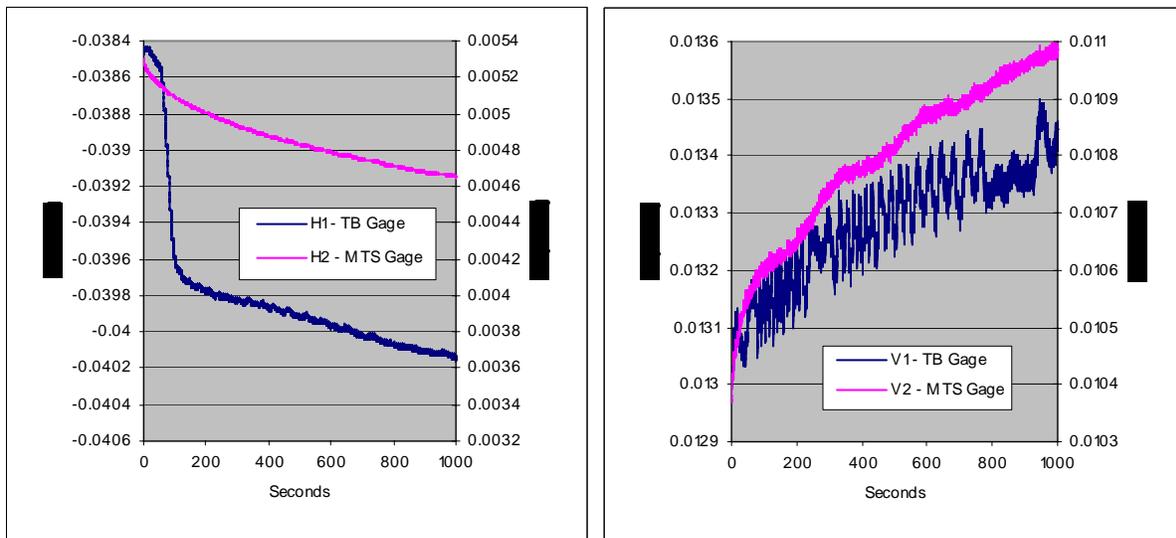
Figures 2.2.2 - Examples of poor test responses – Creep Test (skip and vibration)

The skipping, the above left graph, could be attributable to low friction and/or a loss of contact, between the carbide tip(s) and the specimen surface.

Figure 2.2.3 - Two views of the new gage system (Requires further work.)

The design of this new on-specimen sensor system is still very immature, requires yet another redesign, and is the most mechanically and technically challenging part of the **Simple IDT**, but this was also holding up the completion and evaluation of the **Simple IDT** system. A meeting was held with the project manager from the Florida Department of Transportation to discuss the problems and issues associated with the on-specimen sensor system. Although key to a truly **Simple IDT** testing system, the design of this sensor system (Figure 2.2.3) is being tabled temporarily, and a set of MTS extensometers will be used to complete the evaluation of the **Simple IDT**.

2.3 Strain Gage Conditioning

The PXI controller manufactured by National Instruments, Inc., and contained within the **Simple IDT**, is a very flexible full-featured controller. A user or designer can add input cards, depending on the type of signal, whether analog or digital, only limited by the number of slots available in the PXI chassis. Shedworks, Inc. originally configured the controller to include an analog input card to interface with the strain gage conditioners, which were to be supplied with the on-specimen measuring system.

When received, the prototype gage system included strain gage conditioners manufactured by Dataforth, Inc. Initial tests were performed on a polymer specimen, and it was found that there was an extraordinary and unacceptable level of noise in the signal. The magnitude of the noise level, approximately 200 micro-inches, was high enough to obscure the specimen response. An example of the gage response, and the noise level, is shown in Figure 2.3.1 below.
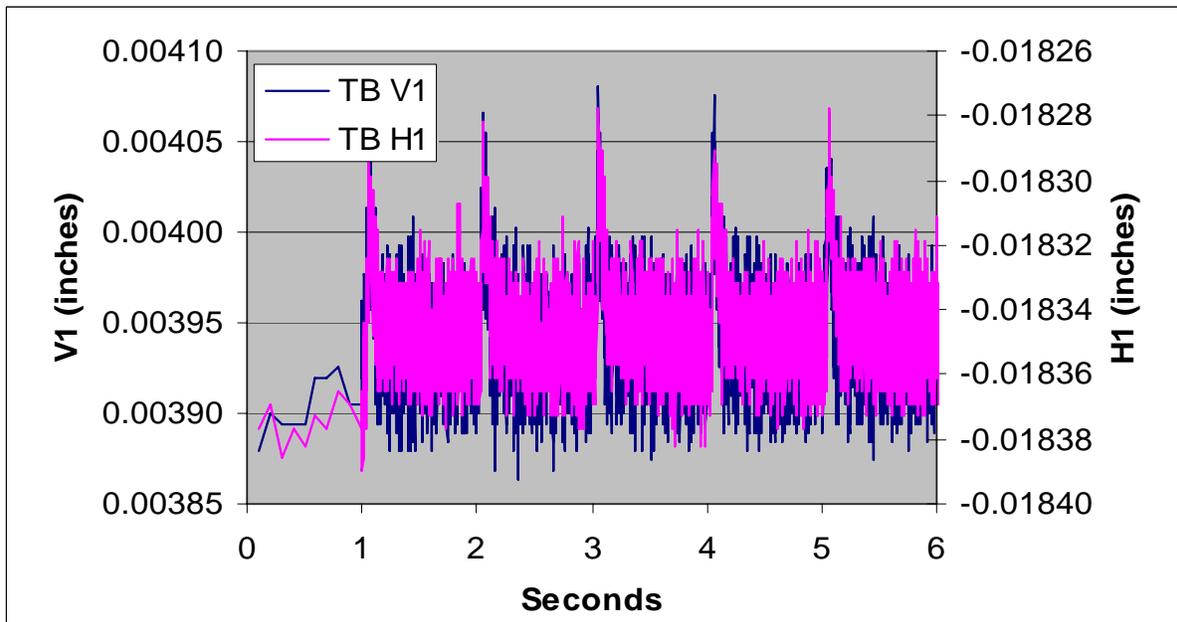
Figure 2.3.1 – Example of early prototype system specimen response (noise)

An evaluation of the system components was undertaken to determine the source of this noise. There were three possible sources for this noise: the signal source, e.g., the gage, the signal conditioner, or the input card to the National Instruments conditioner. Some hardware and software changes were made at this point in the development of the **Simple IDT**. Shedworks added hardware and software filters, in the hopes that this would reduce the signal noise from the strain gages, without success. Many additional combinations were tested, which included using UF's MTS gages, conditioned through the Dataforth electronics, as well as conditioning the new

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gages through the signal conditioner used by the University of Florida. It was then determined

that the source of this noise was both poor initial gage construction and the Dataforth signal con-

ditioners. The product instructions and electrical specifications of the Dataforth signal condi-

tioners were reviewed, and nothing could be found to explain the observations. Contact was

made with the manufacturer of the product and discussions ended without resolution.

The signal conditioner used by the University of Florida in its testing system is a

Hottinger Baldwin Messtechnik MGC signal conditioner with strain gage input cards.

Additional tests using the MGC signal conditioner proved conclusively that the source of the

problem was the Dataforth electronics. Tests were performed on the **Simple IDT** with MTS

gages attached to one side of the specimen and the new gage system with Dataforth strain gage

conditioners on the other.   It can clearly be seen in Figure 2.3.2, the improvement of the signal

quality and signal to noise ratio between the MGC and Dataforth signal conditioners, for the

same MTS gage.
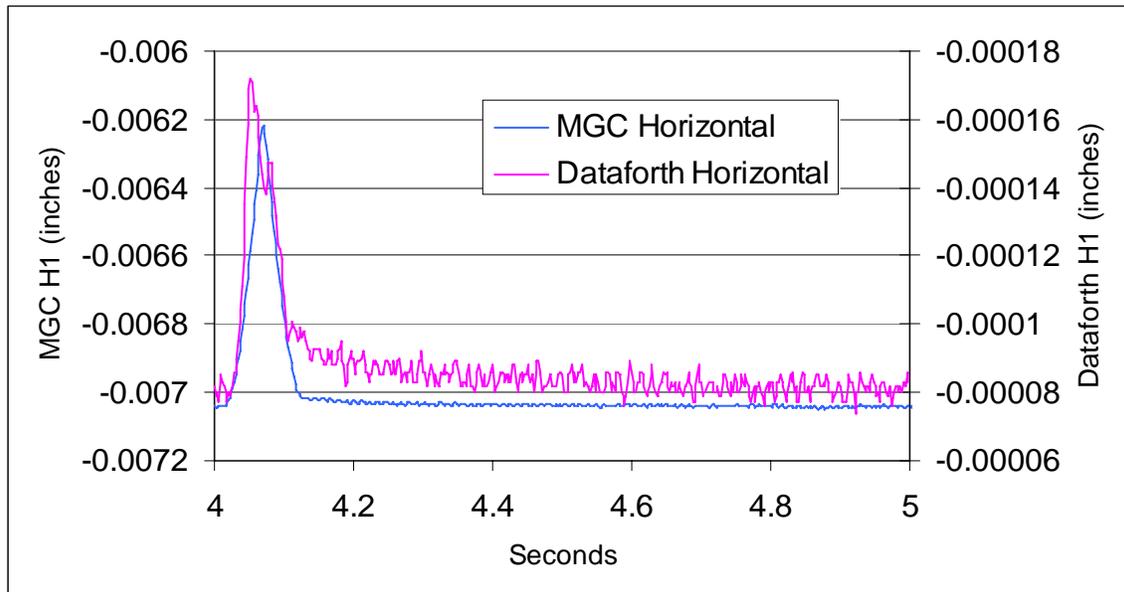
Figure 2.3.2 – Comparison of signal conditioners using the same gage

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Unfortunately, the HBM product is prohibitively expensive, costing close to half of the proposed selling price for the **Simple IDT**. Therefore, the addition of this component to the **Simple IDT** could potentially place its purchase out of reach for most consumers. This led the researchers at the University of Florida to propose a change in the **Simple IDT** hardware. Joint efforts and discussions between UF and Shedworks led to the conclusion that completely different conditioner cards would be required to solve compatibility problems, reduce the noise to acceptable levels, and maintain the overall cost of the product to a minimum. These efforts identified the National Instruments 4220 strain gage conditioner cards as a potential solution. These cards are compatible with the National Instruments PXI controller, and added features not available with the Dataforth system, including variable excitation voltage, gain, and filtering. Unfortunately, the PXI chassis embedded in the **Simple IDT** did not have sufficient slots for the addition of these extra cards. This would require an upgrade of the PXI chassis, to one with additional slots, therefore, the **Simple IDT** was returned to the Shedworks for this makeover. Additionally, National Instruments had unveiled its Version 8.0 of LabVIEW, the software that was being used for control and data acquisition of the **Simple IDT**, and this new version would be integrated into the returned product. Shedworks completed the new hardware and software installation and returned the new and improved version of the **Simple IDT** to the University of Florida for continued evaluation.

The **Simple IDT** system was returned from Shedworks after having been upgraded with the new National Instruments 4220 strain gage conditioner cards. Previous testing had identified the need to upgrade the existing electronics due to high noise encountered in the on-surface strain measurements. Testing shows that the addition of these cards had effectively reduced the signal noise, 90-95%, to about 10-20 micro inches, from the 200 + micro inches of noise

previously measured. This observed noise is roughly double the 5-10 micro inches of noise

usually encountered in either the MTS system at the University Florida or the MTS system at the

Florida Department of Transportation State Materials Office. It was determined that this noise

level was acceptable, and this would be proved during the system evaluation. If necessary, there

are other filtering techniques, which may further reduce this noise, but these will not be pursued

unless this noise level affected the testing or testing results. An additional benefit derived from

these new cards is the ability to apply lower seating loads, which is required for creep tests and

all testing at higher temperatures.

2.4 LabVIEW testing software

LabVIEW, a product of the National Instruments Corp., was previously used by

Shedworks in the design of their product the FlexOLT. It provided the command-and-control

language, including the more sophisticated PID feedback capabilities, as well as mixed mode,

fast rate, multiple input data acquisition.   It is a versatile software package, and Shedworks was

convinced that they could design an instrumentation panel, within the software, to control the

Simple IDT and collect the data necessary for the three tests used in UF's cracking performance

prediction model.

A detailed summary of all three tests were prepared, including how the tests are run, the

order in which they are run, the required format and the data acquisition requirements for the

data output files. Included with the summaries were copies of output files for all three tests,

which would add additional information as to the column order of the data and the organization

of the data headers. This information was sent to Shedworks so that they could design and build

the **Simple IDT** control console. The detailed summary of each test and copy of the exampled

data files are included in the Appendix B.

CHAPTER 3

SYSTEM EVALUATION

3.1 Overview

The system evaluation of the **Simple IDT** would be carried out in a round-robin format. The Florida Department of Transportation's State Materials Office agreed to select the asphalt mix design; then batch, mix, and compact the test verification specimens. These compacted pills would be moved to the University of Florida and sliced into IDT specimens. Three IDT systems are to be used in this evaluation:

1. The **Simple IDT**
2. The Superpave IDT system at the University of Florida
3. The Superpave IDT system at FDOT's State Materials Office

The State Materials Office supplied the test samples to be tested. The samples were cut at the University of Florida, dried to remove any moisture and then tested to determine the % air-void content of the cut specimens. The cut specimens were sorted by their % air void content and grouped for testing. The average air voids per group were kept as close as possible to minimize the effect of air voids content in the performance parameters. (See the Figure and the Specimen Matrix and Allocation Table below.)

The evaluation of the **Simple IDT** system was performed at three temperatures: 0ºC, 10ºC, and 20ºC. This will be used to determine the precision and accuracy of the new system in comparison to two different systems; the MTS system at UF and the MTS system at the State Materials Office. The testing systems at the University of Florida and at the Florida Department of Transportation State Materials Office have previously been tested in comparison with each other. The tests used for that comparison are the same tests that will be used for evaluation of

SIDT Specimen Data
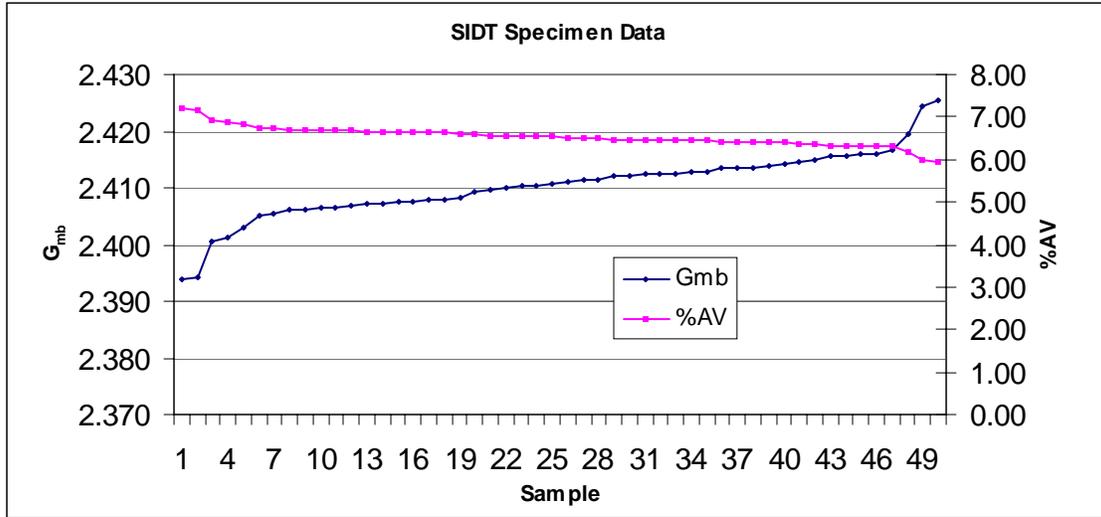
Gmb — %AV

Figure 3.1.1 – Graph of test specimens ranked by air void content and G$_{mb}$

Table 3.1.1 - Specimen matrix and allocation table

| | G$_{mm}$ | 2.579 | | | | | | | | | | | | | | | | | |

Sample ID	G$_{mb}$	%AV		Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Set 8	Set 9	Set 10	Set 11	Set 12	Set 13	Set 14	Set 15
4B2	2.394	7.18																
4A2	2.394	7.16																
6C2	2.400	6.93	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8C2	2.401	6.89	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8B2	2.403	6.83	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4B1	2.405	6.74	4	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
7B1	2.406	6.72	5	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
7C2	2.406	6.71	6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
6B2	2.406	6.70	7	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
3C2	2.406	6.70	8	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
5C2	2.406	6.69	9	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
1C1	2.407	6.68	10	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
2C2	2.407	6.67	11	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
4C2	2.407	6.66	12	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
6A1	2.407	6.65	13	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
5B2	2.408	6.64	14	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
1B1	2.408	6.64	15	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
7A2	2.408	6.64	16	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
3B2	2.408	6.61	17	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
2B2	2.409	6.58	18	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
4C1	2.410	6.56	19	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
5C1	2.410	6.55	20	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
6B1	2.410	6.54	21	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
3B1	2.410	6.54	22	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
8B1	2.411	6.53	23	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
4A1	2.411	6.52	24	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
8A2	2.412	6.49	25	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
8D2	2.412	6.49	26	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
2A2	2.412	6.47	27	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
7C1	2.412	6.47	28	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
1A2	2.412	6.46	29	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
1A1	2.412	6.46	30	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
2A1	2.413	6.46	31	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1B2	2.413	6.44	32	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
8A1	2.413	6.44	33	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
5A2	2.413	6.42	34	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
3A2	2.414	6.42	35	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
6A2	2.414	6.41	36	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
1C2	2.414	6.41	37	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
3A1	2.414	6.39	38	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
8D1	2.415	6.37	39	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
2B1	2.415	6.36	40	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
3C1	2.416	6.33	41	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
5A1	2.416	6.33	42	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
2C1	2.416	6.32	43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
6C1	2.416	6.32	44	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
5B1	2.417	6.29	45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
7B2	2.419	6.19																
7A1	2.424	6.00		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
8C1	2.426	5.95																
				6.88	6.72	6.70	6.67	6.64	6.61	6.55	6.53	6.49	6.46	6.45	6.42	6.39	6.34	6.31
			0.63	0.002409	0.000218	4.9E-05	6.48E-05	6.85E-05	0.000853	0.000142	9.1E-05	0.000152	1.86E-05	6.59E-05	1.21E-05	0.000317	0.000308	0.000218
					MTS	SIDT	FDOT	FDOT	MTS	SIDT	SIDT	FDOT	MTS	MTS	SIDT	FDOT		
				6.88	6.72	6.70	6.67	6.64	6.61	6.55	6.53	6.49	6.46	6.45	6.42	6.39	6.34	6.31
				0.002409	0.000218	4.9E-05	6.48E-05	6.85E-05	0.000853	0.000142	9.1E-05	0.000152	1.86E-05	6.59E-05	1.21E-05	0.000317	0.000308	0.000218

the **Simple IDT**. The results of that previous comparison revealed both systems performed equally, or gave equal values when testing specimens for stiffness, M_r, using the resilient modulus test, or strength, St. That analysis did indicate that there was slight increase in the slope or m-value of the creep curve, with the MTS gages used by the University of Florida giving the slightly higher value. This has been attributed mainly to the difference in design of the extensometers and their method of attachment to the specimen. This difference did not appear to affect the conclusion of the system comparisons.

3.2 University of Florida Superpave IDT system description

The Superpave IDT system at the University of Florida has been in place for many years. It has been the principal tool used for asphalt materials mixture characterization. Originally purchased and installed in the 1980s, the system, manufactured by MTS Systems Corporation, Eden Prairie, Minnesota; used an early 400 series analog system controller and was later upgraded to the current Teststar IIS digital system controller in approximately 1998. The load frame has a capacity of 22,000 pounds, which far exceeds the needs for most asphalt materials characterization, at even the coldest testing temperatures, and includes an environmental chamber manufactured by RTP, Russells Technical Products. The temperature range of the environmental chamber is -10° C to 60° C, with an accuracy of 0.2° C, as required by Superpave specifications.

Early in the development of the Superpave IDT, on-specimen measurements or strains were acquired via micro-miniature LVDT's, Linear Variable Displacement Transducers. The bodies and cores of the LVDT's were mounted in plastic holders and snapped onto brass buttons glued to the face of the specimens. This system, originally developed by Roque and Buttlar at

Penn State, was adopted by UF when both transferred to this institution. Later, MTS Systems Corporation, with input from Roque, designed a set of clip-on extensometers to replace the LVDT's. These extensometers are designed to rely on a minimum spring force to maintain contact with knife edge's mounted to aluminum buttons or points, glued to the face of the specimens (see figure). These MTS extensometers are currently used by the University of Florida in their Superpave IDT system.

Signal conditioning for these MTS extensometers is accomplished via a Hottinger Baldwin Messtechnik MGC data acquisition system. The signal conditioners, within the MGC, provide variable excitation voltage, signal scaling, analog to digital conversion, gain control, digital filtering, and re-conversion to an analog output signal. The MGC is capable of high signal resolution and speed, provides long-term stability and low noise output.

Hydraulic power is provided to the MTS load frame via an MTS SilentFlo hydraulic power supply. This hydraulic power supply provides the actuator, or system, high-pressure hydraulic fluid at 3000 psi, at a flow rate of approximately 5.5 gallons per minute. Heat removal from the hydraulic power supply is accomplished via a portable chiller manufactured by BUDZAR Industries, and is properly sized to the hydraulic power supply.

3.3 FDOT Superpave IDT system description

The Superpave IDT system at the Florida Department of Transportation's State Materials Office has also been in place for many years. This system is manufactured by MTS Systems Corporation, and was originally set up for asphalt mixture testing using an MTS 458 analog controller. This analog controller was programmable via PC using a MTS software package called Testlink, through the Microprofiler built into the controller. Following UF's lead,

FDOT's State Materials Office also upgraded their system to MTS's Teststar IIS digital system controller in approximately 1999.

The Superpave IDT load frame, at the State Materials Office, is a larger load frame having a capacity of 55,000 pounds, but has installed an actuator of 22,000 pounds. This system was originally set up with an environmental chamber manufactured by the Thermotron Corporation, and used liquid nitrogen injection for cooling. This environmental chamber suffered from high temperature fluctuation and low stability, and therefore, in conjunction with the University of Florida it too was upgraded to a chamber manufactured by RTP. This environmental chamber has equivalent specifications to one in use at the University of Florida.

Early in its asphalt mixture testing history, the State Materials Office used extensometers, manufactured by MTS, which measured the full vertical and horizontal diametral strain across asphalt specimens. Following Roque's and Buttlar's transfer to UF, and based on their research, FDOT adopted the same system of micro-miniature LVDT's to measure the on-specimen deformations or strains. Experience at all three institutions clearly evidenced the pitfalls of the system of measurement. The Florida Department of Transportation State Materials Office chose to upgrade their on-specimen measurement system to one manufacturer by the Epsilon Corporation.

This Epsilon extensometer system has equivalent specifications to the MTS system of gages, but differs in their method of attachment to the specimen. Whereas the MTS system uses aluminum gage points, a system of knife edges and spring tension to maintain contact, the Epsilon system uses steel gage points and miniature Alnico magnets for attachment of the extensometer's to the specimen faces (see figure).

As in the UF system, signal conditioning for the Epsilon extensometers is also accomplished via a Hottinger Baldwin Messtechnik MGC data acquisition system. The same benefits of the system as described before apply here.

Hydraulic power is provided to this MTS load frame via an older, but still capable, MTS hydraulic power supply. This hydraulic power supply provides the same fluid pressure, at a higher flow rate of approximately 11 gallons per minute. Heat removal from this hydraulic power supply is accomplished via building processed water, an asset built into the State Materials Office testing laboratory.

3.4 Testing software

The testing software is used to control the application of the load, which includes the magnitude, the wave shape, and the duration of the load; and the data acquisition data during the tests. The load and the required data vary with the test type. The University of Florida primary uses three tests in its Superpave IDT test suite, they are: a resilient modulus or stiffness test, a 1000 second creep test, and a strength test. These tests are run in this order to reduce the accumulated damage to the specimen.

The resilient modulus test requires the application of a haversine load to the specimen of 0.1 second duration, followed by a rest period of 0.9 seconds. This load pattern or cycle is repeated five to seven times, depending on how many clean, even cycles are recorded. The data acquisition rate for this test is 500 Hz, and the data analysis package requires a minimum of 2500 data lines, therefore, a minimum of five load applications are required. The magnitude of the applied load is adjusted or limited, so that the horizontal deformations are between 100 to 300 micro inches. This limit varies with testing temperature and the material or mixture being tested.

The creep test requires the application of a constant load, applied as a step function, for a duration of 1000 seconds. The magnitude of this applied creep load is only a small fraction or portion of the load used for the same specimen during the resilient modulus test, typically around 5%. The magnitude of this load is adjusted so that the horizontal deformations meet certain criterion. These criterions are limits set on the horizontal deformations at 100 seconds, and as a not-to-exceed value at the end of the test. These limits can vary with test temperature or with the specimen type, but most importantly, with heavily aged specimens. For example, heavily aged specimens may exhibit low creep strain, with a slope close to zero; therefore, there may be little difference between the 100s and 1000s deformations. These are treated as special cases.

The data acquisition rate for the creep test changes or varies with time, after the application of the load. For the first 10 seconds of the test, the data acquisition rate is set at 10 Hz or 10 samples per second, for a total of 100 data points. For the next 290 seconds, the data acquisition rate is set at 1 Hz or one sample per second, for a total of 290 data points. The last 700 seconds of the test require only one data point every five seconds, for a total of 140 data points. In total, the creep test data acquisition generates 540 lines of data, including the 10 pre-load data points.

The last test in this series is the strength test. This is a destructive test, which takes the specimen to failure, and can also be described as a modified Lottman test. The specimen is loaded at a constant rate of deformation of 2 inches per minute, and is considered failed when the load peaks and then falls or yields 20% from the peak value. The data acquisition rate can either be set to take data readings for every 30 pound change in load, or it can be a combination time-dependent, and load crossing data. Depending on the strength of the material and the temperature at which the test is performed, the number of data lines is usually between 150 to 400 lines.

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All the above tests are preceded by one second worth of data just prior to starting the test, sampled at 10 Hz, to establish a baseline or zero from which to reference the data. A detailed description of each test and a short example of each data file can be found in Appendix B. These examples also show the column order in which the data needs to be collected and prepared, and the line where the first data point is expected for analysis by the University of Florida's ITLT Express software package.

3.4.1 UF and FDOT MPT software

The testing systems at both the University of Florida and the Florida Department of Transportation's State Materials Office use MTS Teststar IIs system controllers. These controllers are highly flexible and both use MTS's Multi-Purpose Testware, or MPT for short, testing software. Within MPT, programs or configurations have been written for the three tests: resilient modulus, creep, and strength; which control the application of the load and set the data acquisition parameters for the tests. These programs are very flexible, allow any parameter to be changed, and have been made available and are available to anyone who wishes to use or try them.

3.4.2 Simple IDT software

The control and data acquisition software for the **Simple IDT** has been written by Shedworks, Inc. using the National Instruments LabVIEW program. The virtual instruments or VI's, as National Instruments calls them, have been converted into an executable file or application. Within this application, the user can change the type of test to be performed, the seating load, the maximum applied load, the number of cycles or the length of duration of the test. The application also includes menus for calibration of all sensors, and tuning parameters for machine control. The main page of the application also includes a real-time graphing or plotting function for all sensors, meters showing actuator position and load, as well as control tabs to

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move the actuator in either load or position control. These controls facilitate the loading and unloading of specimens into the **Simple IDT** testing unit. More details regarding the use, set up, and calibration of the **Simple IDT**, can be found in the user's manual (see Appendix E).

CHAPTER 4

TEST RESULTS AND ANALYSIS

4.1 Overview

The specimens were separated and prepared for testing according to the specimen matrix and allocation table, previously discussed in Chapter 3. The specimens were organized by testing temperature and testing location. The specimens were then measured for thickness at four equally spaced locations approximately 90° apart, and an average thickness was calculated. These specimens were laboratory produced and compacted in a Superpave Gyratory Compactor (SGC), therefore, their diameter was fixed at 150 mm, or 5.906 inches and this diametrical dimension was used for analysis. (The specimen dimension summary is included in the Appendix). A simplified testing allocation table is shown here for completeness.

Table 4.1 - Simplified testing table

Specimens Tested at 0°C			Specimens Tested at 10°C			Specimens Tested at 20°C		
MTS	SIDT	FDOT	MTS	FDOT	SIDT	MTS	SIDT	FDOT
7A2	4C1	6A1	4B1	1C1	6B2	7C1	3B1	8A2
3B2	5C1	5B2	7B1	2C2	3C2	1A2	8B1	8D2
2B2	6B1	1B1	7C2	4C2	5C2	1A1	4A1	2A2

The specimens scheduled to be tested at the University of Florida, in either the **Simple IDT** or the Superpave IDT, were further prepared by applying aluminum gage points or buttons, using a toughened cyanoacrylate adhesive (Loctite #426). These points are adhered to the middle quartile of both specimen faces in both the horizontal and vertical directions, at a gauge

length of 1.500 inches. The specimens to be tested at the Florida Department of Transportation State Materials Office were similarly prepared with steel gage points, or buttons, for their Epsilon extensometer measuring system.

Testing took place in no particular order, but all testing started with 10°C, followed by testing at 0° C, and finishing with testing at 20°C. Specimens were subjected to soaking and stabilization at the testing temperature for a minimum of eight hours. Testing immediately followed, in the order previously described: first resilient modulus, followed by the 1000 second creep test, and ending with the strength test.

4.1.1 Resilient modulus

The resilient modulus, or M_r, is computed by applying measured repeated loads to a specimen, and measuring the deformation response of the specimen. The resulting computation is stress over strain, and it is the most common method for measuring the stiffness of asphalt mixtures. A complete description of the test and loading methods, including derivations and equations for Poisson's ratio and resilient modulus, can be found in literature by Roque and Buttlar, 1992 and 1994, et al.

The first system tested was the Superpave IDT system at the University of Florida. The system was tested using the specimens designated in the testing matrix. Depending on the test temperature, a load (low) was carefully selected, and applied to the first specimen to determine the material response. The horizontal deformation was measured from the recorded data, and the load was sequentially increased, until the horizontal deformation exceeded 100 micro inches. This final load was used for all subsequent tests, allowing for variations due to slight changes in specimen thickness.

Since the groupings of specimens were carefully controlled for air void content, for specimens used between systems at a particular temperature, the load that was established to

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produce the specific specimen response, i.e., horizontal deformation, was used for all specimens between all systems.

During testing, each data file was carefully screened to catch errors due to misaligned or wrongly placed gages, and/or eccentric loading. If found, these errors were corrected on the spot and the sample was rerun to obtain a corrected data file. After testing, all M_r data files were subsequently screened to remove empty lines from the header and the file extensions were changed to **txm**, the file extension ITLT Express requires for analysis of the resilient modulus data. The results of the analysis are shown in the Table and Figure below.

Table 4.1.1 - M_r data analysis output

Temp	M_r (GPa)		
	UF MTS	SIDT	SMO MTS
0°C	17.63	19.13	18.63
10°C	13.50	12.35	12.56
20°C	6.85	7.29	7.93
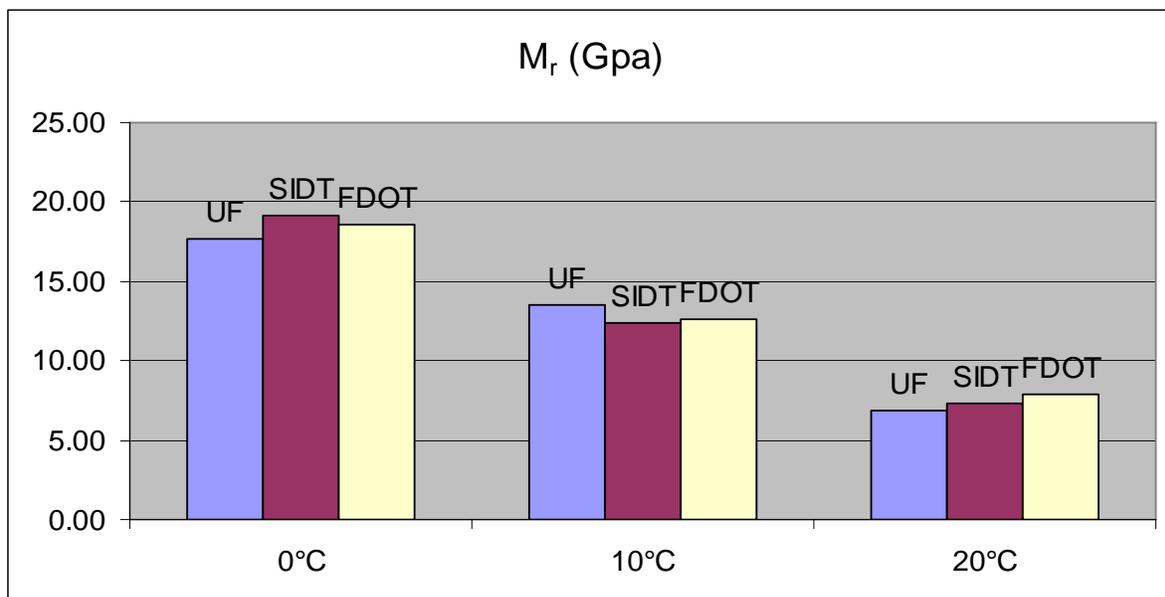
Figure 4.1.1 - M_r analysis data

Analysis of the resilient modulus data show that the **Simple IDT** testing system compares equally with the fixed systems at the University of Florida and at the Florida Department of Transportation State Materials Office.

4.1.2 Creep compliance

The creep compliance, or creep test, as it is more commonly referred to, is performed by applying a static load to the specimen and measuring the time-dependent vertical and horizontal deformations. The specimen compliance is then calculated from this data by dividing the strain by the applied stress.

The creep test is performed on the same specimen immediately following the resilient modulus test. The creep load or static load that is applied to the specimen is a percentage of the load which was applied during the resilient modulus test. This load is typically 5% of the magnitude used in the resilient modulus.

As with the resilient modulus test, the first specimens and system tested at all temperatures were the specimens and the Superpave IDT system at the University of Florida. Again, depending on the test temperature, a low load was carefully selected, and applied to the first specimen to determine the material response. The horizontal deformations were measured and monitored for the first 100 seconds of the test. If the creep curves read 90μin before 90 seconds elapse, or the curves do not exhibit the expected creep-like response, then the test was terminated. Unequal response between the specimen faces may require an adjustment to the gages, or a re-seating of the specimen due to an eccentric loading condition. If the horizontal deformations were below approximately 80μin at 100 seconds, the test was terminated, and the test rerun with a nominally increased creep load. If the specimen response at 100 seconds was between approximately 80μin to 120μin, a prediction of the horizontal deformations was

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graphically estimated to 1000 seconds. This estimation determines whether an upper bound on the horizontal deformations will be reached which may produce or induce damage to the specimen. If this upper bound will not be exceeded, the test was allowed to proceed to completion and terminate. Total test time or duration is 1000 seconds.

Once the creep load was established for the first specimen at a particular temperature, that creep load was used for all specimens, on all systems. Some variation in that creep load was allowed for differences in specimen thickness, and specimen response. Typically, little or no change was necessary to the creep load.

After testing, all creep data files were subsequently screened to remove empty lines from the header and the file extensions were changed to **txc**, the file extension ITLT Express requires for analysis of the creep compliance data. For analysis, the slope of the creep compliance curve or the m-value at some time, *t*, is normally used for comparison between tests. The results of the analysis are shown in the table and graph below.

Table 4.1.2 - Creep data analysis output

Temp	m-value		
	UF MTS	SIDT	SMO MTS
0°C	0.487	0.462	0.450
10°C	0.591	0.662	0.542
20°C	0.682	0.703	0.630
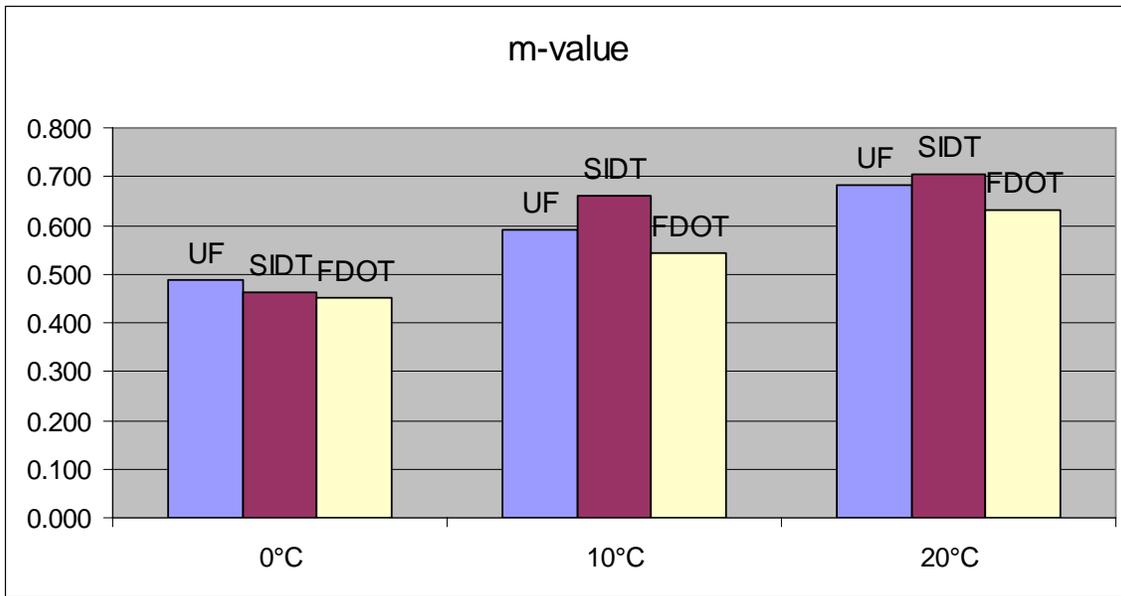
Figure 4.1.2 - Creep analysis data

Analysis of the creep compliance data show that the **Simple IDT** testing system compares equally with the fixed systems at the University of Florida and at the Florida Department of Transportation State Materials Office. The data at 0°C does exhibit less variation than the data at 10°C and 20°C, respectively, but the FDOT State Materials Office data has the lowest slope at all temperatures. This is most likely due to the differences in the gage type and construction, e.g., MTS gages versus Epsilon gages. This trend has been observed before in other comparison tests performed between the University of Florida and the Florida Department of Transportation's State Materials Office. The trend is attributed to the method of attachment of the MTS gages which uses a spring or contact force of approximately 50 g to maintain contact between the knife edges. It has been proposed that this contact force initiates a localized failure in the material surrounding the gage points. This would obviously be lessened when the material is stiffer, which accounts for the observations at the lower temperature. How this variation affects the cracking performance parameters in this study, will be shown later.

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4.1.3 Tensile strength

The tensile strength test is performed by loading a specimen to failure at a constant rate of deformation. The deformation rate used in these tests, by the University of Florida, is 2 inches, or 50.8 mm, per minute. The load response of the specimen is allowed to peak and yield as the specimen is taken to failure during this test. The test is considered complete when the load response falls by 20% of the peak value.

Special attention needs to be drawn on performing these tests on specimens at or below 0°C. The specimen behavior at these temperatures is brittle in nature, and the specimens seemingly shatter or explode when taken to failure. Safety limits must be set on the equipment to minimize this effect or damage to any manufacturer's gages can be sustained.

All specimens were successfully failed. After testing, all strength data files were subsequently screened to remove empty lines from the header and the file extensions were changed to **txs**, the file extension ITLT Express requires for analysis of the creep compliance data.

For analysis, the data from each face of the specimen is analyzed to determine the point of first failure. This is accomplished by plotting the vertical minus the horizontal deformations for each face and selecting that point in time where this calculation deviates from the linear. The first point in time, whether from face one or face two of the specimen is determined to be the point of first failure. The load and the deformations are extracted from the data at this point of first failure and used in the computations for tensile strength and strain at failure. The results of the analysis are shown in the table and graph below.

Table 4.1 3 - Strength data analysis output

	St (Mpa)		
Temp	UF MTS	SIDT	SMO MTS
0°C	3.470	3.360	3.390
10°C	2.530	2.310	2.410
20°C	1.290	1.260	1.340
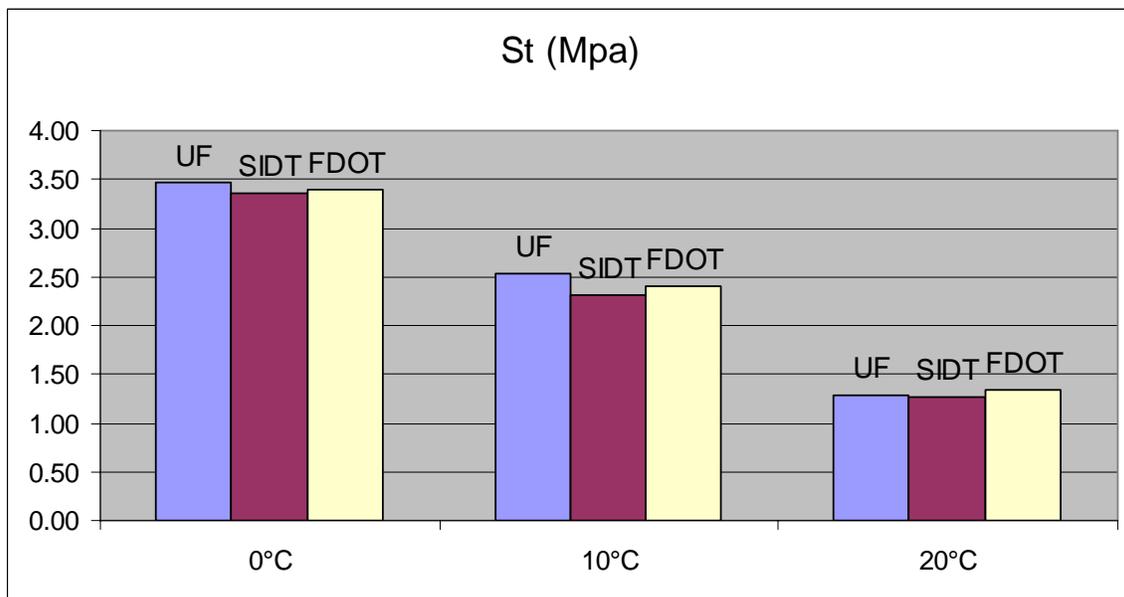
Figure 4.1.3 - Strength analysis data

Analysis of the strength data show that the **Simple IDT** testing system compares extremely well with the fixed systems at the University of Florida and at the Florida Department of Transportation State Materials Office. The data is consistent at all temperatures, and exhibits the greatest variation at 10°C. This is likely due to random testing error.

4.1.4 Energy ratio

It is now clearly recognized that top-down cracking is real problem, and a major form of distress in hot mix asphalt pavements. Many state agencies and research universities are spending valuable time and resources in an effort to understand and characterize this phenomenon. The Florida Department of Transportation asked the University of Florida to develop a tool or method which could be used to categorize and characterize a mixture with respect to its top-down cracking performance. From the years of work that had been performed at the University of Florida, it was clear that there was no one single major property or characteristic which could be used to predict that performance. A parameter, called the energy ratio, or ER, was derived from the HMA fracture mechanics model developed at the University of Florida. This parameter was able to accurately discriminate between companion field test pavements which had exhibited top-down cracking, and those which had none.

The energy ratio is defined as the dissipated creep strain energy threshold of a mixture, $DSCE_{HMA}$, divided by the minimum dissipated creep strain energy required to resist damage in the same mixture, $DSCE_{min}$. This theory is based on the approach that each mixture has a damage threshold limit, which if exceeded, will produce a macro- crack, or un-healable damage. These energy values can be easily calculated from parameters obtained from the tests performed using the Superpave IDT. The $DCSE_{HMA}$ is calculated from tensile properties obtained from the resilient modulus and strength tests, while the $DSCE_{min}$ is calculated from properties and variables obtained from the creep and strength tests.

The energy ratios were computed for the mixture tested on all three systems, at all three temperatures, using an applied stress of 150 psi for all calculations. This stress is used in the HMA Fracture Model to calculate the crack growth. The results of the analysis are shown in the table and graph below.

Mixtures with an energy ratio greater than 1 will be less susceptible to cracking, with higher values being better. However, the energy ratio alone does not completely characterize the cracking performance of the mixture. If a mixture has too low a $DCSE_{HMA}$, i.e., < 0.75, the mixture could fail, or if the ER is below 1, but the mixture has a high $DCSE_{HMA}$, > 2.5, the mixture should perform well.

The original ER concept was developed for Superpave IDT tests performed at 10°C, and while there is no historical ER analysis for tests performed at other temperatures, the calculations were performed and presented here for completeness.

Table 4.1.4 - Energy ratio analysis output

	Energy Ratio		
Temp	UF MTS	SIDT	SMO MTS
0°C	2.644	2.821	2.730
10°C	2.018	2.225	2.260
20°C	0.659	0.619	0.810
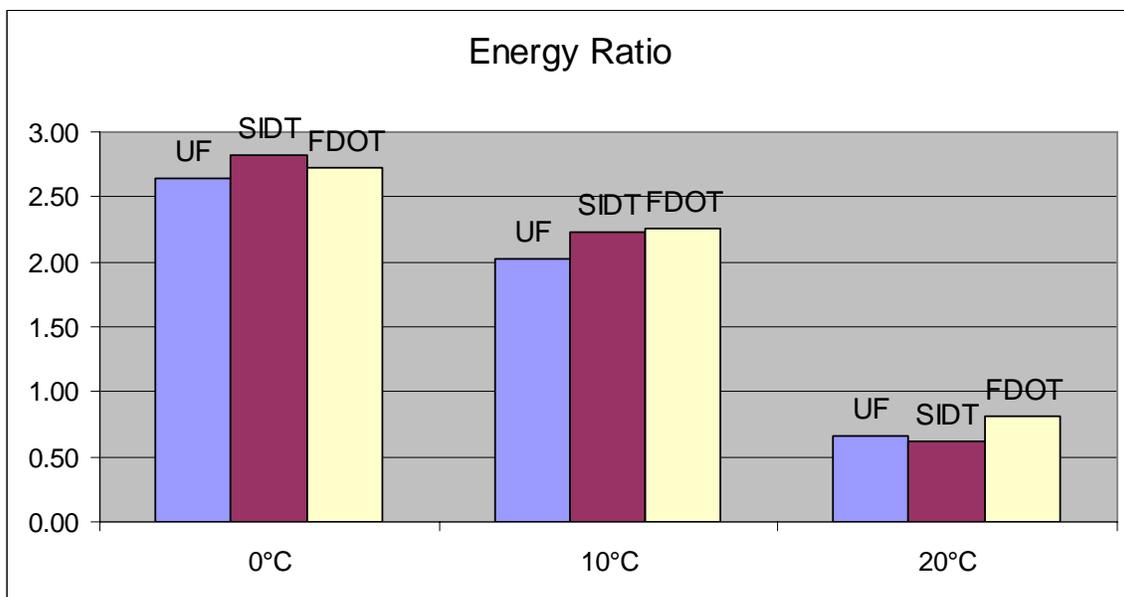
Figure 4.1.4 - Energy ratio analysis data

Analysis of the energy ratio data show that the **Simple IDT** testing system compares extremely well with the fixed systems at the University of Florida and at the Florida Department of Transportation State Materials Office. The data is consistent and exhibits equal variation at all temperatures.   The energy ratio at 10° C has slightly higher variability than the energy ratio calculated at the other temperatures due to the lower value obtained from the data at the University of Florida.

CHAPTER 5

SOFTWARE DEVELOPMENT

5.1 Overview

The operation of a Superpave IDT testing system can be very complicated, especially for the inexperienced user. The testing systems at the University of Florida and the Florida Department of Transportation are manufactured by one supplier, but many other manufacturers offer similar systems. These two systems have been particularly tailored and programmed to test bituminous mixtures. Specific test programs or configurations, as they are called by MTS, have been written for each test; M_r, Creep, and Strength; which control the actions of the testing system and generate or acquire data from the system and specimen in a manner needed for analysis. These programs, and sometimes the system, require input from the operator to properly perform a test. Normally, this comes from training and experience, which is the performance of hundreds or thousands of tests. Determining the correct load to apply to a specimen and verifying the output as good or bad is left to the operator and can be very subjective. Therefore, the operator serves a vitally important role in quality control, both of the test and the output or collected data. Additionally, the operator must prepare the data so that it can be used by the analysis software **IDT Express**. This requires the operator to open the data files, delete empty lines or gaps in the data, modify the file header, and save the data file in text format with a specific file extension for recognition by the analysis program **IDT Express**.

The development of the **Simple IDT** is intended for use by operators at the agency and contractor level who would not necessarily have any or much experience performance testing bituminous mixtures in a research setting. We have therefore established a goal to provide with the **Simple IDT** the software program **IDT^{Assist}**, which will provide operators of the **Simple IDT**,

assistance or guidance as they perform the three Superpave IDT tests as required by the University of Florida HMA Fracture Mechanics Model. In the past, Superpave IDT tests were generally performed on mixtures slated to be used as structural components in pavements, but more recently, Superpave IDT tests are also being performed on open graded friction courses or OGFC's. **IDT**^{Assist} will work when testing either structural mixes or OGFC's and will assist the operator in three areas: load selection, quality control of the data, and data file correction and conversion for **IDT Express**.

The Superpave IDT tests are performed in the order which minimizes the damage sustained by the specimen under test. The order is: 1) resilient modulus, 2) creep, and 3) strength tests. **IDT**^{Assist} will assist the operator in performing all three tests in order, or each routine can be used individually, to run multiple tests of any one test. When starting the application **IDT**^{Assist}, a simple window opens up with three buttons labeled for the three tests. Simply left clicking on any button will start that particular routine.

5.1.1 Resilient modulus

Clicking on the button labeled *MR Analysis* will start that routine or portion of the application. A second window or menu appears which is divided into an upper and lower section. The upper section assists the operator in selecting the initial load which to apply to the specimen. The required inputs from the operator are:

- Specimen thickness – numeric input (in inches)

- Test temperature - 0°C, 10°C, or 20°C (check box)

- The mixed type - dense grade or OGFC (check box)

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The output the operator receives is a load in pounds force which the operator would input into the **Simple IDT** control program to run the first test, and is calculated using this standard equation:

$$P = \frac{Mr * H * t}{(\mu + 0.27)}$$

(Eq. 5.1.1 a)

where, P is the calculated output in pounds (lbs), M_r the estimated material modulus or stiffness (psi), H is the desired average horizontal deformation in inches (in), t is the specimen thickness in inches (in), and μ is the Poisson's ratio. The variable H is currently hard-coded or fixed at 150 micro inches (we have underestimated the modulus numbers in our predictive equations to return a modest initial load, therefore, we use 150μin to reduce the number of load iterations to get a valid test, and it is consistent with our 2nd load calculation), and the Poisson's ratio, μ and material modulus, M_r vary with temperature and are selected from the following Figure:
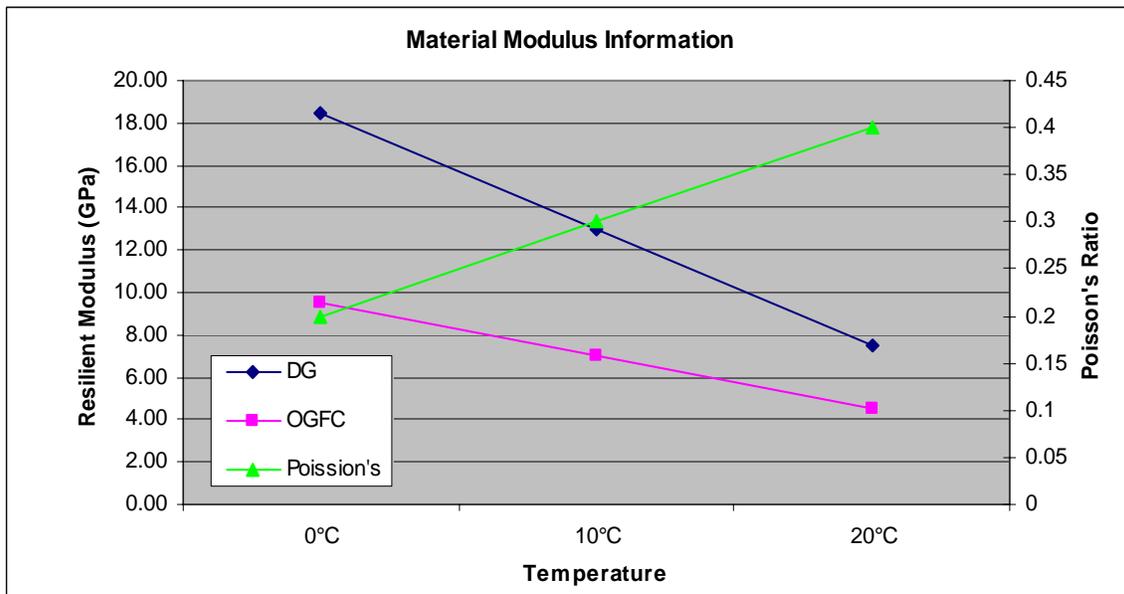
Figure 5.1.1 – Reference material modulus information

The operator will perform a first resilient modulus test on the specimen with the calculated trial load. In the **Simple IDT** control console, the operator will be required to name the output file. It is important that the file name contain the letters "mr" in the name to flag the file for the correct analysis routine. When finished with this first test, the operator will analyze that file, by first browsing the data folder and selecting the name of the file just previously created, and clicking on button labeled *PERFORM ANALYSIS*. The *BROWSE* and *PERFORM ANALYSIS* buttons are located in the bottom portion of the resilient modulus application.

When the operator analyzes a resilient modulus data file, several operations occur in sequence or parallel:

1. The data file is cleared of empty lines in the body of the data or in the header, the number of data lines are counted and checked to be greater than 2500, and this new file is saved with a *.txm* extension for use by the **IDT Express**.

2. The vertical and horizontal resilient deformations are measured for every load cycle.

3. A trimmed mean average is calculated for the horizontal resilient deformations and displayed for each specimen face as $\Delta H1$ and $\Delta H2$.

4. The true applied load is measured from the data and displayed.

5. Decision rules or filters are applied to the horizontal resilient deformations to provide the operator a method to insure quality control of the data. Each decision rule or filter generates an action to either run another test with an increased load, to abort any additional testing due to possible damage to the specimen, or to proceed to the next test, that is, the creep test. These decision rules or filters are summarized in the table below, and include the action which they generate.

The first three constraints are based on the precondition that the ratio of max $(\Delta H1, \Delta H2)$ to min $(\Delta H1, \Delta H2)$ should be less than 1.8. This constraint will limit or control the difference between the two sides or faces of the specimen.

Table 5.1.1 - M$_r$ data quality control rules and filters

Decision Rules for Resilient Modulus		TRUE
max(ΔH1, ΔH2)/min(ΔH1, ΔH2) ≤ 1.8 and	min(ΔH1, ΔH2) ≤ 100 μin	Re-run test
max(ΔH1, ΔH2)/min(ΔH1, ΔH2) ≤ 1.8 and	100 μin ≤ ΔH1 and ΔH2 ≤ 300 μin	Continue
max(ΔH1, ΔH2)/min(ΔH1, ΔH2) ≤ 1.8 and	max(ΔH1,ΔH2) ≥ 300 μin	End test
max(ΔH1, ΔH2)/min(ΔH1, ΔH2) > 1.8		End test

The first constraint indicates that the load applied to the specimen was insufficient to produce the required specimen response, in other words, the horizontal deformations are too low. The operator will be advised to rerun the test with an increased load which is calculated using the following equation:

$$NewLoad \quad = OldLoad \quad \times \frac{150\ \mu in}{\frac{(\Delta h1 + \Delta h2)}{2}}$$

(Eq. 5.1.1 b)

The second constraint checks the magnitude of the horizontal deformations. If the specimen data passes the criteria, the program will advise the operator to continue to the creep test.

The third constraint is one which will be rarely encountered, but is in place as a safety net. If the specimen response produces horizontal deformations which are greater than 300 micro inches, the specimen is most likely damaged or failed, and proceeding would be meaningless.

The forth constraint determines that the difference between the sides or faces is too large, it advises the operator to check the extensometers and the position of the specimen for the possibility of eccentric or off axis loading.

It would be next to impossible to account for every erroneous or problematic data combination that an operator will encounter, but these current rules should cover the majority of the decisions which normally arise. Additional rules and filters can be easily added to the software as they are needed, and the current rules can be modified as more experience or data is gained in their use.

5.1.2 Creep compliance

The second button on the **IDT**^Assist menu is labeled *CR Analysis*. This portion of the application will normally be run directly following the resilient modulus test, but it can also be used as a stand-alone routine. If used as a stand-alone routine, the operator is still required to select the mix type, the test temperature, and the specimen thickness, to generate an initial load for resilient modulus in the upper portion of the resilient modulus application. This initial M_r load, or the last load generated in the M_r routine is used to calculate an initial or seed load which will be the first applied creep load to the specimen. This initial or first creep load is calculated when the operator pushes the *Perform Analysis* button in the **IDT**^Assist application using the following equation:

$$1stCreepLoad = 0.04 * LastMiddle3CycleAvgLoad \qquad \text{(Eq. 5.1.2 a)}$$

The operator will select to run the creep test, from the pulldown test menu, in the **Simple IDT** control console and a set of inputs will appear requiring entry from the operator. This is where the operator will input the first creep load, name the data file, and perform the first creep test for a duration of 100 seconds.

Following this initial creep test, the operator will perform an analysis of that file, by first browsing the data folder and selecting the name of the file just previously created, and clicking on button labeled *PERFORM ANALYSIS*. The *BROWSE* and *PERFORM ANALYSIS* buttons are located in the bottom portion of the Creep Compliance application. Just as with the M_r application, several operations occur in sequence or parallel during analysis of this data file:

1. The data file is cleared of empty lines in the body of the data or in the header, the data lines organized, and this new file is saved with a *.txc* extension for use by the **IDT Express**

2. The vertical deformations, V1 and V2, and the horizontal deformations, H1 and H2, are measured at 100 seconds

3. A nonlinear regression analysis is performed on the horizontal deformation data and the values of H1 and H2 at 1000 seconds are predicted or forecast, and the slope of the creep curves, m_1 and m_2, are calculated. This regression is performed on the last 30 seconds of creep data to capture only the viscous response and minimize error from the elastic response.

4. Decision rules or filters are applied to the horizontal deformations to provide the operator a method to insure quality control of the data. Each decision rule or filter generates an action to either run another test with an increased load, to abort any additional testing due to possible damage to the specimen, or to continue with the 1000 second test. These decision rules or filters are summarized in the table below, and include the action which they generate.

In all cases, the slope or m_x of the creep compliance curves are calculated as a quality control check on the data. A single m_x value close to zero or negative, raises a flag, and may indicate a problem with that gage. If both slope values are close to zero or negative, this is a possible indication of a heavily aged and/or stiff mixture, i.e., a special case, or a creep load which is too low for adequate material response. Therefore, the first seven constraints first check to determine whether both slopes are greater than 0.1

Table 5.1.2 - C_r data quality control rules and filters

Decision Rules for Creep Compliance			TRUE
m1 & m2 $\geq$ 0.1 &	$\Delta H1(100)$ & $\Delta H2(100) < 80\mu in$ or {(($\Delta H1(100)$, $\Delta H2(100)) < 80\mu in$ & $80\mu in \leq (\Delta H2(100), \Delta H1(100)) \leq 130\mu in$}	& max($\Delta H1(100),\Delta H2(100)$)/ min($\Delta H1(100),\Delta H2(100)$) ≤ 2.35	Re-run test
		& max($\Delta H1(100),\Delta H2(100)$)/ min($\Delta H1(100),\Delta H2(100)$) > 2.35	Check
	$80\mu in \leq \Delta H1(100)$ & $\Delta H2(100) \leq 130\mu in$	& $\Delta H1(1000)$ and $\Delta H2(1000)$ $< 900\ \mu in$	Continue with 1000 sec test
		& max($\Delta H1(1000),\Delta H2(1000)$) $> 900\ \mu in$	Re-run test
	$130\mu in \leq \Delta H1(100)$ & $\Delta H2(100) \leq 300\mu in$ or {$80\mu in \leq (\Delta H1(100),\Delta H2(100)) \leq 130\mu in$ & $130\mu in \leq (\Delta H2(100), \Delta H1(100)) \leq 300\mu in$}	& max($\Delta H1(100),\Delta H2(100)$)/ min($\Delta H1(100),\Delta H2(100)$) ≤ 2.35	Re-run test
		& max($\Delta H1(100),\Delta H2(100)$)/ min($\Delta H1(100),\Delta H2(100)$) > 2.35	Check
	& max($\Delta H1(100),\Delta H2(100)$) $> 300\mu in$		End test
m1 & m2 $<$ 0.1			Check

The first two constraints indicate that the load applied to the specimen was insufficient to produce the required specimen response, in other words, the horizontal deformations are too low. In these cases, the ratio of the two horizontal deformations determines whether the measurements are acceptable, as defined by the second part of the constraints. These tertiary constraints limit

the difference between the two deformations. If the data passes both constraints, the operator is advised to run another test and the software will calculate a new creep load. If the data fails the second constraint, the operator is advised to check the extensometers, and inspect for the possibility of an eccentric loading condition and then to rerun the test at the previous load.

If the test data meets or passes the first constraints conditions, the operator is prompted to run another 100 second creep test with an increased load, which is calculated using the following equation:

$$NewLoad = OldLoad * \frac{100\mu in}{\frac{(\Delta H1(100) + \Delta H2(100))}{2}} \qquad \text{(Eq. 5.1.2 b)}$$

where $\Delta H1(100)$ and $\Delta H2(100)$ are the horizontal deformations at the end of the 100 second test.

If the second constraints conditions are met; the operator is prompted to check the gages and the specimen setup for possible eccentric loading conditions, and to rerun the test at the same load.

The third constraint is the preferred response, in which both deformations pass within a predefined range at 100 seconds and the computed values for $\Delta H1(1000)$ and $\Delta H2(1000)$ are less than a maximum defined deformation in 1000 seconds. The operator is then prompted to rerun the test at the current load, and to change the test duration to 1000 seconds.

The forth constraint is one not normally encountered. In this case, both face deformations meet the 100 second requirements, but the $\Delta H1(1000)$ and $\Delta H2(1000)$ computed values exceed the 1000 second limit. This could be reasoned to be caused due to a poorly executed test, testing a mix which is unusually soft, or a mix with exceedingly high air voids further compacting or unable to tolerate or support the applied load, etc. These conditions are unlikely to occur, but the constraint is placed here as a safety net to catch this aberrant possibility.

The fifth constraint addresses the application of too high a creep load, but not sufficiently high to induce damage in the specimen. The operator would be advised to rerun the test with a reduced load calculated using the previous equation.

The sixth constraint is similar to the fifth constraint, but it also acts to limit the difference between the two face deformations. In this case, the operator would be advised to check the extensometers, inspect for the possibility of an eccentric loading condition, and to rerun the test with a reduced load calculated using the previous equation.

The seventh constraint addresses the application of an exceedingly high creep load which causes or may cause permanent damage to the specimen. It is questionable whether valid data would be acquired from the specimen if a new creep test were to be performed. In this case, the operator would be advised to terminate testing of this specimen.

As mentioned earlier, the slope or m_x of the creep compliance curves are calculated as a quality control check on the data. In the last constraint both m_x values either close to zero or negative, may signal a material which is heavily aged or stiff, or may indicate that the applied load is insufficient. In both cases, the operator is advised to check the gauges and to use caution if increasing the applied load and possibly causing an unexpected dramatic failure of the specimen.

As mentioned in the previous resilient modulus discussion, it would be next to impossible to account for every erroneous or problematic data combination that an operator will encounter, but these rules should cover the majority of the decisions which normally arise. As before, additional rules and filters can be easily added to the software as they are needed, and the rules can be modified as more experience or data is gained in their use.

5.1.3 Tensile strength

The third button on the **IDT**^{Assist} menu is labeled ST Analysis. This portion of the application will normally be run directly following the creep compliance test, but it too can also be used as a stand-alone routine. If used as a stand-alone routine, the operator is still required to select the mix type, the test temperature, and the specimen thickness, as done previously, but not to generate an initial M_r load. Instead, selecting the mix type advises the operator what deformation rate to apply to the specimen during the strength test. Dense graded mixtures require the load rate to be 2 inches per minute or 50.8 mm per minute, and OGFC specimens require double that rate or 4.0 inches per minute or 101.6 mm per minute.

The operator will select to run the strength test from the pulldown test menu in the **Simple IDT** control console and a set of inputs will appear requiring entry from the operator. Here, the operator will input the deformation rate generated by **IDT**^{Assist}, name the strength data file, and then perform the strength test.

When the strength test is completed, the operator will perform an analysis of that file, by first browsing the data folder and selecting the name of the file just previously created, and clicking on button labeled *PERFORM ANALYSIS*. The *BROWSE* and *PERFORM ANALYSIS* buttons are located in the bottom portion of the Tensile Strength application. In the M_r and C_r applications, several operations occurred, but since in this test the specimen has been failed, no additional testing is required, therefore, only one post-testing operation takes place with this data file:

1. The data file is cleared of empty lines in the body of the data or in the header, the data lines organized, and this new file is saved with a *.txs* extension for use by the **IDT Express.**

At the end of this sequence, the operator has successfully completed the testing of one specimen. The experience gained testing the first specimen can be used with any additional specimens of the same type. All Superpave IDT testing is performed in triplicate, that is, three specimens are required for any mixture, and those tests are analyzed as a group. After testing is completed and the data files have been converted to the *.tcm*, *.txc*, and *.tcs* extensions, they are lastly transferred to the *Data* folder within the **IDT Express** software package for final analysis.

CHAPTER 6

SUMMARY

6.1 Overview

Current asphalt mixture design procedures fail to address the issue of cracking performance. It is clear that there is yet no one single asphalt material property or characteristic which can be used to predict that performance. Research at the University of Florida has identified key mixture parameters that control cracking performance. A comprehensive parameter, called the energy ratio or ER, was derived from the University of Florida HMA fracture mechanics model which was able to accurately discriminate between field test pavements which had exhibited top-down cracking and those which had none.

The energy ratio is calculated from mixture parameters obtained from relatively simple tests performed using the Superpave indirect tension tests (IDT). Traditionally, these tests are performed on large testing systems which are heavy, require fixed utilities, and sometimes, very specialized training.

The Florida Department of Transportation has deemed the energy ratio concept to be pivotal in designing asphalt mixtures with improved cracking performance and would like to implement a system which takes advantage of these mixture parameters. This implementation was not realistic without the development of a tool which mix designers and contractors alike, could use to test mixtures quickly and easily. Therefore, the University of Florida was engaged to help design, develop, and evaluate a simplified Superpave IDT testing system which would be suitable for routine use in asphalt mixture design, and in the optimization, specification and quality control of these mixtures.

A **Simple IDT** testing platform has been developed that is small and portable, incorporating all of the most important performance features of the heavier fixed systems.

The **Simple IDT** is intended to be used as a routine testing apparatus by laboratory personnel with little or no expertise in the performance testing of asphalt mixtures. A software application named **IDT**[Assist] was developed to guide **Simple IDT** operators in the proper selection of loads and strains to properly characterize mixtures.

Figure 6.1a - Simple IDT testing machine
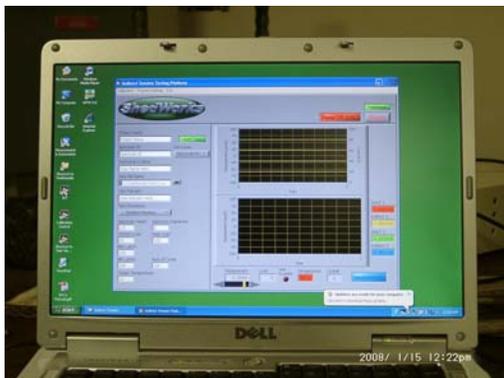
Figure 6.1b – Simple IDT control panel

Figure 6.1c – Simple IDT testing bay
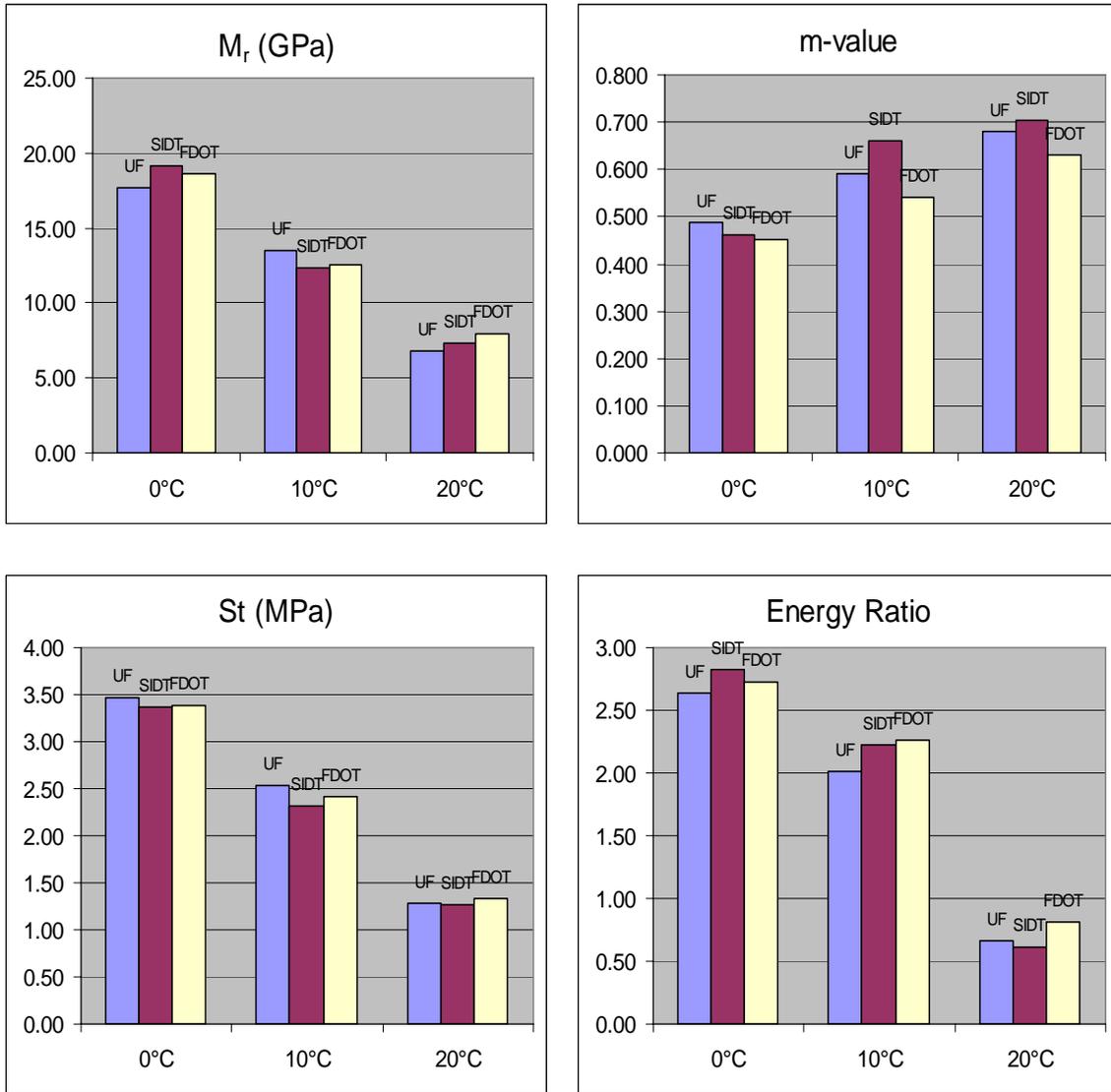
Figures 6.1d-g - Graphical comparisons of key mixture parameters

The **Simple IDT** was evaluated at three different testing temperatures using a mixture prepared by the Florida Department of Transportation's State Materials Office. As shown in the table below, the testing results show excellent correspondence with key mixture parameters obtained from two different fixed Superpave IDT systems at the University of Florida and at the State Materials Office Bituminous Research Laboratory.

Table 6.1 - Complete IDT testing results

Simple IDT Mix		m-value	D_1	S_t (Mpa)	M_R (Gpa)	FE (kJ/m³)	$DCSE_{HMA}$ (kJ/m³)	Stress (psi)	a	$DCSE_{MIN}$ (kJ/m³)	ER
UF MTS	0°C	0.487	2.32E-07	3.47	17.63	2.1	1.8	150	4.07E-08	0.665	2.64
	10°C	0.591	7.06E-07	2.53	13.50	6.7	6.5	150	4.60E-08	3.202	2.02
	20°C	0.682	1.15E-06	1.29	6.85	4.7	4.6	150	5.29E-08	6.948	0.66
SIDT	0°C	0.462	2.34E-07	3.36	19.13	1.9	1.6	150	4.13E-08	0.569	2.82
	10°C	0.662	4.06E-07	2.31	12.35	5.8	5.6	150	4.72E-08	2.510	2.22
	20°C	0.703	1.35E-06	1.26	7.29	5.6	5.5	150	5.30E-08	8.876	0.62
SMO MTS	0°C	0.450	2.59E-07	3.39	18.63	1.9	1.6	150	4.12E-08	0.582	2.73
	10°C	0.542	4.96E-07	2.41	12.56	4.1	3.9	150	4.66E-08	1.714	2.26
	20°C	0.630	1.49E-06	1.34	7.93	5.9	5.8	150	5.26E-08	7.141	0.81

Simple IDT Mix		m-value	D_1	S_t (Mpa)	M_R (Gpa)	FE (kJ/m³)	$DCSE_{HMA}$ (kJ/m³)	Stress (psi)	a	$DCSE_{MIN}$ (kJ/m³)	ER
AVG	0°C	0.466	2.42E-07	3.41	18.46	2.0	1.7	150	4.11E-08	0.605	2.73
	10°C	0.598	5.36E-07	2.42	12.81	5.5	5.3	150	4.66E-08	2.475	2.17
	20°C	0.672	1.33E-06	1.30	7.35	5.4	5.3	150	5.28E-08	7.655	0.70
STD	0°C	0.019	1.51E-08	0.057	0.762	0.115	0.090		3.24E-10	0.052	0.089
	10°C	0.060	1.54E-07	0.110	0.613	1.320	1.302		6.14E-10	0.745	0.131
	20°C	0.037	1.71E-07	0.040	0.545	0.624	0.635		2.20E-10	1.062	0.101

The test specimens were organized by air void content and grouped in such a manner as to reduce the variability between temperatures and testing systems. After analysis, the test data shows consistency, repeatability and low variability for the test parameters independent of the testing system and testing temperature. Most, if not all, of the variability encountered during analysis is likely attributable to the nature of the HMA material and random testing error.

A systematic trend does appear in the m-value data for the specimens tested at the Florida Department of Transportation's State Materials Office. The m-value from these tests is consistently the lowest at every temperature. This is most likely due to the differences between the extensometers used in the **Simple IDT** and the University of Florida testing system versus the extensometer system used at the State Materials Office. There is no apparent or visible trend in either the M_r or Strength data, which further validates and supports the time dependent nature of the problem as seen in the m-value data. Regardless, these differences do not appear to affect the energy ratio calculation for the materials tested at each location, and any decisions made on account of this data would prove to be equivalent.

6.2 Conclusions

A simplified Superpave IDT testing system was successfully designed, developed, and evaluated. The key features of the **Simple IDT** unit are:

- It is a self-contained and portable IDT testing platform on wheels, with physical dimensions that allow it to be rolled through standard doorways.

- It consists of a 10,000 lb load frame mounted within an environmental chamber capable of temperatures from 0°C to 40°C (±0.2°C).

- Includes a self-contained hydraulic power supply with an air cooled heat exchanger.

- Machine control and data acquisition is achieved real-time via a digital controller, a National Instruments PXI series controller system.

- **Simple IDT** control and operation is performed remotely, using a Laptop PC, with software written using National Instrument's LabVIEW.

- Loading system is servo-hydraulically controlled, using PID feedback.

- Power utilities required for <u>this</u> unit is a 120 volt - 30 amp circuit.

- A software application named **IDT**^Assist was developed to guide **Simple IDT** operators during testing to properly select test loads and strains, and to perform quality control checks on the test data to ensure proper specimen response and machine operation.

Current practice in IDT specimen preparation is the gluing or attachment of gage points to the specimen faces, where the extensometers or sensors are placed to measure the vertical and horizontal deformations. The original intention was to develop a system which precluded the need to do such preparation. Several prototype measuring systems were developed, but each failed in providing measurements without errors, distortion, or noise which reduced or greatly impinged the quality of the data. It was decided to deliver a device which performed equal to the bigger, fixed system, while continuing to work on and improve this newer sensor system.

It was also intended that the **Simple IDT** would be powered by the commonly available standard electrical outlet (120V-20A) and not require special utilities. This first unit was designed with standard off-the-shelf components; compressor and evaporator (mechanical unit), and a heater strip; to provide the cooling and heating for the environmental chamber. These components were currently used in the original equipment designed by Shedworks, Inc. Unfortunately, the other changes and modifications made to the testing platform; larger controller, etc; increased the current draw above 20 amps. This required UF to re-wire this first model **Simple IDT** to operate on 120 volts – 30 amps, and the installation of a NEMA 30A -125V connection to successfully operate this unit without tripping the electrical reset. All subsequent models of

the **Simple IDT** will be produced using a Solid-State Cooling System which provides equivalent or better performance, reduces the weight and noise, and consumes or uses much less current allowing for standard 120V – 20A connection.

6.3 Recommendations

The following recommendations are made with respect to this project and equipment:

- UF should continue to pursue the development of the on-specimen measuring system to preclude the need to attach gage points to the specimen surfaces. This on-specimen measuring system should be tested using the remaining HMA specimens used in the comparison trial

- Parallel mixture testing should take place and continue between the Superpave IDT systems at the University of Florida, the Florida Department of Transportation's State Materials Office, and the **Simple IDT** testing platform to establish a database of performance parameters, including energy ratio, for selected asphalt mixtures produced within the state.

- Continue to validate, update or upgrade as necessary, the software application **IDT^{Assist}**, including the rules, filters, and initial conditions for optimal performance and reliability.

- Place additional **Simple IDT's** into service in selected locations to monitor their use and acceptance as a quality control tool.

- A sensitivity study should be conducted of the mix performance parameters and the energy ratio with respect to known construction variables encountered in the field, e.g., AC content, compaction, gradation, etc.

REFERENCES

Roque, R., Birgisson, B., Drakos, Dietrich, B., 2004. *Development and Field Evaluation of Energy-Based Criteria for Top-Down Cracking Performance of Hot Mix Asphalt*. Association of Asphalt Paving Technologists.

Roque, R., and Buttlar, W.G., 1992. *The Development of a Measurement and Analysis System to Accurately Determine Asphalt Concrete Properties Using the Indirect Tensile Test*. Association of Asphalt Paving Technologists.

Buttlar, W. G., and Roque, R., 1994. *Experimental Development and Evaluation of the New SHRP Measurement and Analysis System for Indirect Tensile Testing of Asphalt Mixtures at Low Temperatures*. Association of Asphalt Paving Technologists.

APPENDICES

APPENDIX A

Test Specimen
Densities
and
Dimensions

Simple IDT Test Samples					
Sample ID	Weights (grams)			Density	Absorbed	%
	Dry	In H_2O	SSD	G_{mb}	H_2O	AV
1A1	1709.9	1003.3	1712.1	2.412	2.2	6.46
1A2	1705.5	1001.1	1708.1	2.412	2.6	6.46
1B1	1679.0	984.4	1681.7	2.408	2.7	6.64
1B2	1717.2	1007.9	1719.6	2.413	2.4	6.44
1C1	1712.4	1002.7	1714.2	2.407	1.8	6.68
1C2	1683.6	988.7	1686.2	2.414	2.6	6.41
2A1	1742.8	1021.7	1744.1	2.413	1.3	6.46
2A2	1701.5	998.9	1704.3	2.412	2.8	6.47
2B1	1752.5	1028.6	1754.3	2.415	1.8	6.36
2B2	1653.3	969.8	1656.0	2.409	2.7	6.58
2C1	1674.8	983.4	1676.6	2.416	1.8	6.32
2C2	1713.6	1004.6	1716.5	2.407	2.9	6.67
3A1	1708.6	1002.5	1710.2	2.414	1.6	6.39
3A2	1700.8	997.8	1702.5	2.414	1.7	6.42
3B1	1683.2	986.5	1684.8	2.410	1.6	6.54
3B2	1713.1	1004.1	1715.4	2.408	2.3	6.61
3C1	1720.2	1009.6	1721.7	2.416	1.5	6.33
3C2	1719.8	1008.3	1723.0	2.406	3.2	6.70
4A1	1689.8	990.9	1691.8	2.411	2.0	6.52
4A2	1720.5	1004.5	1723.1	2.394	2.6	7.16
4B1	1630.5	954.1	1632.0	2.405	1.5	6.74
4B2	1733.3	1011.4	1735.5	2.394	2.2	7.18
4C1	1729.5	1015.0	1732.7	2.410	3.2	6.56
4C2	1688.6	988.0	1689.5	2.407	0.9	6.66
5A1	1691.0	992.2	1692.2	2.416	1.2	6.33
5A2	1681.9	987.7	1684.6	2.413	2.7	6.42
5B1	1677.2	985.4	1679.4	2.417	2.2	6.29
5B2	1761.0	1032.4	1763.8	2.408	2.8	6.64
5C1	1719.8	1009.0	1722.6	2.410	2.8	6.55
5C2	1696.3	994.1	1699.0	2.406	2.7	6.69
6A1	1741.3	1019.8	1743.1	2.407	1.8	6.65
6A2	1720.4	1010.0	1722.8	2.414	2.4	6.41
6B1	1642.2	963.0	1644.3	2.410	2.1	6.54
6B2	1747.3	1023.9	1750.1	2.406	2.8	6.70
6C1	1656.7	972.4	1658.1	2.416	1.4	6.32
6C2	1729.7	1011.2	1731.8	2.400	2.1	6.93
7A1	1678.3	988.8	1681.1	2.424	2.8	6.00
7A2	1762.8	1032.9	1765.0	2.408	2.2	6.64
7B1	1718.8	1006.8	1721.3	2.406	2.5	6.72
7B2	1694.0	995.6	1695.8	2.419	1.8	6.19
7C1	1657.4	972.4	1659.5	2.412	2.1	6.47
7C2	1753.0	1026.3	1754.9	2.406	1.9	6.71
8A1	1651.4	968.4	1652.8	2.413	1.4	6.44
8A2	1735.1	1019.5	1739.0	2.412	3.9	6.49
8B1	1740.9	1023.7	1745.9	2.411	5.0	6.53
8B2	1647.4	963.7	1649.3	2.403	1.9	6.83
8C1	1699.6	1001.1	1701.8	2.426	2.2	5.95
8C2	1761.8	1030.1	1763.8	2.401	2.0	6.89
8D1	1658.4	973.7	1660.5	2.415	2.1	6.37
8D2	1753.7	1029.2	1756.4	2.412	2.7	6.49

Simple IDT Sample Dimensions					
Sample ID	T_1	T_2	T_3	T_4	T_{ave}
1A1	1.559	1.603	1.602	1.594	1.590
1A2	1.579	1.586	1.615	1.599	1.595
1B1	1.566	1.571	1.580	1.580	1.574
1B2	1.600	1.598	1.603	1.608	1.602
1C1	1.599	1.607	1.614	1.604	1.606
1C2	1.565	1.572	1.591	1.590	1.580
2A1	1.622	1.637	1.632	1.618	1.627
2A2	1.575	1.581	1.607	1.607	1.593
2B1	1.617	1.637	1.648	1.649	1.638
2B2	1.545	1.548	1.557	1.555	1.551
2C1	1.565	1.570	1.557	1.555	1.562
2C2	1.575	1.593	1.643	1.618	1.607
3A1	1.586	1.601	1.618	1.599	1.601
3A2	1.580	1.586	1.590	1.588	1.586
3B1	1.570	1.581	1.579	1.571	1.575
3B2	1.590	1.595	1.612	1.605	1.601
3C1	1.599	1.611	1.610	1.599	1.605
3C2	1.600	1.609	1.626	1.623	1.615
4A1	1.586	1.592	1.580	1.577	1.584
4A2	1.597	1.605	1.628	1.624	1.614
4B1	1.516	1.531	1.534	1.527	1.527
4B2	1.596	1.615	1.639	1.626	1.619
4C1	1.607	1.621	1.635	1.624	1.622
4C2	1.561	1.570	1.584	1.580	1.574
5A1	1.575	1.586	1.583	1.577	1.580
5A2	1.549	1.561	1.585	1.577	1.568
5B1	1.561	1.572	1.563	1.556	1.563
5B2	1.612	1.635	1.674	1.660	1.645
5C1	1.622	1.626	1.604	1.604	1.614
5C2	1.549	1.570	1.618	1.608	1.586
6A1	1.628	1.632	1.630	1.623	1.628
6A2	1.579	1.598	1.623	1.609	1.602
6B1	1.526	1.541	1.540	1.529	1.534
6B2	1.612	1.621	1.651	1.636	1.630
6C1	1.534	1.546	1.551	1.539	1.543
6C2	1.592	1.608	1.639	1.620	1.615
7A1	1.574	1.577	1.556	1.548	1.564
7A2	1.598	1.636	1.693	1.668	1.649
7B1	1.573	1.582	1.580	1.576	1.578
7B2	1.583	1.597	1.629	1.615	1.606
7C1	1.536	1.549	1.557	1.540	1.546
7C2	1.619	1.637	1.647	1.635	1.635
8A1	1.528	1.547	1.542	1.529	1.537
8A2	1.605	1.619	1.648	1.633	1.626
8B1	1.619	1.643	1.636	1.624	1.631
8B2	1.527	1.539	1.556	1.543	1.541
8C1	1.563	1.586	1.581	1.571	1.575
8C2	1.630	1.642	1.655	1.650	1.644
8D1	1.539	1.549	1.545	1.544	1.544
8D2	1.614	1.628	1.654	1.643	1.635
				Min	1.527
				Max	1.649
				Diff	0.122

APPENDIX B

Test Descriptions
Summaries
and
Data Output Formats

1. Resilient Modulus

Overview

A periodic load is applied to the specimen. This wave form loads the specimen for 0.1 seconds and then rests for 0.9 seconds, therefore, the frequency is 1 hertz. The applied load is haversine in the shape, offset sinusoid, going from 10 lbs to the operator selected peak load, returning to 10 lbs and repeating. Five complete load cycles are needed for the analysis program. The analysis program ranks the output data, and it trims/cuts the two extreme cycles (trimmed mean approach), and analyzes three cycles remaining from the set. The program requires a minimum of 2500 data points (lines). Depending on the data acquisition program, it may be necessary to apply six load pulses.

Test Sequence

1) All tests start with an operator applied seating load of less than 10 lbs, (approximately 6-8 lbs), manually applied to the specimen.

2) Program starts with a header section for specimen identification; inputs may or may not be entered, at the user's discretion. (If date and time inputs are automated, this item can be eliminated):

   a. specimen ID

   b. specimen dimensions, diameter and thickness

   c. date and time

3) If the operator is ready, and "all systems are go," the operator then initiates the test. In the MTS software this is a built in on-screen software button.

4) The program then increases the seating load to 10 lbs. This is the minimum load that remains on the specimen through the remainder of the test.

5) The system then applies the load pulses, acquires data, plots the load pulse real-time, checks for displacement and load limits (do not want to exceed on-specimen extensometer's range, thus avoiding damage), and allows for early operator test termination (software button, as above), in case something is amiss.

   a. Data acquisition is at a frequency of 500 points per second (500 Hz)

   b. Data order is H1, V1, H2, V2, Axial Force, Time, Axial Displacement

   c. Data output file is specimen.dat in the MTS system. For analysis, we change the name (to identify the specimen) and the file extension (for analysis), Example: *specimen ID.txm*.

   d. Output is in generally in small US engineering units, could allow for small SI units also.

6) After completing the application of the load pulses, the actuator retracts, and the load is completely removed from the specimen.

7) Operator opens data file and checks the data to determine whether the applied load was sufficient to obtain horizontal resilient deformations (H_1 and H_2) greater than 100 u-in and less than 300 u-in (within the linear region). This is measured from the peak of the measurement to the beginning of the next load cycle.

8) Depending on measurement, the operator will increase the load and perform an additional test(s) until this requirement is met, or if satisfied, goes onto the next test, the creep test.

Sample specimen.dat Output

Below is an example of the M_r specimen.dat data output file from UF's MTS test system, to show header spacing, column order, and data lines. Output is in MS Excel.

The top two lines in this file are trimmed or deleted, so the operator is in cell A1, and the first data line starts at Row 12. The must be done to make the data file compatible (usable) with the analysis program ITLT Express.

	A	B	C	D	E	F	G	H	I	
1	MTS793|MPT|ENU|1|2|./|:|1|0|0|A									
2										
3	Operator	Information	Testing	Time	Time:	3.05957	Sec	########	2:42:39	PM
4	Specimen	ID	hvsmr82b1							
5	Specimen	Diameter	6	in						
6	Time									
7	Operator	Information	End							
8										
9	Cyclic	Acquisition	Cyclic	Data	Time:	10.60547	Sec	########	2:42:46	PM
10	Stored	at:	1	cycle	Stored	for:		19 segments	Relative	to:
11	Points:	3033								
12	H1	V1	H2	V2	Axial	Force	Time	Axial	Displacement	
13	in	in	in	in	lbf	Sec	in			
14	-0.01202	-0.02367	-0.01258	-0.02124	-28.8705	4.54834	-0.01122			
15	-0.01202	-0.02367	-0.01258	-0.02123	-29.5419	4.550293	-0.01088			
16	-0.01202	-0.02367	-0.01258	-0.02124	-28.8705	4.552246	-0.01088			
17	-0.01202	-0.02367	-0.01258	-0.02123	-28.8705	4.554199	-0.01071			
18	-0.01202	-0.02367	-0.01258	-0.02123	-28.8705	4.556152	-0.01054			
19	-0.01202	-0.02367	-0.01258	-0.02123	-28.8705	4.558106	-0.01037			

specimen

2. 1000 Second Creep Test

Overview

This test places and maintains a fixed load on the specimen for 1000 seconds and then removes the load. The applied load is square in the shape (a step function), with a rise time as quick as possible, typically 0.1 second (without going into oscillation). The load rises from the seating load to the operator selected or inputted peak load. The program varies the data acquisition frequency during the test, (more later).

Test Sequence

1) All tests start with a seating load less than 10 lbs, (approximately 6-8 lbs), which is manually applied to the specimen, by the operator, before the test starts.

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2) Program starts with a header section for specimen identification, inputs may or may not be entered, users discretion. (If date and time inputs are automated, this item can be eliminated) :

    a. Specimen ID

    b. Specimen dimensions, diameter and thickness

    c. Date and time

3) If the operator is ready, and "all systems are go," the operator then initiates the test. In the MTS software this is a built in on-screen software button.

4) The program increases the seating load to 10 lbs.

5) The system applies the load, acquires data, plots the real-time deformation curves for H_1 and H_2, checks for displacement and load limits (do not want to exceed on-specimen extensometer's range, thus avoiding damage), and allows for early operator test termination (software button, as above), in case something is amiss.

    a. Data acquisition is dependent on the time in the test:

        i. 10 pre-trigger data points are collected at 10 Hz, for one second, before the application of the load.

        ii. This acquisition frequency continues for the first ten seconds after application of the load (100 data points). (The first ten seconds into the test)

        iii. After the first ten seconds, the data acquisition frequency changes to 1 Hz, for a duration of 290 seconds. (Now 300 seconds into the test.)

        iv. After 300 seconds, the data acquisition frequency changes to .2 Hz or one data point every 5 seconds. This continues to test termination

b. Data order is H1, V1, H2, V2, Axial Force, Time

c. Data file is creep1000.dat in the MTS system. For analysis, we change the name
    (to identify the specimen) and the file extension (for analysis), Example: *specimen
    ID.txc*.

d. Output is in generally in small US engineering units, could allow for small SI
    units also.

e. The operator will check the H_1 and H_2 deformations at 100 seconds. If they are
    less than 100 u-in or greater than 130 u-in, the test is aborted, for either too low or
    too high a load. If the load was too low, the load will be increased and the speci-
    men retested after an operator determined rest period. Conversely, if the load was
    too high, the load will be decreased, and again, retested after the operator deter-
    mined rest period.

f. The test has a total deformation limit of 750 u-in at the end of the 1000 second
    test period. This may be exceeded slightly, but is based on operator judgment.
    Normally, if H_1 and H_2 fall between the two limits at 100 seconds, exceeding 750
    u-in at 1000 seconds does not occur.

6) After the 1000 seconds, the actuator is retracted and the load is completely removed from
    the specimen.

7) The operator will go onto the next test, the strength test.

Sample creep1000.dat Output

Below is an example of the C_{r1000} creep1000.dat data output file from UF's MTS test
system, to show header spacing, column order, and data lines. Output is in MS Excel.

The top two lines in this file are trimmed or deleted, so the operator is in cell A1, and the first data line starts at Row 10. The must be done to make the data file compatible (usable) with the analysis program ITLT Express.

	A	B	C	D	E	F	G	H	I
1	MTS793|MPT|ENU|1|2|.|/|:|1|0|0|A								
2									
3	Operator	Information	Test	time	Time:	3.836914	Sec	########	2:51:24 PM
4	Specimen	ID	hwscreep82b1						
5	Specimen	Diameter	6	in					
6		test	time						
7	Operator	Information	End						
8									
9	Data	Acquisition	Time:	9.964844	Sec	########	2:51:30 PM		
10	H1	V1	H2	V2	Axial	Force	Time		
11	in	in	in	in	lbf	Sec			
12	-0.01202	-0.02386	-0.01259	-0.0221	-5.37134	9.059082			
13	-0.01202	-0.02385	-0.01259	-0.0221	-8.05696	9.15918			
14	-0.01202	-0.02386	-0.01259	-0.0221	-5.37134	9.259277			
15	-0.01202	-0.02385	-0.01259	-0.02209	-6.04274	9.359375			
16	-0.01202	-0.02385	-0.01259	-0.0221	-6.04274	9.459473			
17	-0.01202	-0.02385	-0.01259	-0.0221	-4.02852	9.55957			
18	-0.01202	-0.02386	-0.01259	-0.0221	-8.05696	9.659668			

creep1000

3. Strength Test

Overview

An almost constant strain rate is applied to the specimen. The specimen is loaded at a constant rate of displacement, 2 inches per minute, per AASHTO/ASTM's modified Lottman test. The sustained load is monitored, and after the load peaks and drops off by 10-20 %, the specimen is considered failed. The test is now complete and the actuator reverses and returns to its home or initial position.

Test Sequence

1) All tests start with a seating load of less than 10 lbs, (approximately 6-8 lbs), which is manually applied to the specimen, by the operator, before the test starts.

2) Program starts with a header section for specimen identification, inputs may or may not be entered, users discretion. (If date and time inputs are automated, this item can be eliminated):

    a. Specimen ID

    b. Specimen dimensions, diameter and thickness

    c. Date and time

3) If the operator is ready, and "all systems are go," the operator then initiates the test. In the MTS software this is a built in on-screen software button.

4) The program then increases the seating load to 10 lbs.

5) The system then applies the strain rate, acquires data, plots the real-time load output, checks for displacement and load limits (do not want to exceed on-specimen extensometer's range, thus avoiding damage), allows for early operator test termination (software button, as above), in case something is amiss, and detects the specimen's point of failure.

    a. Data acquisition is set so that a sufficient number of data points are collected for analysis:

        i. 10 pre-trigger data points are collected at 10 Hz, for one second, before the application of the strain rate.

        ii. Data is acquired every 30 lb change in load, (level crossing data collection).

        iii. The data is also collected at maximum peak load and interleaved into the data stream.

    b. Data order is H1, V1, H2, V2, Axial Force, Time, Axial Displacement

c. Data file is strength.dat in MTS system. For analysis, we change the name (to identify the specimen) and the file extension (for analysis), Example: *specimen ID.txs*.

d. Output is in generally in small US engineering units, could allow for small SI units also.

6) After specimen failure has been detected, the actuator is retracted and the load is completely removed from the specimen.

7) Since this specimen is now broken, the operator will now proceed to the next specimen.

Sample strength.dat Output

Below is an example of the S_t strength.dat data output file from UF's MTS test system, to show header spacing, column order, and data lines. Output is in MS Excel.

The top two lines in this file are trimmed or deleted, so the data is in cell A1, and the first data line starts at Row 4. The must be done to make the data file compatible (usable) with the analysis program ITLT Express.

	A	B	C	D	E	F	G	H	I
1	MTS793|MPT|ENU|1|2|.|/|:|1|0|0|A								
2									
3	Data	Acquisitior	Time:	10.73438	Sec	########	3:17:35	PM	
4	H1	V1	H2	V2	Axial	Force	Time	Axial	Displacement
5	in	in	in	in	lbf	Sec	in		
6	-0.01177	-0.02362	-0.01242	-0.02183	-38.2701	6.57666	-0.01139		
7	-0.01177	-0.02361	-0.01242	-0.02183	-68.4834	6.756836	-0.01751		
8	-0.01177	-0.02361	-0.01241	-0.02182	-99.3682	6.838379	-0.02023		
9	-0.01176	-0.0236	-0.01241	-0.02181	-129.581	6.881348	-0.02176		
10	-0.01176	-0.02359	-0.01241	-0.02181	-159.795	6.909668	-0.02278		
11	-0.01175	-0.02358	-0.0124	-0.0218	-192.022	6.928711	-0.02312		
12	-0.01175	-0.02358	-0.0124	-0.0218	-223.578	6.945801	-0.02397		
13	-0.01175	-0.02357	-0.0124	-0.0218	-256.477	6.962891	-0.02431		
14	-0.01174	-0.02356	-0.01239	-0.02179	-289.376	6.976074	-0.02465		
15	-0.01174	-0.02355	-0.01239	-0.02178	-322.947	6.987793	-0.02516		

strength

APPENDIX C

Test Data
ITLT Express
Specimen Output Files

FDOT Tests at 0°C

INSTANTANEOUS			
RESILIENT MODULUS (GPa)			
CYCLE	T1= 0.0C	T2= 0.0C	T3= 0.0C
1	19.22	19.22	19.22
2	19.34	19.34	19.34
3	19.42	19.42	19.42

POISSONS RATIO: FROM RESILIENT MODULUS DATA				
CYCLE		T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
1	CALCULATED:	0.33	0.33	0.33
	USED:	0.33	0.33	0.33
2	CALCULATED:	0.32	0.32	0.32
	USED:	0.32	0.32	0.32
3	CALCULATED:	0.32	0.32	0.32
	USED:	0.32	0.32	0.32

(**) - Used Poissons Ratio was manually inputted

TOTAL			
RESILIENT MODULUS (GPa)			
CYCLE	T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
1	18.62	18.62	18.62
2	18.66	18.66	18.66
3	18.6	18.6	18.6

POISSONS RATIO: FROM RESILIENT MODULUS DATA				
CYCLE		T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
1	CALCULATED:	0.33	0.33	0.33
	USED:	0.33	0.33	0.33
2	CALCULATED:	0.32	0.32	0.32
	USED:	0.32	0.32	0.32
3	CALCULATED:	0.32	0.32	0.32
	USED:	0.32	0.32	0.32

(**) - Used Poissons Ratio was manually inputted

RESILIENT MODULUS TEST DATA FILE NAMES AND SPECIMEN DIMENSIONS

T1 = 0.0C			T2 = 0.0C			T3 = 0.0C		
Filename	Thickness (in)	Diameter (in)	Filename	Thickness (in)	Diameter (in)	Filename	Thickness (in)	Diameter (in)
1B1.txm	1.57	5.91	1B1.txm	1.57	5.91	1B1.txm	1.57	5.91
5B2.txm	1.65	5.91	5B2.txm	1.65	5.91	5B2.txm	1.65	5.91
6A1.txm	1.63	5.91	6A1.txm	1.63	5.91	6A1.txm	1.63	5.91

NORMALIZED DEFORMATIONS (MICROINCHES)		

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CYCLE	T1 =	0.0C			T2 =	0.0C			T3 =	0.0C		
	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}
1	2	78	2	143	2	78	2	143	2	78	2	143
	*5	99	*4	148	*5	99	*4	148	*5	99	*4	148
	*4	102	*5	181	*4	102	*5	181	*4	102	*5	181
	*1	102	*6	205	*1	102	*6	205	*1	102	*6	205
	*3	106	*1	209	*3	106	*1	209	*3	106	*1	209
	6	118	3	248	6	118	3	248	6	118	3	248
	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	t2	79	2	146	x2	79	2	146	2	79	2	146
	5	103	*4	155	5	103	*4	155	*5	103	*4	155
	1	105	*5	189	1	105	*5	189	*1	105	*5	189
	*4	106	*6	214	*4	106	*6	214	*4	106	*6	214
	*3	110	*1	216	*3	110	*1	216	*3	110	*1	216
	6	123	3	257	6	123	3	257	6	123	3	257
	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}
2	2	78	2	144	2	78	2	144	2	78	2	144
	*5	99	*4	151	*5	99	*4	151	*5	99	*4	151
	*4	100	*5	184	*4	100	*5	184	*4	100	*5	184
	*1	102	*1	207	*1	102	*1	207	*1	102	*1	207
	*3	104	*6	209	*3	104	*6	209	*3	104	*6	209
	6	120	3	249	6	120	3	249	6	120	3	249
	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	2	80	12	149	2	80	2	149	2	80	2	149
	*5	103	x4	156	*5	103	*4	156	*5	103	*4	156
	*4	105	5	190	*4	105	*5	190	*4	105	*5	190
	*1	105	1	215	*1	105	*1	215	*1	105	*1	215
	*3	109	*6	215	*3	109	*6	215	*3	109	*6	215
	6	125	3	258	6	125	3	258	6	125	3	258
	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}
3	2	78	2	149	2	78	2	149	2	78	2	149
	*4	100	*4	149	*4	100	*4	149	*4	100	*4	149
	*1	100	*5	182	*1	100	*5	182	*1	100	*5	182
	*5	101	*6	207	*5	101	*6	207	*5	101	*6	207
	*3	103	*1	208	*3	103	*1	208	*3	103	*1	208
	6	120	3	248	6	120	3	248	6	120	3	248
	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	2	81	2	152	2	81	2	152	2	81	2	152
	*5	105	*4	155	*5	105	*4	155	*5	105	*4	155
	*4	105	*5	188	*4	105	*5	188	*4	105	*5	188
	*1	106	*1	218	*1	106	*1	218	*1	106	*1	218
	*3	108	*6	218	*3	108	*6	218	*3	108	*6	218
	6	125	3	258	6	125	63	258	6	125	3	258

INDIRECT TENSILE STRENGTH (MPa)

T1 =	**0.0C**	T2 =	**0.0C**	T3 =	**0.0C**
	3.59		**3.59**		**3.59**
	3.48		**3.48**		**3.48**
	3.11		**3.11**		**3.11**

AVERAGE STRENGTHS (MPa)

3.39	**3.39**	**3.39**

POISSONS RATIO: FROM STRENGTH DATA

	T1 =	**0.0C**	T2 =	**0.0C**	T3 =	**0.0C**
Calc:		**0.33**		**0.33**		**0.33**
Used:		**0.33**		**0.33**		**0.33**

NORMALIZED DEFORMATIONS AT 500 SECONDS (MICROINCHES)

T1 =	**0.0C**			T2 =	**0.0C**			T3 =	**0.0C**		
FACE	X	FACE	Y	FACE	X	FACE	Y	FACE	X	FACE	Y
2	**279**	**4**	**550**	**2**	**279**	**4**	**550**	**2**	**279**	**4**	**550**
***4**	**352**	***2**	**559**	***4**	**352**	***2**	**559**	***4**	**352**	***2**	**559**
***5**	**366**	***5**	**634**	***5**	**366**	***5**	**634**	***5**	**366**	***5**	**634**
***1**	**370**	***1**	**690**	***1**	**370**	***1**	**690**	***1**	**370**	***1**	**690**
***3**	**396**	***6**	**805**	***3**	**396**	***6**	**805**	***3**	**396**	***6**	**805**
6	**423**	**3**	**889**	**6**	**423**	**3**	**889**	**6**	**423**	**3**	**889**

SPECIMEN THICKNESSES AND DIAMETERS (INCHES)

T1 =	**0.0C**	T2 =	**0.0C**	T3 =	**0.0C**
Thickness	Diameter	Thickness	Diameter	Thickness	Diameter
1.57	**5.91**	**1.57**	**5.91**	**1.57**	**5.91**
1.65	**5.91**	**1.65**	**5.91**	**1.65**	**5.91**
1.63	**5.91**	**1.63**	**5.91**	**1.63**	**5.91**

STRENGTH TEST DATA FILE NAMES

T1 =	**0.0C**	T2 =	**0.0C**	T3 =	**0.0C**
Filename		Filename		Filename	
1B1.txs		**1B1.txs**		**1B1.txs**	
5B2.txs		**5B2.txs**		**5B2.txs**	
6A1.txs		**6A1.txs**		**6A1.txs**	

TRIMMED MEAN VALUES

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	T1 = **0.0C**	T2 = **0.0C**	T3 = **0.0C**
INITIAL TANGENT MODULUS (GPa)	8.4	8.4	8.4
FAILURE STRAIN (Microstrain)	**832.52**	**832.52**	**832.52**
FRACTURE ENERGY (kJ/m3)	1.9	1.9	1.9
POISSONS RATIO	**0.33**	**0.33**	**0.33**

INDIVIDUAL VALUES USED TO CALCULATE TRIMMED MEAN VALUES

INITIAL TANGENT MODULUS (GPa)

FACE	T1 = **0.0C**	FACE	T2 = **0.0C**	FACE	T3 = **0.0C**
6	**7.5**	**6**	**7.5**	**6**	**7.5**
***3**	**7.8**	***3**	**7.8**	***3**	**7.8**
***1**	**8.1**	***1**	**8.1**	***1**	**8.1**
***4**	**8.7**	***4**	**8.7**	***4**	**8.7**
***5**	**9**	***5**	**9**	***5**	**9**
2	**11.3**	**2**	**11.3**	**2**	**11.3**

FAILURE STRAIN (Microstrain)

FACE	T1 = **0.0C**	FACE	T2 = **0.0C**	FACE	T3 = **0.0C**
5	**684.87**	**5**	**684.87**	**5**	**684.87**
***6**	**760.6**	***6**	**760.6**	***6**	**760.6**
***2**	**761.34**	***2**	**761.34**	***2**	**761.34**
***4**	**838.67**	***4**	**838.67**	***4**	**838.67**
***1**	**969.45**	***1**	**969.45**	***1**	**969.45**
3	**1337.71**	**3**	**1337.71**	**3**	**1337.71**

FRACTURE ENERGY (kJ/m^3)

FACE	T1 = **0.0C**	FACE	T2 = **0.0C**	FACE	T3 = **0.0C**
5	**1.3**	**5**	**1.3**	**5**	**1.3**
***6**	**1.4**	***6**	**1.4**	***6**	**1.4**
***2**	**1.8**	***2**	**1.8**	***2**	**1.8**
***4**	**1.9**	***4**	**1.9**	***4**	**1.9**
***1**	**2.3**	***1**	**2.3**	***1**	**2.3**
3	**3.3**	**3**	**3.3**	**3**	**3.3**

(*) - Faces used to calculate trimmed mean values

CREEP COMPLIANCE (1/Gpa)

TIME (SEC)	T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
1	0.092	0.092	0.092
2	0.103	0.103	0.103
5	0.128	0.128	0.128
10	0.153	0.153	0.153
20	0.192	0.192	0.192
50	0.261	0.261	0.261
100	0.341	0.341	0.341
200	0.46	0.46	0.46
500	0.669	0.669	0.669
1000	0.886	0.886	0.886

POISSONS RATIO: FROM CREEP DATA

	T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
CALCULATED:	0.4	0.4	0.4
USED:	0.4	0.4	0.4

(**) - Used Poissons Ratio was manually inputted

NORMALIZED DEFORMATIONS AT 500 SECONDS (MICROINCHES)

_T1 = 0.0C_				_T2 = 0.0C_				_T3 = 0.0C_			
FACE	X	FACE	Y	FACE	X	FACE	Y	FACE	X	FACE	Y
2	91	2	69	2	91	2	69	2	91	2	69
*3	191	*4	210	*3	191	*4	210	*3	191	*4	210
*5	194	*5	279	*5	194	*5	279	*5	194	*5	279
*1	198	*1	320	*1	198	*1	320	*1	198	*1	320
*4	201	*3	352	*4	201	*3	352	*4	201	*3	352
6	252	6	356	6	252	6	356	6	252	6	356

CREEP TEST DATA FILE NAMES AND AVERAGE CREEP LOADS (LBS)

T1 = 0.0C		T2 = 0.0C		T3 = 0.0C	
Filename	Load	Filename	Load	Filename	Load
1B1.txc	205.5	1B1.txc	205.5	1B1.txc	205.5
5B2.txc	199.4	5B2.txc	199.4	5B2.txc	199.4
6A1.txc	197.7	6A1.txc	197.7	6A1.txc	197.7

SPECIMEN THICKNESSES AND DIAMETERS (INCHES)

T1 = 0.0C		T2 = 0.0C		T3 = 0.0C	
Thickness	Diameter	Thickness	Diameter	Thickness	Diameter
1.57	5.91	1.57	5.91	1.57	5.91
1.65	5.91	1.65	5.91	1.65	5.91
1.63	5.91	1.63	5.91	1.63	5.91

Calculating D_1 and m-value from a fixed D_0

Temp (ºC)	Time (s)	D(t) (1/Gpa)	Fitted D (1/Gpa)	Diff square (#)
	1	**0.092**	0.086	3.73E-05
	2	**0.103**	0.100	1.13E-05
	5	**0.128**	0.126	4.80E-06
	10	**0.153**	0.154	1.36E-06
	20	**0.192**	0.193	8.08E-07
0.0C	50	**0.261**	0.267	3.21E-05
	100	**0.341**	0.347	3.12E-05
	200	**0.460**	0.456	1.81E-05
	500	**0.669**	0.664	2.85E-05
	1000	**0.886**	0.889	8.36E-06

SUM OF DIFF SQUARED   **0.000**

Set 1 Fitted Solution		
	(1/GPa)	(1/psi)
D_0 **(fixed)**	4.83E-02	3.33E-07
D_1	3.75E-02	2.59E-07
m-value	0.449998	0.449998

Solve
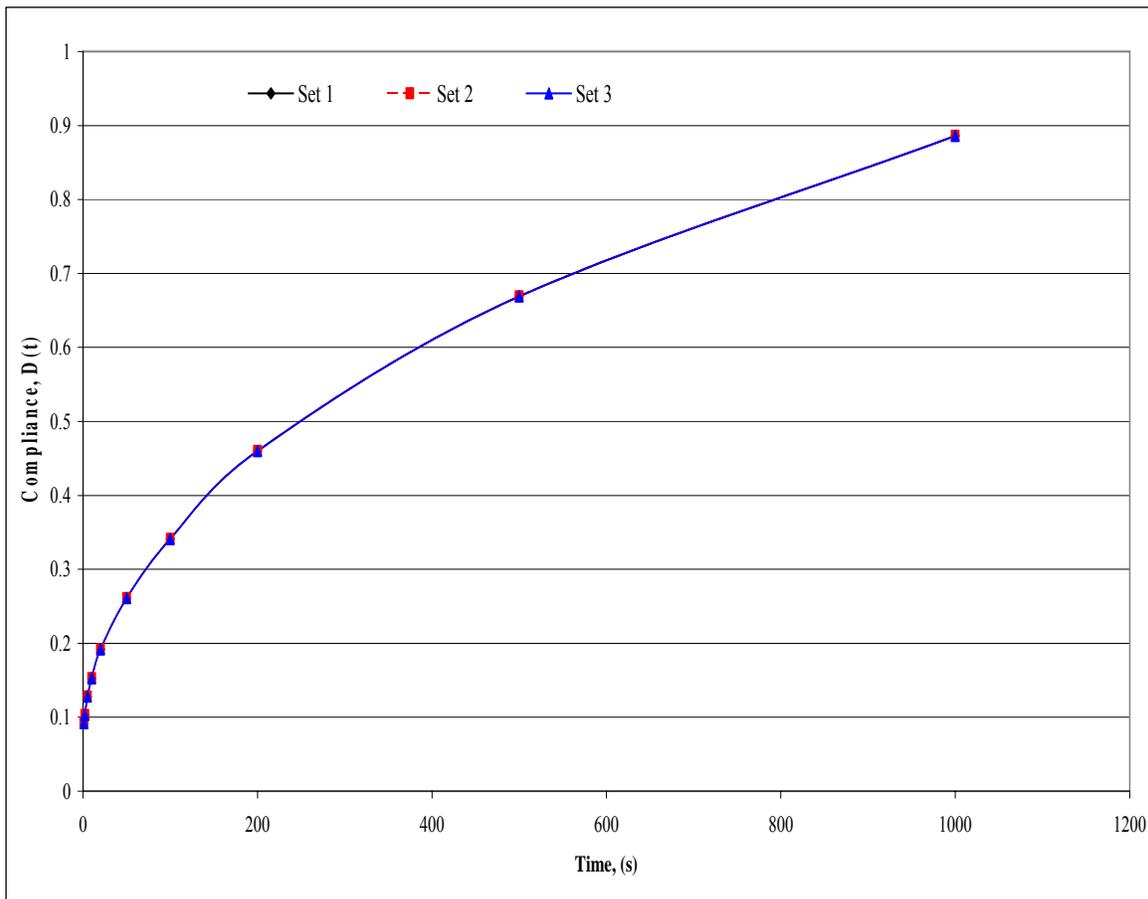
ENERGY RATIO

Project Name		m-value	D_1	S_t (Mpa)	M_R (Gpa)	FE (kJ/m^3)	DCSE$_{HMA}$ (kJ/m^3)	Stress (psi)	a	DCSE$_{MIN}$ (kJ/m^3)	ER
	Set 1	0.450	2.59E-07	3.39	18.63	1.9	1.6	150	4.12E-08	0.582	2.73
	Set 2	0.450	2.59E-07	3.39	18.63	1.9	1.6	150	4.12E-08	0.582	2.73
	Set 3	0.450	2.59E-07	3.39	18.63	1.9	1.6	150	4.12E-08	0.582	2.73

FDOT Tests at 10°C

INSTANTANEOUS

RESILIENT MODULUS (GPa)

CYCLE		T1= 10.0C	T2= 10.0C	T3= 10.0C
1		13.68	13.68	13.68
2		13.48	13.48	13.48
3		13.22	13.22	13.22

POISSONS RATIO: FROM RESILIENT MODULUS DATA

CYCLE		T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
1	CALCULATED:	0.25	0.25	0.25
	USED:	0.25	0.25	0.25
2	CALCULATED:	0.26	0.26	0.26
	USED:	0.26	0.26	0.26
3	CALCULATED:	0.28	0.28	0.28
	USED:	0.28	0.28	0.28

(**) - Used Poissons Ratio was manually inputted

TOTAL

RESILIENT MODULUS (GPa)

CYCLE		T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
1		12.73	12.73	12.73
2		12.53	12.53	12.53
3		12.41	12.41	12.41

POISSONS RATIO: FROM RESILIENT MODULUS DATA

CYCLE		T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
1	CALCULATED:	0.26	0.26	0.26
	USED:	0.26	0.26	0.26
2	CALCULATED:	0.26	0.26	0.26
	USED:	0.26	0.26	0.26
3	CALCULATED:	0.26	0.26	0.26
	USED:	0.26	0.26	0.26

(**) - Used Poissons Ratio was manually inputted

RESILIENT MODULUS TEST DATA FILE NAMES AND SPECIMEN DIMENSIONS

T1 =	10.0C		T2 =	10.0C		T3 =	10.0C	
Filename	Thickness (in)	Diameter (in)	Filename	Thickness (in)	Diameter (in)	Filename	Thickness (in)	Diameter (in)
1C1.txm	1.61	5.91	1C1.txm	1.61	5.91	1C1.txm	1.61	5.91
2C2.txm	1.61	5.91	2C2.txm	1.61	5.91	2C2.txm	1.61	5.91
4C2.txm	1.57	5.91	4C2.txm	1.57	5.91	4C2.txm	1.57	5.91

NORMALIZED DEFORMATIONS (MICROINCHES)											
CYCLE	T1 =	10.0C			T2 =	10.0C			T3 =	10.0C	

CYCLE 1

FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}
2	67	4	139	2	67	4	139	2	67	4	139
*6	79	*2	161	*6	79	*2	161	*6	79	*2	161
*4	87	*6	174	*4	87	*6	174	*4	87	*6	174
*1	93	*3	181	*1	93	*3	181	*1	93	*3	181
*3	93	*5	189	*3	93	*5	189	*3	93	*5	189
5	104	1	212	5	104	1	212	5	104	1	212

FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
t2	70	4	148	x2	70	4	148	2	70	4	148
6	83	*2	170	6	83	*2	170	*6	83	*2	170
4	93	*6	184	4	93	*6	184	*4	93	*6	184
*3	100	*3	194	*3	100	*3	194	*3	100	*3	194
*1	100	*5	200	*1	100	*5	200	*1	100	*5	200
5	111	1	225	5	111	1	225	5	111	1	225

CYCLE 2

FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}
2	67	4	140	2	67	4	140	2	67	4	140
*6	78	*2	159	*6	78	*2	159	*6	78	*2	159
*4	88	*6	174	*4	88	*6	174	*4	88	*6	174
*1	93	*3	183	*1	93	*3	183	*1	93	*3	183
*3	96	*5	191	*3	96	*5	191	*3	96	*5	191
5	105	1	211	5	105	1	211	5	105	1	211

FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
2	73	24	151	2	73	4	151	2	73	4	151
*6	84	x2	170	*6	84	*2	170	*6	84	*2	170
*4	94	6	186	*4	94	*6	186	*4	94	*6	186
*1	100	3	198	*1	100	*3	198	*1	100	*3	198
*3	104	*5	204	*3	104	*5	204	*3	104	*5	204
5	112	1	224	5	112	1	224	5	112	1	224

CYCLE 3

FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}
2	66	4	140	2	66	4	140	2	66	4	140
*6	81	*2	160	*6	81	*2	160	*6	81	*2	160
*4	89	*6	174	*4	89	*6	174	*4	89	*6	174
*1	94	*3	184	*1	94	*3	184	*1	94	*3	184
*3	100	*5	188	*3	100	*5	188	*3	100	*5	188
5	104	1	211	5	104	1	211	5	104	1	211

FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
2	72	4	149	2	72	4	149	2	72	4	149
*6	86	*2	172	*6	86	*2	172	*6	86	*2	172
*4	95	*6	188	*4	95	*6	188	*4	95	*6	188
*1	99	*3	200	*1	99	*3	200	*1	99	*3	200
*3	106	*5	202	*3	106	*5	202	*3	106	*5	202
5	113	1	225	5	113	41	225	5	113	1	225

INDIRECT TENSILE STRENGTH (MPa)

T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
2.53	2.53	2.53
2.36	2.36	2.36
2.34	2.34	2.34

AVERAGE STRENGTHS (MPa)

2.41	2.41	2.41

POISSONS RATIO: FROM STRENGTH DATA

	T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
Calc:	0.31	0.31	0.31
Used:	0.31	0.31	0.31

NORMALIZED DEFORMATIONS AT 500 SECONDS (MICROINCHES)

T1 = 10.0C				T2 = 10.0C				T3 = 10.0C			
FACE	X	FACE	Y	FACE	X	FACE	Y	FACE	X	FACE	Y
1	0	4	757	1	0	4	757	1	0	4	757
*6	491	*5	887	*6	491	*5	887	*6	491	*5	887
*4	502	*1	997	*4	502	*1	997	*4	502	*1	997
*2	540	*2	997	*2	540	*2	997	*2	540	*2	997
*5	552	*3	1000	*5	552	*3	1000	*5	552	*3	1000
3	581	6	1072	3	581	6	1072	3	581	6	1072

SPECIMEN THICKNESSES AND DIAMETERS (INCHES)

T1 = 10.0C		T2 = 10.0C		T3 = 10.0C	
Thickness	Diameter	Thickness	Diameter	Thickness	Diameter
1.61	5.91	1.61	5.91	1.61	5.91
1.61	5.91	1.61	5.91	1.61	5.91
1.57	5.91	1.57	5.91	1.57	5.91

STRENGTH TEST DATA FILE NAMES

T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
Filename	Filename	Filename
1C1.txs	1C1.txs	1C1.txs
2C2.txs	2C2.txs	2C2.txs
4C2.txs	4C2.txs	4C2.txs

TRIMMED MEAN VALUES

	T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
INITIAL TANGENT MODULUS (GPa)	4.1	4.1	4.1
FAILURE STRAIN (Microstrain)	2250.75	2250.75	2250.75
FRACTURE ENERGY (kJ/m^3)	4.1	4.1	4.1
POISSONS RATIO	0.31	0.31	0.31

INDIVIDUAL VALUES USED TO CALCULATE TRIMMED MEAN VALUES

INITIAL TANGENT MODULUS (GPa)

FACE	T1 = 10.0C	FACE	T2 = 10.0C	FACE	T3 = 10.0C
2	3.4	2	3.4	2	3.4
*3	3.8	*3	3.8	*3	3.8
*5	3.9	*5	3.9	*5	3.9
*6	4.2	*6	4.2	*6	4.2
*4	4.5	*4	4.5	*4	4.5
1	8577.2	1	8577.2	1	8577.2

FAILURE STRAIN (Microstrain)

FACE	T1 = 10.0C	FACE	T2 = 10.0C	FACE	T3 = 10.0C
1	0.51	1	0.51	1	0.51
*4	1685.51	*4	1685.51	*4	1685.51
*3	2273.05	*3	2273.05	*3	2273.05
*5	2481.74	*5	2481.74	*5	2481.74
*6	2562.69	*6	2562.69	*6	2562.69
2	3418.86	2	3418.86	2	3418.86

FRACTURE ENERGY (kJ/m^3)

FACE	T1 = 10.0C	FACE	T2 = 10.0C	FACE	T3 = 10.0C
1	0	1	0	1	0
*4	2.9	*4	2.9	*4	2.9
*3	4	*3	4	*3	4
*5	4.6	*5	4.6	*5	4.6
*6	4.9	*6	4.9	*6	4.9
2	6.9	2	6.9	2	6.9

(*) - Faces used to calculate trimmed mean values

CREEP COMPLIANCE (1/Gpa)

TIME (SEC)	T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
1	0.118	0.118	0.118
2	0.141	0.141	0.141
5	0.203	0.203	0.203
10	0.272	0.272	0.272
20	0.389	0.389	0.389
50	0.644	0.644	0.644
100	0.935	0.935	0.935
200	1.331	1.331	1.331
500	2.165	2.165	2.165
1000	3.065	3.065	3.065

POISSONS RATIO: FROM CREEP DATA

	T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
CALCULATED:	0.4	0.4	0.4
USED:	0.41	0.41	0.41

(**) - Used Poissons Ratio was manually inputted

NORMALIZED DEFORMATIONS AT 500 SECONDS
(MICROINCHES)

	T1 =	10.0C			T2 =	10.0C			T3 =	10.0C	
FACE	X	FACE	Y	FACE	X	FACE	Y	FACE	X	FACE	Y
3	138	3	141	3	138	3	141	3	138	3	141
*1	145	*6	191	*1	145	*6	191	*1	145	*6	191
*6	160	*1	237	*6	160	*1	237	*6	160	*1	237
*4	199	*2	247	*4	199	*2	247	*4	199	*2	247
*2	230	*4	297	*2	230	*4	297	*2	230	*4	297
5	255	5	346	5	255	5	346	5	255	5	346

CREEP TEST DATA FILE NAMES AND AVERAGE CREEP LOADS (LBS)

T1 = 10.0C		T2 = 10.0C		T3 = 10.0C	
Filename	Load	Filename	Load	Filename	Load
1C1.txc	50.3	1C1.txc	50.3	1C1.txc	50.3
2C2.txc	66.5	2C2.txc	66.5	2C2.txc	66.5
4C2.txc	54.1	4C2.txc	54.1	4C2.txc	54.1

SPECIMEN THICKNESSES AND DIAMETERS (INCHES)

T1 = 10.0C		T2 = 10.0C		T3 = 10.0C	
Thickness	Diameter	Thickness	Diameter	Thickness	Diameter
1.61	5.91	1.61	5.91	1.61	5.91
1.61	5.91	1.61	5.91	1.61	5.91
1.57	5.91	1.57	5.91	1.57	5.91

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Calculating D_1 and m-value from a fixed D_0

Temp	Time	D(t)	Fitted D	Diff square
(ºC)	(s)	(1/Gpa)	(1/Gpa)	(#)
	1	**0.118**	0.120	5.11E-06
	2	**0.141**	0.153	1.45E-04
	5	**0.203**	0.220	3.02E-04
	10	**0.272**	0.299	7.20E-04
	20	**0.389**	0.413	5.78E-04
10.0C	50	**0.644**	0.648	1.28E-05
	100	**0.935**	0.921	2.02E-04
	200	**1.331**	1.319	1.54E-04
	500	**2.165**	2.136	8.68E-04
	1000	**3.065**	3.087	4.93E-04

SUM OF DIFF SQUARED   **0.003**

Set 1 Fitted Solution

	(1/GPa)	(1/psi)
D_0 (fixed)	4.83E-02	3.33E-07
D_1	7.19E-02	4.96E-07
m-value	0.541967	0.541967

Solve
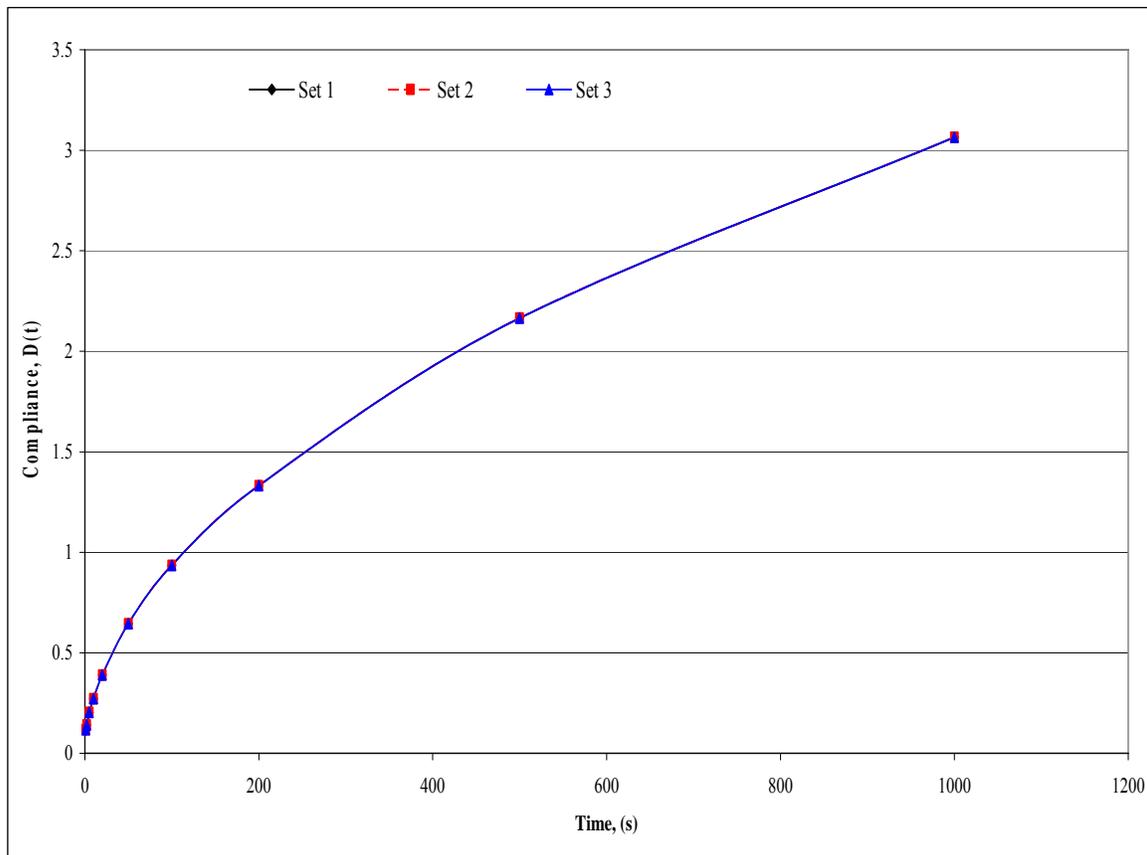
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ENERGY RATIO

Project Name	m-value	D_1	S_t (Mpa)	M_R (Gpa)	FE (kJ/m^3)	DCSE$_{HMA}$ (kJ/m^3)	Stress (psi)	a	DCSE$_{MIN}$ (kJ/m^3)	ER
Set 1	0.542	4.96E-07	2.41	12.56	4.1	3.9	150	4.66E-08	1.714	2.26
Set 2	0.542	4.96E-07	2.41	12.56	4.1	3.9	150	4.66E-08	1.714	2.26
Set 3	0.542	4.96E-07	2.41	12.56	4.1	3.9	150	4.66E-08	1.714	2.26

FDOT Tests at 20°C

INSTANTANEOUS

RESILIENT MODULUS (GPa)

CYCLE		T1= 20.0C	T2= 20.0C	T3= 20.0C
1		9.07	9.07	9.07
2		9	9	9
3		9	9	9

POISSONS RATIO: FROM RESILIENT MODULUS DATA

CYCLE		T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
1	CALCULATED:	0.39	0.39	0.39
	USED:	0.39	0.39	0.39
2	CALCULATED:	0.4	0.4	0.4
	USED:	0.4	0.4	0.4
3	CALCULATED:	0.4	0.4	0.4
	USED:	0.4	0.4	0.4

(**) - Used Poissons Ratio was manually inputted

TOTAL

RESILIENT MODULUS (GPa)

CYCLE		T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
1		8.07	8.07	8.07
2		7.94	7.94	7.94
3		7.78	7.78	7.78

POISSONS RATIO: FROM RESILIENT MODULUS DATA

CYCLE		T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
1	CALCULATED:	0.39	0.39	0.39
	USED:	0.39	0.39	0.39
2	CALCULATED:	0.4	0.4	0.4
	USED:	0.4	0.4	0.4
3	CALCULATED:	0.4	0.4	0.4
	USED:	0.4	0.4	0.4

(**) - Used Poissons Ratio was manually inputted

RESILIENT MODULUS TEST DATA FILE NAMES AND SPECIMEN DIMENSIONS

T1 =	20.0C		T2 =	20.0C		T3 =	20.0C	
Filename	Thickness (in)	Diameter (in)	Filename	Thickness (in)	Diameter (in)	Filename	Thickness (in)	Diameter (in)
2A2.txm	1.59	5.91	2A2.txm	1.59	5.91	2A2.txm	1.59	5.91
8A2.txm	1.63	5.91	8A2.txm	1.63	5.91	8A2.txm	1.63	5.91
8D2.txm	1.64	5.91	8D2.txm	1.64	5.91	8D2.txm	1.64	5.91

	NORMALIZED DEFORMATIONS (MICROINCHES)											
CYCLE	T1 = 20.0C				T2 = 20.0C				T3 = 20.0C			
	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}
1	4	80	4	128	4	80	4	128	4	80	4	128
	*2	82	*2	136	*2	82	*2	136	*2	82	*2	136
	*6	85	*6	139	*6	85	*6	139	*6	85	*6	139
	*3	111	*5	186	*3	111	*5	186	*3	111	*5	186
	*5	114	*3	204	*5	114	*3	204	*5	114	*3	204
	1	130	1	233	1	130	1	233	1	130	1	233
	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	t4	90	4	144	x4	90	4	144	4	90	4	144
	6	93	*6	150	6	93	*6	150	*6	93	*6	150
	2	93	*2	159	2	93	*2	159	*2	93	*2	159
	*3	125	*5	209	*3	125	*5	209	*3	125	*5	209
	*5	127	*3	228	*5	127	*3	228	*5	127	*3	228
	1	148	1	266	1	148	1	266	1	148	1	266
	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}
2	4	82	4	129	4	82	4	129	4	82	4	129
	*2	83	*2	136	*2	83	*2	136	*2	83	*2	136
	*6	86	*6	141	*6	86	*6	141	*6	86	*6	141
	*3	111	*5	184	*3	111	*5	184	*3	111	*5	184
	*5	116	*3	204	*5	116	*3	204	*5	116	*3	204
	1	129	1	230	1	129	1	230	1	129	1	230
	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	4	91	24	148	4	91	4	148	4	91	4	148
	*2	94	x6	155	*2	94	*6	155	*2	94	*6	155
	*6	96	2	162	*6	96	*2	162	*6	96	*2	162
	*3	127	5	209	*3	127	*5	209	*3	127	*5	209
	*5	131	*3	232	*5	131	*3	232	*5	131	*3	232
	1	149	1	267	1	149	1	267	1	149	1	267
	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}
3	4	80	4	127	4	80	4	127	4	80	4	127
	*2	83	*2	137	*2	83	*2	137	*2	83	*2	137
	*6	87	*6	141	*6	87	*6	141	*6	87	*6	141
	*3	111	*5	185	*3	111	*5	185	*3	111	*5	185
	*5	116	*3	205	*5	116	*3	205	*5	116	*3	205
	1	127	1	232	1	127	1	232	1	127	1	232
	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	4	93	4	149	4	93	4	149	4	93	4	149
	*2	95	*6	157	*2	95	*6	157	*2	95	*6	157
	*6	99	*2	164	*6	99	*2	164	*6	99	*2	164
	*3	131	*5	213	*3	131	*5	213	*3	131	*5	213
	*5	132	*3	235	*5	132	*3	235	*5	132	*3	235
	1	151	1	268	1	151	81	268	1	151	1	268

INDIRECT TENSILE STRENGTH (MPa)

T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
1.38	1.38	1.38
1.33	1.33	1.33
1.29	1.29	1.29

AVERAGE STRENGTHS (MPa)

1.34	1.34	1.34

POISSONS RATIO: FROM STRENGTH DATA

	T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
Calc:	0.44	0.44	0.44
Used:	0.44	0.44	0.44

NORMALIZED DEFORMATIONS AT 500 SECONDS (MICROINCHES)

T1 = 20.0C				T2 = 20.0C				T3 = 20.0C			
FACE	X	FACE	Y	FACE	X	FACE	Y	FACE	X	FACE	Y
4	728	4	1138	4	728	4	1138	4	728	4	1138
*6	741	*6	1193	*6	741	*6	1193	*6	741	*6	1193
*2	848	*2	1423	*2	848	*2	1423	*2	848	*2	1423
*5	964	*5	1444	*5	964	*5	1444	*5	964	*5	1444
*3	965	*3	1629	*3	965	*3	1629	*3	965	*3	1629
1	1095	1	1974	1	1095	1	1974	1	1095	1	1974

SPECIMEN THICKNESSES AND DIAMETERS (INCHES)

T1 = 20.0C		T2 = 20.0C		T3 = 20.0C	
Thickness	Diameter	Thickness	Diameter	Thickness	Diameter
1.59	5.91	1.59	5.91	1.59	5.91
1.63	5.91	1.63	5.91	1.63	5.91
1.64	5.91	1.64	5.91	1.64	5.91

STRENGTH TEST DATA FILE NAMES

T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
Filename	Filename	Filename
2A2.txs	2A2.txs	2A2.txs
8A2.txs	8A2.txs	8A2.txs
8D2.txs	8D2.txs	8D2.txs

TRIMMED MEAN VALUES			
	T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
INITIAL TANGENT MODULUS (GPa)	1.2	1.2	1.2
FAILURE STRAIN (Microstrain)	5502.69	5502.69	5502.69
FRACTURE ENERGY (kJ/m^3)	5.9	5.9	5.9
POISSONS RATIO	0.44	0.44	0.44

INDIVIDUAL VALUES USED TO CALCULATE TRIMMED MEAN VALUES

INITIAL TANGENT MODULUS (GPa)

FACE	T1 = 20.0C	FACE	T2 = 20.0C	FACE	T3 = 20.0C
1	0.9	1	0.9	1	0.9
*3	1	*3	1	*3	1
*2	1.1	*2	1.1	*2	1.1
*5	1.2	*5	1.2	*5	1.2
*4	1.3	*4	1.3	*4	1.3
6	1.7	6	1.7	6	1.7

FAILURE STRAIN (Microstrain)

FACE	T1 = 20.0C	FACE	T2 = 20.0C	FACE	T3 = 20.0C
6	2902.25	6	2902.25	6	2902.25
*5	4266.42	*5	4266.42	*5	4266.42
*4	5383.65	*4	5383.65	*4	5383.65
*3	6127.54	*3	6127.54	*3	6127.54
*2	6233.16	*2	6233.16	*2	6233.16
1	7781.68	1	7781.68	1	7781.68

FRACTURE ENERGY (kJ/m^3)

FACE	T1 = 20.0C	FACE	T2 = 20.0C	FACE	T3 = 20.0C
6	2.8	6	2.8	6	2.8
*5	4.2	*5	4.2	*5	4.2
*4	5.9	*4	5.9	*4	5.9
*3	6.6	*3	6.6	*3	6.6
*2	7	*2	7	*2	7
1	8.7	1	8.7	1	8.7

(*) - Faces used to calculate trimmed mean values

CREEP COMPLIANCE (1/Gpa)

TIME (SEC)	T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
1	0.197	0.197	0.197
2	0.346	0.346	0.346
5	0.599	0.599	0.599
10	0.911	0.911	0.911
20	1.421	1.421	1.421
50	2.56	2.56	2.56
100	3.973	3.973	3.973
200	6.174	6.174	6.174
500	10.961	10.961	10.961
1000	16.762	16.762	16.762

POISSONS RATIO: FROM CREEP DATA

	T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
CALCULATED:	0.49	0.49	0.49
USED:	0.49	0.49	0.49

(**) - Used Poissons Ratio was manually inputted

NORMALIZED DEFORMATIONS AT 500 SECONDS
(MICROINCHES)

T1 = 20.0C				T2 = 20.0C				T3 = 20.0C			
FACE	X	FACE	Y	FACE	X	FACE	Y	FACE	X	FACE	Y
1	245	2	261	1	245	2	261	1	245	2	261
*6	264	*5	342	*6	264	*5	342	*6	264	*5	342
*2	313	*6	363	*2	313	*6	363	*2	313	*6	363
*5	389	*4	424	*5	389	*4	424	*5	389	*4	424
*4	476	*1	652	*4	476	*1	652	*4	476	*1	652
3	503	3	876	3	503	3	876	3	503	3	876

CREEP TEST DATA FILE NAMES AND AVERAGE CREEP LOADS (LBS)

T1 = 20.0C		T2 = 20.0C		T3 = 20.0C	
Filename	Load	Filename	Load	Filename	Load
2A2.txc	21	2A2.txc	21	2A2.txc	21
8A2.txc	19	8A2.txc	19	8A2.txc	19
8D2.txc	19.7	8D2.txc	19.7	8D2.txc	19.7

SPECIMEN THICKNESSES AND DIAMETERS (INCHES)

T1 = 20.0C		T2 = 20.0C		T3 = 20.0C	
Thickness	Diameter	Thickness	Diameter	Thickness	Diameter
1.59	5.91	1.59	5.91	1.59	5.91
1.63	5.91	1.63	5.91	1.63	5.91
1.64	5.91	1.64	5.91	1.64	5.91

Calculating D_1 and m-value from a fixed D_0

Temp (°C)	Time (s)	D(t) (1/Gpa)	Fitted D (1/Gpa)	Diff square (#)
	1	**0.197**	0.264	4.47E-03
	2	**0.346**	0.382	1.29E-03
	5	**0.599**	0.643	1.91E-03
	10	**0.911**	0.968	3.28E-03
	20	**1.421**	1.472	2.64E-03
20.0C	50	**2.560**	2.586	6.54E-04
	100	**3.973**	3.976	7.92E-06
	200	**6.174**	6.128	2.13E-03
	500	**10.961**	10.880	6.51E-03
	1000	**16.762**	16.816	2.87E-03
		SUM OF DIFF SQUARED		**0.026**

Set 1 Fitted Solution

	(1/GPa)	(1/psi)
D_0 (fixed)	4.83E-02	3.33E-07
D_1	2.15E-01	1.49E-06
m-value	0.630348	0.630348

Solve
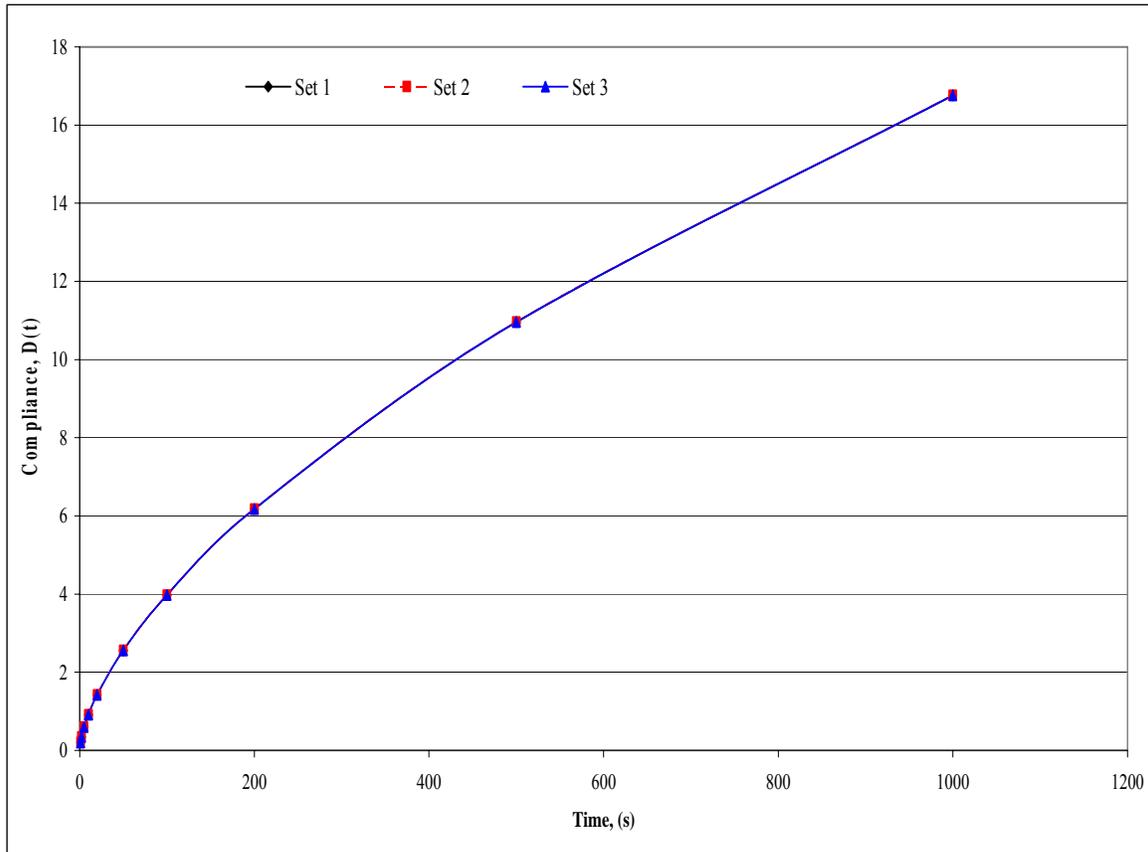
ENERGY RATIO

Project Name	m-value	D_1	S_t (Mpa)	M_R (Gpa)	FE (kJ/m^3)	DCSE$_{HMA}$ (kJ/m^3)	Stress (psi)	a	DCSE$_{MIN}$ (kJ/m^3)	ER
Set 1	0.630	1.49E-06	1.34	7.93	5.9	5.8	150	5.26E-08	7.141	0.81
Set 2	0.630	1.49E-06	1.34	7.93	5.9	5.8	150	5.26E-08	7.141	0.81
Set 3	0.630	1.49E-06	1.34	7.93	5.9	5.8	150	5.26E-08	7.141	0.81

SIDT Tests at 0°C

INSTANTANEOUS		

RESILIENT MODULUS (GPa)

CYCLE	T1= 0.0C	T2= 0.0C	T3= 0.0C
1	19.34	19.34	19.34
2	19.52	19.52	19.52
3	19.2	19.2	19.2

POISSONS RATIO: FROM RESILIENT MODULUS DATA

CYCLE		T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
1	CALCULATED:	0.26	0.26	0.26
	USED:	0.26	0.26	0.26
2	CALCULATED:	0.25	0.25	0.25
	USED:	0.25	0.25	0.25
3	CALCULATED:	0.26	0.26	0.26
	USED:	0.26	0.26	0.26

(**) - Used Poissons Ratio was manually inputted

TOTAL		

RESILIENT MODULUS (GPa)

CYCLE	T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
1	19.1	19.1	19.1
2	19.35	19.35	19.35
3	18.93	18.93	18.93

POISSONS RATIO: FROM RESILIENT MODULUS DATA

CYCLE		T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
1	CALCULATED:	0.27	0.27	0.27
	USED:	0.27	0.27	0.27
2	CALCULATED:	0.25	0.25	0.25
	USED:	0.25	0.25	0.25
3	CALCULATED:	0.27	0.27	0.27
	USED:	0.27	0.27	0.27

(**) - Used Poissons Ratio was manually inputted

RESILIENT MODULUS TEST DATA FILE NAMES AND SPECIMEN DIMENSIONS

T1 =	0.0C		T2 =	0.0C		T3 =	0.0C	
Filename	Thickness (in)	Diameter (in)	Filename	Thickness (in)	Diameter (in)	Filename	Thickness (in)	Diameter (in)
4C1.txm	1.62	5.91	4C1.txm	1.62	5.91	4C1.txm	1.62	5.91
5C1.txm	1.61	5.91	5C1.txm	1.61	5.91	5C1.txm	1.61	5.91
6B1.txm	1.53	5.91	6B1.txm	1.53	5.91	6B1.txm	1.53	5.91

		NORMALIZED DEFORMATIONS (MICROINCHES)										
CYCLE		T1 =	0.0C			T2 =	0.0C			T3 =	0.0C	
	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}
1	4	78	4	166	4	78	4	166	4	78	4	166
	*2	107	*6	215	*2	107	*6	215	*2	107	*6	215
	*6	108	*1	216	*6	108	*1	216	*6	108	*1	216
	*1	111	*2	225	*1	111	*2	225	*1	111	*2	225
	*5	129	*5	245	*5	129	*5	245	*5	129	*5	245
	3	134	3	288	3	134	3	288	3	134	3	288
	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	t4	80	4	166	x4	80	4	166	4	80	4	166
	1	111	*1	212	1	111	*1	212	*1	111	*1	212
	6	111	*6	219	6	111	*6	219	*6	111	*6	219
	*2	113	*2	228	*2	113	*2	228	*2	113	*2	228
	*5	133	*5	254	*5	133	*5	254	*5	133	*5	254
	3	137	3	297	3	137	3	297	3	137	3	297
	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}
2	4	81	4	169	4	81	4	169	4	81	4	169
	*6	106	*1	219	*6	106	*1	219	*6	106	*1	219
	*2	107	*6	224	*2	107	*6	224	*2	107	*6	224
	*1	110	*2	226	*1	110	*2	226	*1	110	*2	226
	*5	131	*5	250	*5	131	*5	250	*5	131	*5	250
	3	132	3	297	3	132	3	297	3	132	3	297
	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	4	85	14	172	4	85	4	172	4	85	4	172
	*6	109	x1	223	*6	109	*1	223	*6	109	*1	223
	*2	109	2	229	*2	109	*2	229	*2	109	*2	229
	*1	113	6	232	*1	113	*6	232	*1	113	*6	232
	*5	135	*5	252	*5	135	*5	252	*5	135	*5	252
	3	136	3	299	3	136	3	299	3	136	3	299
	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}
3	4	79	4	178	4	79	4	178	4	79	4	178
	*2	108	*6	216	*2	108	*6	216	*2	108	*6	216
	*6	111	*1	220	*6	111	*1	220	*6	111	*1	220
	*1	112	*2	230	*1	112	*2	230	*1	112	*2	230
	*3	132	*5	248	*3	132	*5	248	*3	132	*5	248
	5	134	3	299	5	134	3	299	5	134	3	299
	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	4	81	4	176	4	81	4	176	4	81	4	176
	*6	112	*6	221	*6	112	*6	221	*6	112	*6	221
	*2	114	*1	222	*2	114	*1	222	*2	114	*1	222
	*1	116	*2	232	*1	116	*2	232	*1	116	*2	232
	*3	135	*5	255	*3	135	*5	255	*3	135	*5	255
	5	140	3	306	5	140	63	306	5	140	3	306

INDIRECT TENSILE STRENGTH (MPa)

T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
3.33	3.33	3.33
3.45	3.45	3.45
3.31	3.31	3.31

AVERAGE STRENGTHS (MPa)

3.36	3.36	3.36

POISSONS RATIO: FROM STRENGTH DATA

	T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
Calc:	0.33	0.33	0.33
Used:	0.33	0.33	0.33

NORMALIZED DEFORMATIONS AT 500 SECONDS (MICROINCHES)

| T1 = 0.0C				| T2 = 0.0C				| T3 = 0.0C			
FACE	X	FACE	Y	FACE	X	FACE	Y	FACE	X	FACE	Y
4	239	2	346	4	239	2	346	4	239	2	346
*2	299	*4	555	*2	299	*4	555	*2	299	*4	555
*6	320	*1	604	*6	320	*1	604	*6	320	*1	604
*3	349	*5	638	*3	349	*5	638	*3	349	*5	638
*5	382	*6	664	*5	382	*6	664	*5	382	*6	664
1	589	3	699	1	589	3	699	1	589	3	699

SPECIMEN THICKNESSES AND DIAMETERS (INCHES)

T1 = 0.0C		T2 = 0.0C		T3 = 0.0C	
Thickness	Diameter	Thickness	Diameter	Thickness	Diameter
1.62	5.91	1.62	5.91	1.62	5.91
1.61	5.91	1.61	5.91	1.61	5.91
1.53	5.91	1.53	5.91	1.53	5.91

STRENGTH TEST DATA FILE NAMES

T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
Filename	Filename	Filename
4C1.txs	4C1.txs	4C1.txs
5C1.txs	5C1.txs	5C1.txs
6B1.txs	6B1.txs	6B1.txs

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TRIMMED MEAN VALUES

	T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
INITIAL TANGENT MODULUS (GPa)	9.4	9.4	9.4
FAILURE STRAIN (Microstrain)	817	817	817
FRACTURE ENERGY (kJ/m^3)	1.9	1.9	1.9
POISSONS RATIO	0.33	0.33	0.33

INDIVIDUAL VALUES USED TO CALCULATE TRIMMED MEAN VALUES

INITIAL TANGENT MODULUS (GPa)

FACE	T1 = 0.0C	FACE	T2 = 0.0C	FACE	T3 = 0.0C
1	4.8	1	4.8	1	4.8
*5	8.4	*5	8.4	*5	8.4
*3	8.7	*3	8.7	*3	8.7
*6	10.2	*6	10.2	*6	10.2
*2	10.3	*2	10.3	*2	10.3
4	12.8	4	12.8	4	12.8

FAILURE STRAIN (Microstrain)

FACE	T1 = 0.0C	FACE	T2 = 0.0C	FACE	T3 = 0.0C
6	601.49	6	601.49	6	601.49
*2	683.53	*2	683.53	*2	683.53
*4	776.63	*4	776.63	*4	776.63
*5	889.17	*5	889.17	*5	889.17
*3	918.68	*3	918.68	*3	918.68
1	1185.3	1	1185.3	1	1185.3

FRACTURE ENERGY (kJ/m^3)

FACE	T1 = 0.0C	FACE	T2 = 0.0C	FACE	T3 = 0.0C
6	1.2	6	1.2	6	1.2
*2	1.5	*2	1.5	*2	1.5
*4	1.9	*4	1.9	*4	1.9
*5	1.9	*5	1.9	*5	1.9
*3	2.1	*3	2.1	*3	2.1
1	2.4	1	2.4	1	2.4

(*) - Faces used to calculate trimmed mean values

CREEP COMPLIANCE (1/Gpa)

TIME (SEC)	T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
1	0.105	0.105	0.105
2	0.134	0.134	0.134
5	0.151	0.151	0.151
10	0.161	0.161	0.161
20	0.206	0.206	0.206
50	0.238	0.238	0.238
100	0.313	0.313	0.313
200	0.413	0.413	0.413
500	0.641	0.641	0.641
1000	0.897	0.897	0.897

POISSONS RATIO: FROM CREEP DATA

	T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
CALCULATED:	0.12	0.12	0.12
USED:	0.12	0.12	0.12

(**) - Used Poissons Ratio was manually inputted

NORMALIZED DEFORMATIONS AT 500 SECONDS (MICROINCHES)

T1 = 0.0C				T2 = 0.0C				T3 = 0.0C			
FACE	X	FACE	Y	FACE	X	FACE	Y	FACE	X	FACE	Y
4	40	1	179	4	40	1	179	4	40	1	179
*2	109	*6	261	*2	109	*6	261	*2	109	*6	261
*3	110	*2	263	*3	110	*2	263	*3	110	*2	263
*1	112	*5	301	*1	112	*5	301	*1	112	*5	301
*6	121	*3	307	*6	121	*3	307	*6	121	*3	307
5	166	4	311	5	166	4	311	5	166	4	311

CREEP TEST DATA FILE NAMES AND AVERAGE CREEP LOADS (LBS)

T1 = 0.0C		T2 = 0.0C		T3 = 0.0C	
Filename	Load	Filename	Load	Filename	Load
4C1.txc	200.4	4C1.txc	200.4	4C1.txc	200.4
5C1.txc	200.8	5C1.txc	200.8	5C1.txc	200.8
6B1.txc	201.2	6B1.txc	201.2	6B1.txc	201.2

SPECIMEN THICKNESSES AND DIAMETERS (INCHES)

T1 = 0.0C		T2 = 0.0C		T3 = 0.0C	
Thickness	Diameter	Thickness	Diameter	Thickness	Diameter
1.62	5.91	1.62	5.91	1.62	5.91
1.61	5.91	1.61	5.91	1.61	5.91
1.53	5.91	1.53	5.91	1.53	5.91

Calculating D_1 and m-value from a fixed D_0

Temp (ºC)	Time (s)	D(t) (1/Gpa)	Fitted D (1/Gpa)	Diff square (#)
	1	**0.105**	0.082	5.15E-04
	2	**0.134**	0.095	1.51E-03
	5	**0.151**	0.120	9.72E-04
	10	**0.161**	0.147	2.01E-04
	20	**0.206**	0.184	4.83E-04
0.0C	50	**0.238**	0.256	3.11E-04
	100	**0.313**	0.334	4.39E-04
	200	**0.413**	0.442	8.33E-04
	500	**0.641**	0.649	7.18E-05
	1000	**0.897**	0.877	4.16E-04
		SUM OF DIFF SQUARED		**0.006**

Set 1 Fitted Solution

	(1/GPa)	(1/psi)
D_0 **(fixed)**	4.83E-02	3.33E-07
D_1	**3.40E-02**	**2.34E-07**
m-value	**0.462415**	**0.462415**

Solve
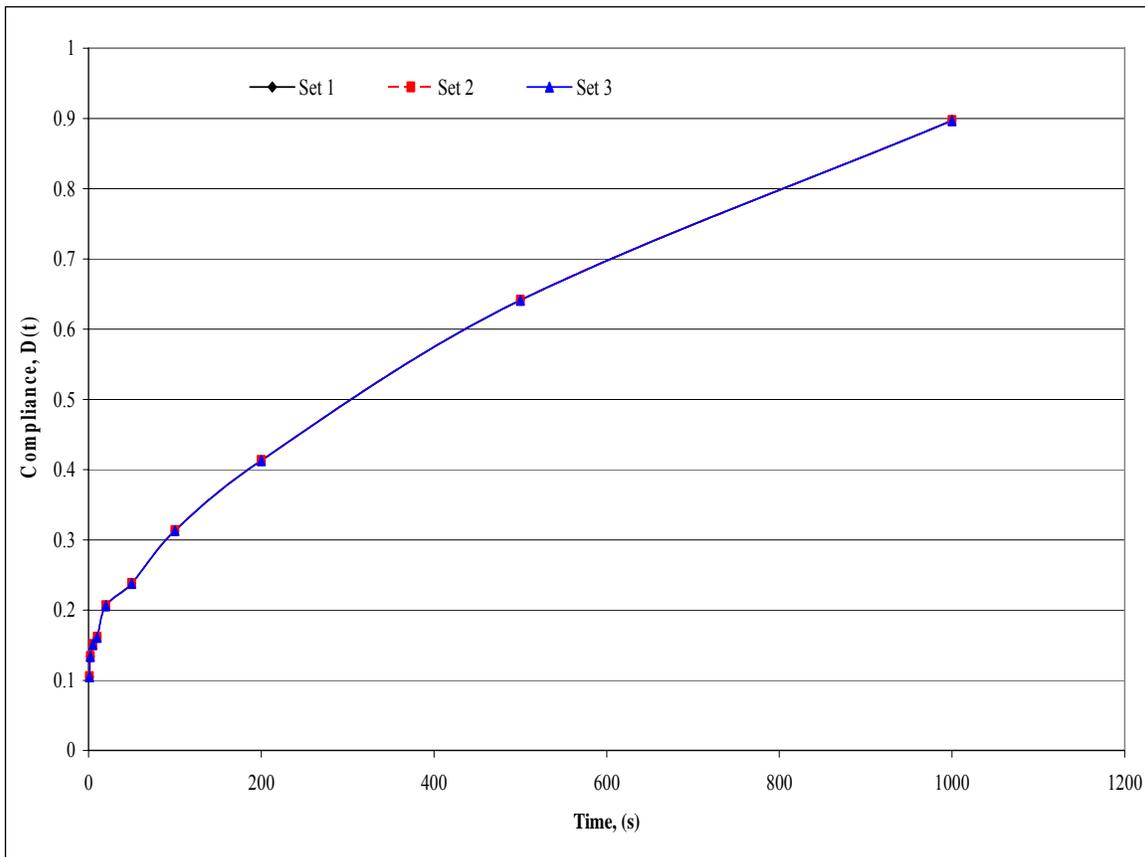
100

ENERGY RATIO

Project Name	m-value	D_1	S_t (Mpa)	M_R (Gpa)	FE (kJ/m^3)	DCSE$_{HMA}$ (kJ/m^3)	Stress (psi)	a	DCSE$_{MIN}$ (kJ/m^3)	ER
Set 1	0.462	2.34E-07	3.36	19.13	1.9	1.6	150	4.13E-08	0.569	2.82
Set 2	0.462	2.34E-07	3.36	19.13	1.9	1.6	150	4.13E-08	0.569	2.82
Set 3	0.462	2.34E-07	3.36	19.13	1.9	1.6	150	4.13E-08	0.569	2.82

SIDT Tests at 10°C

INSTANTANEOUS

RESILIENT MODULUS (GPa)

CYCLE	T1= 10.0C	T2= 10.0C	T3= 10.0C
1	12.92	12.92	12.92
2	12.93	12.93	12.93
3	12.91	12.91	12.91

POISSONS RATIO: FROM RESILIENT MODULUS DATA

CYCLE		T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
1	CALCULATED:	0.27	0.27	0.27
	USED:	0.27	0.27	0.27
2	CALCULATED:	0.27	0.27	0.27
	USED:	0.27	0.27	0.27
3	CALCULATED:	0.27	0.27	0.27
	USED:	0.27	0.27	0.27

(**) - Used Poissons Ratio was manually inputted

TOTAL

RESILIENT MODULUS (GPa)

CYCLE	T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
1	12.44	12.44	12.44
2	12.29	12.29	12.29
3	12.33	12.33	12.33

POISSONS RATIO: FROM RESILIENT MODULUS DATA

CYCLE		T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
1	CALCULATED:	0.27	0.27	0.27
	USED:	0.27	0.27	0.27
2	CALCULATED:	0.29	0.29	0.29
	USED:	0.29	0.29	0.29
3	CALCULATED:	0.27	0.27	0.27
	USED:	0.27	0.27	0.27

(**) - Used Poissons Ratio was manually inputted

RESILIENT MODULUS TEST DATA FILE NAMES AND SPECIMEN DIMENSIONS

T1 = 10.0C			T2 = 10.0C			T3 = 10.0C		
Filename	Thickness (in)	Diameter (in)	Filename	Thickness (in)	Diameter (in)	Filename	Thickness (in)	Diameter (in)
3C2.txm	1.62	5.91	3C2.txm	1.62	5.91	3C2.txm	1.62	5.91
5C2.txm	1.59	5.91	5C2.txm	1.59	5.91	5C2.txm	1.59	5.91
6B2.txm	1.63	5.91	6B2.txm	1.63	5.91	6B2.txm	1.63	5.91

NORMALIZED DEFORMATIONS (MICROINCHES)

CYCLE 1

	T1 = 10.0C				T2 = 10.0C				T3 = 10.0C			
	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}
	2	96	1	155	2	96	1	155	2	96	1	155
	*1	104	*4	207	*1	104	*4	207	*1	104	*4	207
	*3	111	*3	208	*3	111	*3	208	*3	111	*3	208
	*6	111	*5	212	*6	111	*5	212	*6	111	*5	212
	*4	111	*6	224	*4	111	*6	224	*4	111	*6	224
	5	121	2	252	5	121	2	252	5	121	2	252
	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	t2	100	1	160	x2	100	1	160	2	100	1	160
	1	108	*3	212	1	108	*3	212	*1	108	*3	212
	6	115	*4	217	6	115	*4	217	*6	115	*4	217
	*4	115	*5	222	*4	115	*5	222	*4	115	*5	222
	*3	117	*6	237	*3	117	*6	237	*3	117	*6	237
	5	126	2	259	5	126	2	259	5	126	2	259

CYCLE 2

	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}
	2	96	1	163	2	96	1	163	2	96	1	163
	*1	104	*3	199	*1	104	*3	199	*1	104	*3	199
	*3	110	*5	212	*3	110	*5	212	*3	110	*5	212
	*6	112	*4	218	*6	112	*4	218	*6	112	*4	218
	*4	116	*6	230	*4	116	*6	230	*4	116	*6	230
	5	123	2	244	5	123	2	244	5	123	2	244
	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	2	102	21	165	2	102	1	165	2	102	1	165
	*1	109	x3	210	*1	109	*3	210	*1	109	*3	210
	*6	119	5	220	*6	119	*5	220	*6	119	*5	220
	*3	119	4	223	*3	119	*4	223	*3	119	*4	223
	*4	120	*6	243	*4	120	*6	243	*4	120	*6	243
	5	129	2	258	5	129	2	258	5	129	2	258

CYCLE 3

	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}
	2	100	1	169	2	100	1	169	2	100	1	169
	*3	107	*3	204	*3	107	*3	204	*3	107	*3	204
	*1	108	*5	210	*1	108	*5	210	*1	108	*5	210
	*6	114	*4	215	*6	114	*4	215	*6	114	*4	215
	*4	116	*6	246	*4	116	*6	246	*4	116	*6	246
	5	123	2	252	5	123	2	252	5	123	2	252
	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	2	102	1	175	2	102	1	175	2	102	1	175
	*1	111	*3	213	*1	111	*3	213	*1	111	*3	213
	*3	116	*5	221	*3	116	*5	221	*3	116	*5	221
	*4	120	*4	232	*4	120	*4	232	*4	120	*4	232
	*6	121	*6	257	*6	121	*6	257	*6	121	*6	257
	5	128	2	263	5	128	62	263	5	128	2	263

INDIRECT TENSILE STRENGTH (MPa)

T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
2.17	2.17	2.17
2.35	2.35	2.35
2.41	2.41	2.41

AVERAGE STRENGTHS (MPa)

2.31	2.31	2.31

POISSONS RATIO: FROM STRENGTH DATA

	T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
Calc:	0.34	0.34	0.34
Used:	0.34	0.34	0.34

NORMALIZED DEFORMATIONS AT 500 SECONDS (MICROINCHES)

\	T1 = 10.0C	\	\	\	T2 = 10.0C	\	\	\	T3 = 10.0C	\	\
FACE	X	FACE	Y	FACE	X	FACE	Y	FACE	X	FACE	Y
2	395	1	657	2	395	1	657	2	395	1	657
*1	439	*3	771	*1	439	*3	771	*1	439	*3	771
*3	471	*5	804	*3	471	*5	804	*3	471	*5	804
*5	513	*2	912	*5	513	*2	912	*5	513	*2	912
*4	570	*4	1082	*4	570	*4	1082	*4	570	*4	1082
6	575	6	1198	6	575	6	1198	6	575	6	1198

SPECIMEN THICKNESSES AND DIAMETERS (INCHES)

T1 = 10.0C		T2 = 10.0C		T3 = 10.0C	
Thickness	Diameter	Thickness	Diameter	Thickness	Diameter
1.62	5.91	1.62	5.91	1.62	5.91
1.59	5.91	1.59	5.91	1.59	5.91
1.63	5.91	1.63	5.91	1.63	5.91

STRENGTH TEST DATA FILE NAMES

T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
Filename	Filename	Filename
3C2.txs	3C2.txs	3C2.txs
5C2.txs	5C2.txs	5C2.txs
6B2.txs	6B2.txs	6B2.txs

TRIMMED MEAN VALUES

	T1 = **10.0C**	T2 = **10.0C**	T3 = **10.0C**
INITIAL TANGENT MODULUS (GPa)	**3.7**	**3.7**	**3.7**
FAILURE STRAIN (Microstrain)	**2999.45**	**2999.45**	**2999.45**
FRACTURE ENERGY (kJ/m3)	5.8	5.8	5.8
POISSONS RATIO	0.34	0.34	0.34

INDIVIDUAL VALUES USED TO CALCULATE TRIMMED MEAN VALUES

INITIAL TANGENT MODULUS (GPa)

FACE	T1 = **10.0C**	FACE	T2 = **10.0C**	FACE	T3 = **10.0C**
6	**2.3**	**6**	**2.3**	**6**	**2.3**
***5**	**3**	***5**	**3**	***5**	**3**
***4**	**3.1**	***4**	**3.1**	***4**	**3.1**
***3**	**3.8**	***3**	**3.8**	***3**	**3.8**
***1**	**5**	***1**	**5**	***1**	**5**
2	**5.7**	**2**	**5.7**	**2**	**5.7**

FAILURE STRAIN (Microstrain)

FACE	T1 = **10.0C**	FACE	T2 = **10.0C**	FACE	T3 = **10.0C**
2	**1113.34**	**2**	**1113.34**	**2**	**1113.34**
***1**	**1265.89**	***1**	**1265.89**	***1**	**1265.89**
***3**	**2901.47**	***3**	**2901.47**	***3**	**2901.47**
***4**	**3428.47**	***4**	**3428.47**	***4**	**3428.47**
***5**	**4401.99**	***5**	**4401.99**	***5**	**4401.99**
6	**5952.92**	**6**	**5952.92**	**6**	**5952.92**

FRACTURE ENERGY (kJ/m^3)

FACE	T1 = **10.0C**	FACE	T2 = **10.0C**	FACE	T3 = **10.0C**
2	**1.7**	**2**	**1.7**	**2**	**1.7**
***1**	**1.9**	***1**	**1.9**	***1**	**1.9**
***3**	**5.6**	***3**	**5.6**	***3**	**5.6**
***4**	**6.6**	***4**	**6.6**	***4**	**6.6**
***5**	**9**	***5**	**9**	***5**	**9**
6	**12.2**	**6**	**12.2**	**6**	**12.2**

CREEP COMPLIANCE (1/Gpa)

TIME (SEC)	T1 = **10.0C**	T2 = **10.0C**	T3 = **10.0C**
1	**0.168**	**0.168**	**0.168**
2	**0.18**	**0.18**	**0.18**
5	**0.308**	**0.308**	**0.308**
10	**0.394**	**0.394**	**0.394**
20	**0.486**	**0.486**	**0.486**
50	**0.794**	**0.794**	**0.794**
100	**1.224**	**1.224**	**1.224**
200	**2.014**	**2.014**	**2.014**
500	**3.639**	**3.639**	**3.639**
1000	**5.735**	**5.735**	**5.735**

POISSONS RATIO: FROM CREEP DATA

	T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
CALCULATED:	0.15	0.15	0.15
USED:	0.15	0.15	0.15

(**) - Used Poissons Ratio was manually inputted

NORMALIZED DEFORMATIONS AT 500 SECONDS (MICROINCHES)

T1 = 10.0C				T2 = 10.0C				T3 = 10.0C			
FACE	X	FACE	Y	FACE	X	FACE	Y	FACE	X	FACE	Y
1	118	1	144	1	118	1	144	1	118	1	144
*2	125	*3	212	*2	125	*3	212	*2	125	*3	212
*3	173	*2	238	*3	173	*2	238	*3	173	*2	238
*4	184	*5	321	*4	184	*5	321	*4	184	*5	321
*5	197	*4	343	*5	197	*4	343	*5	197	*4	343
6	204	6	374	6	204	6	374	6	204	6	374

CREEP TEST DATA FILE NAMES AND AVERAGE CREEP LOADS (LBS)

T1 = 10.0C		T2 = 10.0C		T3 = 10.0C	
Filename	Load	Filename	Load	Filename	Load
3C2.txc	50.3	3C2.txc	50.3	3C2.txc	50.3
5C2.txc	50.5	5C2.txc	50.5	5C2.txc	50.5
6B2.txc	49.8	6B2.txc	49.8	6B2.txc	49.8

SPECIMEN THICKNESSES AND DIAMETERS (INCHES)

T1 = 10.0C		T2 = 10.0C		T3 = 10.0C	
Thickness	Diameter	Thickness	Diameter	Thickness	Diameter
1.62	5.91	1.62	5.91	1.62	5.91
1.59	5.91	1.59	5.91	1.59	5.91
1.63	5.91	1.63	5.91	1.63	5.91

Calculating D_1 and m-value from a fixed D_0

Temp (ºC)	Time (s)	D(t) (1/Gpa)	Fitted D (1/Gpa)	Diff square (#)
	1	**0.168**	0.107	3.70E-03
	2	**0.180**	0.141	1.49E-03
	5	**0.308**	0.219	7.93E-03
	10	**0.394**	0.318	5.75E-03
	20	**0.486**	0.475	1.17E-04
10.0C	50	**0.794**	0.831	1.37E-03
	100	**1.224**	1.286	3.88E-03
	200	**2.014**	2.007	5.53E-05
	500	**3.639**	3.639	1.37E-07
	1000	**5.735**	5.727	5.63E-05

SUM OF DIFF SQUARED   **0.024**

Set 1 Fitted Solution

	(1/GPa)	(1/psi)
D_0 **(fixed)**	4.83E-02	3.33E-07
D_1	**5.88E-02**	**4.06E-07**
m-value	**0.661578**	**0.661578**

Solve
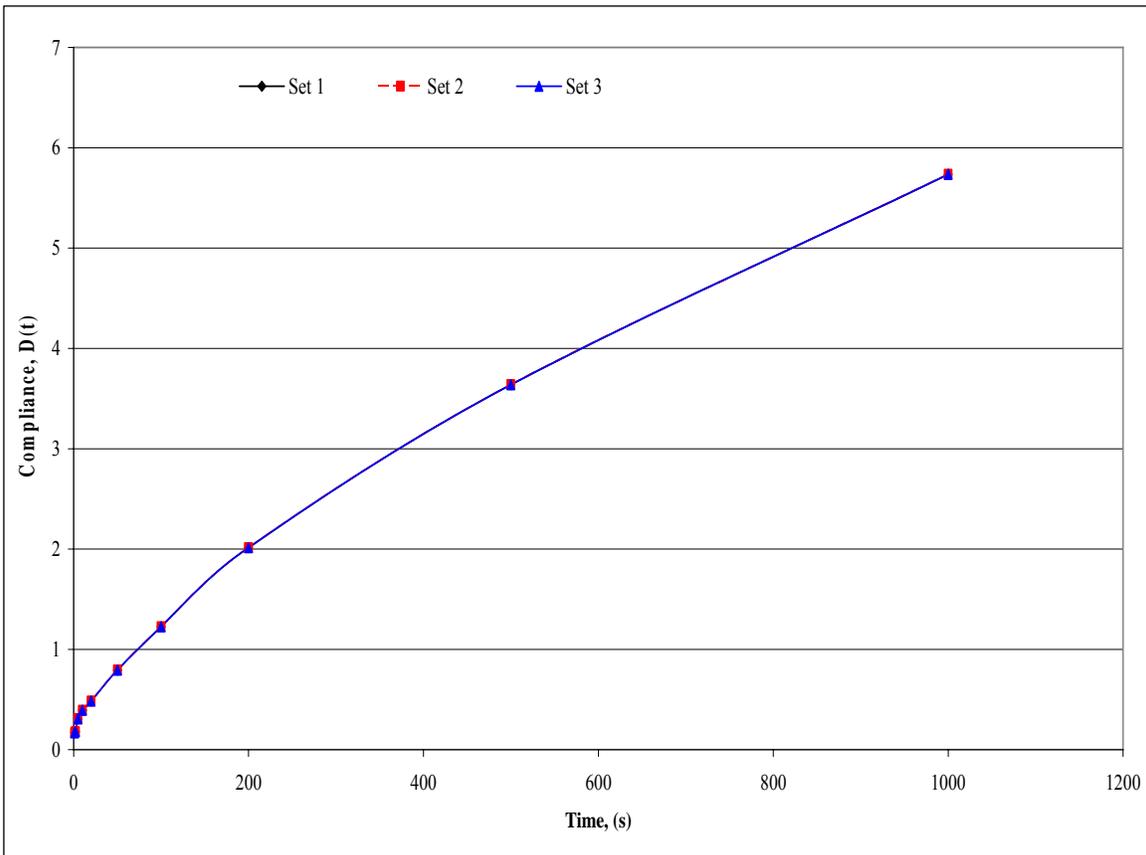
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ENERGY RATIO

Project Name		m-value	D_1	S_t (Mpa)	M_R (Gpa)	FE (kJ/m^3)	$DCSE_{HMA}$ (kJ/m^3)	Stress (psi)	a	$DCSE_{MIN}$ (kJ/m^3)	ER
	Set 1	0.662	4.06E-07	2.31	12.35	5.8	5.6	150	4.72E-08	2.510	2.22
	Set 2	0.662	4.06E-07	2.31	12.35	5.8	5.6	150	4.72E-08	2.510	2.22
	Set 3	0.662	4.06E-07	2.31	12.35	5.8	5.6	150	4.72E-08	2.510	2.22

SIDT Tests at 20°C

INSTANTANEOUS

RESILIENT MODULUS (GPa)

CYCLE	T1= 20.0C	T2= 20.0C	T3= 20.0C
1	8.09	8.09	8.09
2	8.05	8.05	8.05
3	8.1	8.1	8.1

POISSONS RATIO: FROM RESILIENT MODULUS DATA

CYCLE		T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
1	CALCULATED:	0.41	0.41	0.41
	USED:	0.41	0.41	0.41
2	CALCULATED:	0.42	0.42	0.42
	USED:	0.42	0.42	0.42
3	CALCULATED:	0.41	0.41	0.41
	USED:	0.41	0.41	0.41

(**) - Used Poissons Ratio was manually inputted

TOTAL

RESILIENT MODULUS (GPa)

CYCLE	T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
1	7.39	7.39	7.39
2	7.18	7.18	7.18
3	7.29	7.29	7.29

POISSONS RATIO: FROM RESILIENT MODULUS DATA

CYCLE		T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
1	CALCULATED:	0.4	0.4	0.4
	USED:	0.4	0.4	0.4
2	CALCULATED:	0.41	0.41	0.41
	USED:	0.41	0.41	0.41
3	CALCULATED:	0.41	0.41	0.41
	USED:	0.41	0.41	0.41

(**) - Used Poissons Ratio was manually inputted

RESILIENT MODULUS TEST DATA FILE NAMES AND SPECIMEN DIMENSIONS

T1 = 20.0C			T2 = 20.0C			T3 = 20.0C		
Filename	Thickness (in)	Diameter (in)	Filename	Thickness (in)	Diameter (in)	Filename	Thickness (in)	Diameter (in)
3B1.txm	1.58	5.91	3B1.txm	1.58	5.91	3B1.txm	1.58	5.91
4A1.txm	1.58	5.91	4A1.txm	1.58	5.91	4A1.txm	1.58	5.91
8B1.txm	1.63	5.91	8B1.txm	1.63	5.91	8B1.txm	1.63	5.91

NORMALIZED DEFORMATIONS (MICROINCHES)

CYCLE	FACE	T1 = 20.0C H$_{INST}$	FACE	V$_{INST}$	FACE	T2 = 20.0C H$_{INST}$	FACE	V$_{INST}$	FACE	T3 = 20.0C H$_{INST}$	FACE	V$_{INST}$
1	4	81	4	155	4	81	4	155	4	81	4	155
	*2	112	*5	168	*2	112	*5	168	*2	112	*5	168
	*1	125	*2	170	*1	125	*2	170	*1	125	*2	170
	*5	127	*6	241	*5	127	*6	241	*5	127	*6	241
	*6	131	*1	247	*6	131	*1	247	*6	131	*1	247
	3	146	3	308	3	146	3	308	3	146	3	308
	FACE	H$_{TOTAL}$	FACE	V$_{TOTAL}$	FACE	H$_{TOTAL}$	FACE	V$_{TOTAL}$	FACE	H$_{TOTAL}$	FACE	V$_{TOTAL}$
	t4	85	4	168	x4	85	4	168	4	85	4	168
	2	118	*2	180	2	118	*2	180	*2	118	*2	180
	6	140	*5	184	6	140	*5	184	*6	140	*5	184
	*1	140	*6	268	*1	140	*6	268	*1	140	*6	268
	*5	141	*1	276	*5	141	*1	276	*5	141	*1	276
	3	161	3	345	3	161	3	345	3	161	3	345
	FACE	H$_{INST}$	FACE	V$_{INST}$	FACE	H$_{INST}$	FACE	V$_{INST}$	FACE	H$_{INST}$	FACE	V$_{INST}$
2	4	79	4	159	4	79	4	159	4	79	4	159
	*2	112	*5	170	*2	112	*5	170	*2	112	*5	170
	*1	125	*2	174	*1	125	*2	174	*1	125	*2	174
	*5	130	*6	243	*5	130	*6	243	*5	130	*6	243
	*6	133	*1	244	*6	133	*1	244	*6	133	*1	244
	3	140	3	309	3	140	3	309	3	140	3	309
	FACE	H$_{TOTAL}$	FACE	V$_{TOTAL}$	FACE	H$_{TOTAL}$	FACE	V$_{TOTAL}$	FACE	H$_{TOTAL}$	FACE	V$_{TOTAL}$
	4	83	14	175	4	83	4	175	4	83	4	175
	*2	120	x5	186	*2	120	*5	186	*2	120	*5	186
	*1	142	2	193	*1	142	*2	193	*1	142	*2	193
	*5	147	1	273	*5	147	*1	273	*5	147	*1	273
	*6	148	*6	278	*6	148	*6	278	*6	148	*6	278
	3	160	3	347	3	160	3	347	3	160	3	347
	FACE	H$_{INST}$	FACE	V$_{INST}$	FACE	H$_{INST}$	FACE	V$_{INST}$	FACE	H$_{INST}$	FACE	V$_{INST}$
3	4	89	5	170	4	89	5	170	4	89	5	170
	*2	111	*4	173	*2	111	*4	173	*2	111	*4	173
	*5	128	*2	179	*5	128	*2	179	*5	128	*2	179
	*1	129	*1	241	*1	129	*1	241	*1	129	*1	241
	*6	136	*6	249	*6	136	*6	249	*6	136	*6	249
	3	142	3	300	3	142	3	300	3	142	3	300
	FACE	H$_{TOTAL}$	FACE	V$_{TOTAL}$	FACE	H$_{TOTAL}$	FACE	V$_{TOTAL}$	FACE	H$_{TOTAL}$	FACE	V$_{TOTAL}$
	4	93	4	182	4	93	4	182	4	93	4	182
	*2	121	*5	188	*2	121	*5	188	*2	121	*5	188
	*5	143	*2	192	*5	143	*2	192	*5	143	*2	192
	*1	145	*6	270	*1	145	*6	270	*1	145	*6	270
	*6	146	*1	278	*6	146	*1	278	*6	146	*1	278
	3	161	3	343	3	161	83	343	3	161	3	343

INDIRECT TENSILE STRENGTH (MPa)

T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
1.26	1.26	1.26
1.27	1.27	1.27
1.26	1.26	1.26

AVERAGE STRENGTHS (MPa)

1.26	1.26	1.26

POISSONS RATIO: FROM STRENGTH DATA

	T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
Calc:	0.37	0.37	0.37
Used:	0.37	0.37	0.37

NORMALIZED DEFORMATIONS AT 500 SECONDS (MICROINCHES)

	T1 = 20.0C				T2 = 20.0C				T3 = 20.0C		
FACE	X	FACE	Y	FACE	X	FACE	Y	FACE	X	FACE	Y
2	821	5	1108	2	821	5	1108	2	821	5	1108
*4	823	*2	1238	*4	823	*2	1238	*4	823	*2	1238
*1	826	*1	1385	*1	826	*1	1385	*1	826	*1	1385
*5	847	*6	1624	*5	847	*6	1624	*5	847	*6	1624
*6	915	*4	1698	*6	915	*4	1698	*6	915	*4	1698
3	1059	3	1858	3	1059	3	1858	3	1059	3	1858

SPECIMEN THICKNESSES AND DIAMETERS (INCHES)

T1 = 20.0C		T2 = 20.0C		T3 = 20.0C	
Thickness	Diameter	Thickness	Diameter	Thickness	Diameter
1.58	5.91	1.58	5.91	1.58	5.91
1.58	5.91	1.58	5.91	1.58	5.91
1.63	5.91	1.63	5.91	1.63	5.91

STRENGTH TEST DATA FILE NAMES

T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
Filename	Filename	Filename
3B1.txs	3B1.txs	3B1.txs
4A1.txs	4A1.txs	4A1.txs
8B1.txs	8B1.txs	8B1.txs

TRIMMED MEAN VALUES

	T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
INITIAL TANGENT MODULUS (GPa)	1	1	1
FAILURE STRAIN (Microstrain)	5577.34	5577.34	5577.34
FRACTURE ENERGY (kJ/m^3)	5.6	5.6	5.6
POISSONS RATIO	0.37	0.37	0.37

INDIVIDUAL VALUES USED TO CALCULATE TRIMMED MEAN VALUES

INITIAL TANGENT MODULUS (GPa)

FACE	T1 = 20.0C	FACE	T2 = 20.0C	FACE	T3 = 20.0C
3	0.9	3	0.9	3	0.9
*4	0.9	*4	0.9	*4	0.9
*6	1	*6	1	*6	1
*5	1.1	*5	1.1	*5	1.1
*2	1.1	*2	1.1	*2	1.1
1	1.1	1	1.1	1	1.1

FAILURE STRAIN (Microstrain)

FACE	T1 = 20.0C	FACE	T2 = 20.0C	FACE	T3 = 20.0C
5	4601.92	5	4601.92	5	4601.92
*1	4818.75	*1	4818.75	*1	4818.75
*2	4968.61	*2	4968.61	*2	4968.61
*6	5645.08	*6	5645.08	*6	5645.08
*3	6876.92	*3	6876.92	*3	6876.92
4	7281.73	4	7281.73	4	7281.73

FRACTURE ENERGY (kJ/m^3)

FACE	T1 = 20.0C	FACE	T2 = 20.0C	FACE	T3 = 20.0C
5	4.5	5	4.5	5	4.5
*1	4.8	*1	4.8	*1	4.8
*2	5	*2	5	*2	5
*6	5.6	*6	5.6	*6	5.6
*3	7.1	*3	7.1	*3	7.1
4	7.7	4	7.7	4	7.7

CREEP COMPLIANCE (1/Gpa)

TIME (SEC)	T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
1	0.337	0.337	0.337
2	0.489	0.489	0.489
5	0.757	0.757	0.757
10	1.124	1.124	1.124
20	1.76	1.76	1.76
50	3.09	3.09	3.09
100	4.947	4.947	4.947
200	8.106	8.106	8.106
500	15.408	15.408	15.408
1000	25.157	25.157	25.157

POISSONS RATIO: FROM CREEP DATA

	T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
CALCULATED:	0.96	0.96	0.96
USED:	0.5	0.5	0.5

(**) - Used Poissons Ratio was manually inputted

NORMALIZED DEFORMATIONS AT 500 SECONDS
(MICROINCHES)

T1 =	20.0C			T2 =	20.0C			T3 =	20.0C		
FACE	X	FACE	Y	FACE	X	FACE	Y	FACE	X	FACE	Y
5	389	5	415	5	389	5	415	5	389	5	415
*6	432	*6	438	*6	432	*6	438	*6	432	*6	438
*4	511	*4	486	*4	511	*4	486	*4	511	*4	486
*3	593	*2	613	*3	593	*2	613	*3	593	*2	613
*1	595	*1	782	*1	595	*1	782	*1	595	*1	782
2	821	3	900	2	821	3	900	2	821	3	900

CREEP TEST DATA FILE NAMES AND AVERAGE CREEP LOADS (LBS)

T1 = 20.0C		T2 = 20.0C		T3 = 20.0C	
Filename	Load	Filename	Load	Filename	Load
3B1.txc	20.7	3B1.txc	20.7	3B1.txc	20.7
4A1.txc	20.1	4A1.txc	20.1	4A1.txc	20.1
8B1.txc	20.3	8B1.txc	20.3	8B1.txc	20.3

SPECIMEN THICKNESSES AND DIAMETERS (INCHES)

T1 = 20.0C		T2 = 20.0C		T3 = 20.0C	
Thickness	Diameter	Thickness	Diameter	Thickness	Diameter
1.58	5.91	1.58	5.91	1.58	5.91
1.58	5.91	1.58	5.91	1.58	5.91
1.63	5.91	1.63	5.91	1.63	5.91

Calculating D_1 and m-value from a fixed D_0

Temp (ºC)	Time (s)	D(t) (1/Gpa)	Fitted D (1/Gpa)	Diff square (#)
	1	**0.337**	0.244	8.72E-03
	2	**0.489**	0.366	1.51E-02
	5	**0.757**	0.654	1.07E-02
	10	**1.124**	1.033	8.20E-03
	20	**1.760**	1.652	1.17E-02
20.0C	50	**3.090**	3.101	1.32E-04
	100	**4.947**	5.018	5.04E-03
	200	**8.106**	8.138	9.96E-04
	500	**15.408**	15.451	1.86E-03
	1000	**25.157**	25.120	1.38E-03

SUM OF DIFF SQUARED   **0.064**

Set 1 Fitted Solution

	(1/GPa)	(1/psi)
D_0 (fixed)	4.83E-02	3.33E-07
D_1	**1.95E-01**	**1.35E-06**
m-value	**0.702853**	**0.702853**

Solve
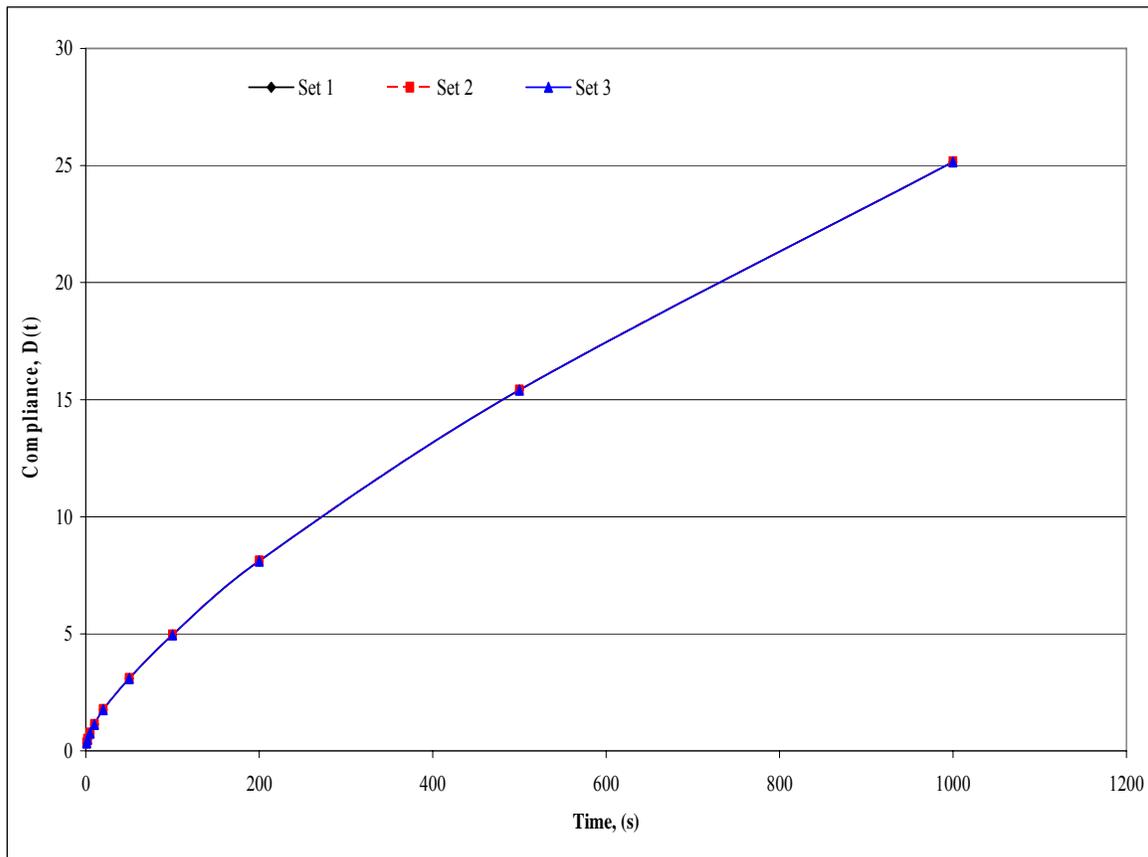
ENERGY RATIO

Project Name		m-value	D_1	S_t (Mpa)	M_R (Gpa)	FE (kJ/m^3)	DCSE$_{HMA}$ (kJ/m^3)	Stress (psi)	a	DCSE$_{MIN}$ (kJ/m^3)	ER
	Set 1	0.703	1.35E-06	1.26	7.29	5.6	5.5	150	5.30E-08	8.876	0.62
	Set 2	0.703	1.35E-06	1.26	7.29	5.6	5.5	150	5.30E-08	8.876	0.62
	Set 3	0.703	1.35E-06	1.26	7.29	5.6	5.5	150	5.30E-08	8.876	0.62

UF Tests at 0°C

INSTANTANEOUS

RESILIENT MODULUS (GPa)

CYCLE	T1= 0.0C	T2= 0.0C	T3= 0.0C
1	17.41	17.41	17.41
2	17.86	17.86	17.86
3	17.82	17.82	17.82

POISSONS RATIO: FROM RESILIENT MODULUS DATA

CYCLE		T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
1	CALCULATED:	0.14	0.14	0.14
	USED:	0.14	0.14	0.14
2	CALCULATED:	0.15	0.15	0.15
	USED:	0.15	0.15	0.15
3	CALCULATED:	0.19	0.19	0.19
	USED:	0.19	0.19	0.19

(**) - Used Poissons Ratio was manually inputted

TOTAL

RESILIENT MODULUS (GPa)

CYCLE	T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
1	17.39	17.39	17.39
2	17.46	17.46	17.46
3	18.04	18.04	18.04

POISSONS RATIO: FROM RESILIENT MODULUS DATA

CYCLE		T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
1	CALCULATED:	0.16	0.16	0.16
	USED:	0.16	0.16	0.16
2	CALCULATED:	0.18	0.18	0.18
	USED:	0.18	0.18	0.18
3	CALCULATED:	0.19	0.19	0.19
	USED:	0.19	0.19	0.19

(**) - Used Poissons Ratio was manually inputted

RESILIENT MODULUS TEST DATA FILE NAMES AND SPECIMEN DIMENSIONS

T1 =	0.0C		T2 =	0.0C		T3 =	0.0C	
Filename	Thickness (in)	Diameter (in)	Filename	Thickness (in)	Diameter (in)	Filename	Thickness (in)	Diameter (in)
2B2.txm	1.55	5.91	2B2.txm	1.55	5.91	2B2.txm	1.55	5.91
3B2.txm	1.6	5.91	3B2.txm	1.6	5.91	3B2.txm	1.6	5.91
7A2.txm	1.65	5.91	7A2.txm	1.65	5.91	7A2.txm	1.65	5.91

| | T1 = 0.0C | | | | T2 = 0.0C | | | | T3 = 0.0C | | | |
CYCLE	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}
1	4	92	5	171	4	92	5	171	4	92	5	171
	*5	96	*4	223	*5	96	*4	223	*5	96	*4	223
	*2	99	*2	225	*2	99	*2	225	*2	99	*2	225
	*6	116	*6	284	*6	116	*6	284	*6	116	*6	284
	*3	117	*3	303	*3	117	*3	303	*3	117	*3	303
	1	133	1	384	1	133	1	384	1	133	1	384
	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	t4	92	5	174	x4	92	5	174	4	92	5	174
	2	101	*4	225	2	101	*4	225	*2	101	*4	225
	5	102	*2	230	5	102	*2	230	*5	102	*2	230
	*3	120	*6	289	*3	120	*6	289	*3	120	*6	289
	*6	124	*3	308	*6	124	*3	308	*6	124	*3	308
	1	135	1	402	1	135	1	402	1	135	1	402
	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}
2	2	91	5	195	2	91	5	195	2	91	5	195
	*4	93	*2	211	*4	93	*2	211	*4	93	*2	211
	*5	101	*4	226	*5	101	*4	226	*5	101	*4	226
	*3	117	*3	300	*3	117	*3	300	*3	117	*3	300
	*6	124	*6	301	*6	124	*6	301	*6	124	*6	301
	1	130	1	388	1	130	1	388	1	130	1	388
	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	4	94	25	184	4	94	5	184	4	94	5	184
	*2	101	x2	210	*2	101	*2	210	*2	101	*2	210
	*5	112	4	226	*5	112	*4	226	*5	112	*4	226
	*3	121	6	301	*3	121	*6	301	*3	121	*6	301
	*6	130	*3	304	*6	130	*3	304	*6	130	*3	304
	1	133	1	401	1	133	1	401	1	133	1	401
	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}
3	4	94	5	188	4	94	5	188	4	94	5	188
	*2	95	*2	199	*2	95	*2	199	*2	95	*2	199
	*5	107	*4	218	*5	107	*4	218	*5	107	*4	218
	*3	120	*3	275	*3	120	*3	275	*3	120	*3	275
	*6	125	*6	300	*6	125	*6	300	*6	125	*6	300
	1	137	1	390	1	137	1	390	1	137	1	390
	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	4	94	5	199	4	94	5	199	4	94	5	199
	*2	97	*2	203	*2	97	*2	203	*2	97	*2	203
	*5	108	*4	219	*5	108	*4	219	*5	108	*4	219
	*3	121	*3	283	*3	121	*3	283	*3	121	*3	283
	*6	133	*6	306	*6	133	*6	306	*6	133	*6	306
	1	141	1	411	1	141	71	411	1	141	1	411

INDIRECT TENSILE STRENGTH (MPa)

T1 =	0.0C	T2 =	0.0C	T3 =	0.0C
	3.38		3.38		3.38
	3.5		3.5		3.5
	3.51		3.51		3.51

AVERAGE STRENGTHS (MPa)

3.47	3.47	3.47

POISSONS RATIO: FROM STRENGTH DATA

	T1 =	0.0C	T2 =	0.0C	T3 =	0.0C
Calc:		0.32		0.32		0.32
Used:		0.32		0.32		0.32

NORMALIZED DEFORMATIONS AT 500 SECONDS (MICROINCHES)

T1 =	0.0C			T2 =	0.0C			T3 =	0.0C		
FACE	X	FACE	Y	FACE	X	FACE	Y	FACE	X	FACE	Y
2	316	6	545	2	316	6	545	2	316	6	545
*3	317	*2	550	*3	317	*2	550	*3	317	*2	550
*6	321	*4	606	*6	321	*4	606	*6	321	*4	606
*4	352	*3	667	*4	352	*3	667	*4	352	*3	667
*5	378	*5	704	*5	378	*5	704	*5	378	*5	704
1	380	1	890	1	380	1	890	1	380	1	890

SPECIMEN THICKNESSES AND DIAMETERS (INCHES)

T1 =	0.0C	T2 =	0.0C	T3 =	0.0C
Thickness	Diameter	Thickness	Diameter	Thickness	Diameter
1.55	5.91	1.55	5.91	1.55	5.91
1.6	5.91	1.6	5.91	1.6	5.91
1.65	5.91	1.65	5.91	1.65	5.91

STRENGTH TEST DATA FILE NAMES

T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
Filename	Filename	Filename
2B2.txs	2B2.txs	2B2.txs
3B2.txs	3B2.txs	3B2.txs
7A2.txs	7A2.txs	7A2.txs

TRIMMED MEAN VALUES

	T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
INITIAL TANGENT MODULUS (GPa)	9.4	9.4	9.4
FAILURE STRAIN (Microstrain)	893.04	893.04	893.04
FRACTURE ENERGY (kJ/m^3)	2.1	2.1	2.1
POISSONS RATIO	0.32	0.32	0.32

INDIVIDUAL VALUES USED TO CALCULATE TRIMMED MEAN VALUES

INITIAL TANGENT MODULUS (GPa)

FACE	T1 = 0.0C	FACE	T2 = 0.0C	FACE	T3 = 0.0C
5	8.5	5	8.5	5	8.5
*1	8.6	*1	8.6	*1	8.6
*4	9	*4	9	*4	9
*6	9.8	*6	9.8	*6	9.8
*3	10.1	*3	10.1	*3	10.1
2	10.4	2	10.4	2	10.4

FAILURE STRAIN (Microstrain)

FACE	T1 = 0.0C	FACE	T2 = 0.0C	FACE	T3 = 0.0C
6	715.05	6	715.05	6	715.05
*2	745.01	*2	745.01	*2	745.01
*3	829.95	*3	829.95	*3	829.95
*4	911.81	*4	911.81	*4	911.81
*5	1085.39	*5	1085.39	*5	1085.39
1	1270.7	1	1270.7	1	1270.7

FRACTURE ENERGY (kJ/m^3)

FACE	T1 = 0.0C	FACE	T2 = 0.0C	FACE	T3 = 0.0C
6	1.6	6	1.6	6	1.6
*2	1.7	*2	1.7	*2	1.7
*3	2	*3	2	*3	2
*4	2.2	*4	2.2	*4	2.2
*5	2.6	*5	2.6	*5	2.6
1	3.2	1	3.2	1	3.2

CREEP COMPLIANCE (1/Gpa)

TIME (SEC)	T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
1	0.13	0.13	0.13
2	0.143	0.143	0.143
5	0.165	0.165	0.165
10	0.176	0.176	0.176
20	0.198	0.198	0.198
50	0.287	0.287	0.287
100	0.316	0.316	0.316
200	0.459	0.459	0.459
500	0.724	0.724	0.724
1000	1.045	1.045	1.045

POISSONS RATIO: FROM CREEP DATA

	T1 = 0.0C	T2 = 0.0C	T3 = 0.0C
CALCULATED:	0.08	0.08	0.08
USED:	0.06	0.06	0.06

(**) - Used Poissons Ratio was manually inputted

NORMALIZED DEFORMATIONS AT 500 SECONDS (MICROINCHES)

	T1 =	0.0C			T2 =	0.0C			T3 =	0.0C	
FACE	X	FACE	Y	FACE	X	FACE	Y	FACE	X	FACE	Y
3	62	3	200	3	62	3	200	3	62	3	200
*5	88	*5	226	*5	88	*5	226	*5	88	*5	226
*2	101	*2	246	*2	101	*2	246	*2	101	*2	246
*1	110	*6	249	*1	110	*6	249	*1	110	*6	249
*6	117	*4	294	*6	117	*4	294	*6	117	*4	294
4	133	1	367	4	133	1	367	4	133	1	367

CREEP TEST DATA FILE NAMES AND AVERAGE CREEP LOADS (LBS)

T1 = 0.0C		T2 = 0.0C		T3 = 0.0C	
Filename	Load	Filename	Load	Filename	Load
2B2.txc	199.9	2B2.txc	199.9	2B2.txc	199.9
3B2.txc	203.6	3B2.txc	203.6	3B2.txc	203.6
7A2.txc	150.7	7A2.txc	150.7	7A2.txc	150.7

SPECIMEN THICKNESSES AND DIAMETERS (INCHES)

T1 = 0.0C		T2 = 0.0C		T3 = 0.0C	
Thickness	Diameter	Thickness	Diameter	Thickness	Diameter
1.55	5.91	1.55	5.91	1.55	5.91
1.6	5.91	1.6	5.91	1.6	5.91
1.65	5.91	1.65	5.91	1.65	5.91

Calculating D_1 and m-value from a fixed D_0

Temp (ºC)	Time (s)	D(t) (1/Gpa)	Fitted D (1/Gpa)	Diff square (#)
	1	**0.130**	0.082	2.31E-03
	2	**0.143**	0.095	2.26E-03
	5	**0.165**	0.122	1.86E-03
	10	**0.176**	0.151	6.07E-04
	20	**0.198**	0.193	2.81E-05
0.0C	50	**0.287**	0.274	1.74E-04
	100	**0.316**	0.364	2.33E-03
	200	**0.459**	0.491	1.02E-03
	500	**0.724**	0.740	2.48E-04
	1000	**1.045**	1.017	7.77E-04

SUM OF DIFF SQUARED   **0.012**

Set 1 Fitted Solution

	(1/GPa)	(1/psi)
D_0 **(fixed)**	4.83E-02	3.33E-07
D_1	**3.36E-02**	**2.32E-07**
m-value	**0.486648**	**0.486648**

Solve
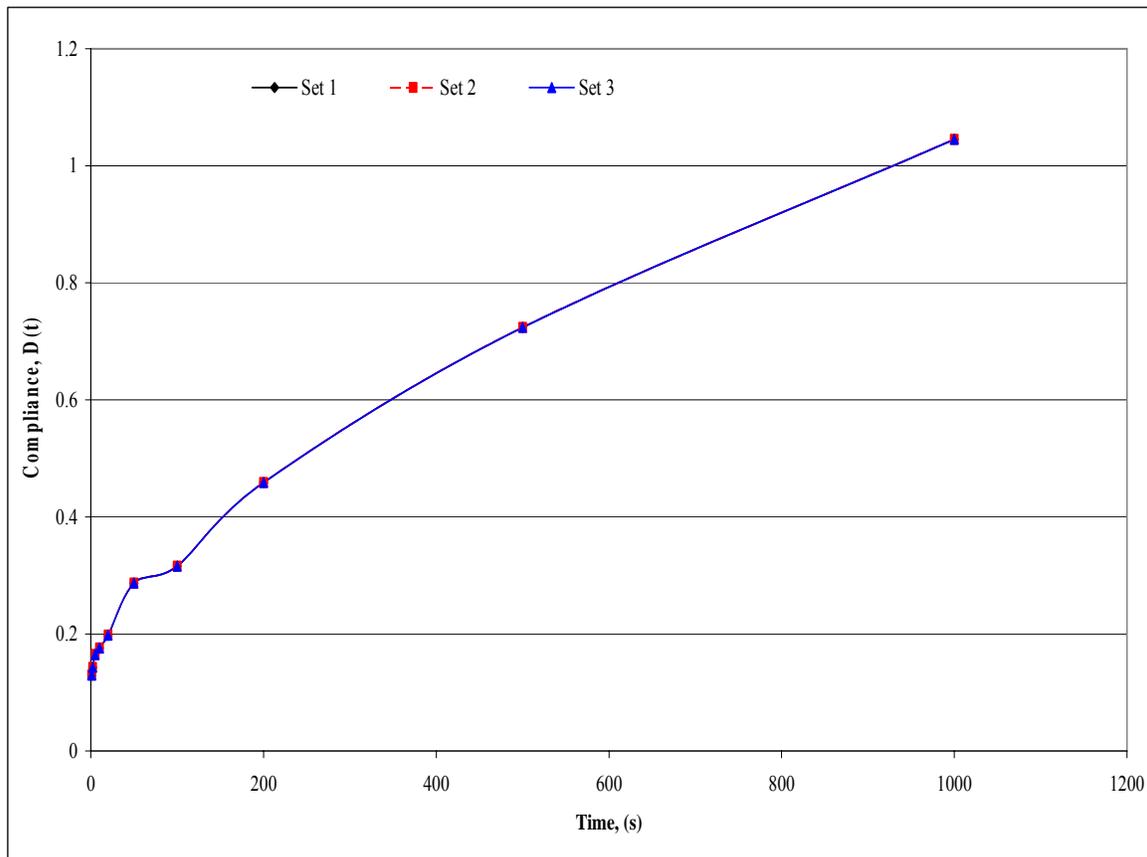
ENERGY RATIO

Project Name	m-value	D_1	S_t (Mpa)	M_R (Gpa)	FE (kJ/m^3)	DCSE$_{HMA}$ (kJ/m^3)	Stress (psi)	a	DCSE$_{MIN}$ (kJ/m^3)	ER
Set 1	0.487	2.32E-07	3.47	17.63	2.1	1.8	150	4.07E-08	0.665	2.64
Set 2	0.487	2.32E-07	3.47	17.63	2.1	1.8	150	4.07E-08	0.665	2.64
Set 3	0.487	2.32E-07	3.47	17.63	2.1	1.8	150	4.07E-08	0.665	2.64

UF Tests at 10°C

INSTANTANEOUS

RESILIENT MODULUS (GPa)

CYCLE	T1= 10.0C	T2= 10.0C	T3= 10.0C
1	14.01	14.01	14.01
2	13.98	13.98	13.98
3	14.33	14.33	14.33

POISSONS RATIO: FROM RESILIENT MODULUS DATA

CYCLE		T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
1	CALCULATED:	0.28	0.28	0.28
	USED:	0.28	0.28	0.28
2	CALCULATED:	0.32	0.32	0.32
	USED:	0.32	0.32	0.32
3	CALCULATED:	0.29	0.29	0.29
	USED:	0.29	0.29	0.29

(**) - Used Poissons Ratio was manually inputted

TOTAL

RESILIENT MODULUS (GPa)

CYCLE	T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
1	13.46	13.46	13.46
2	13.59	13.59	13.59
3	13.46	13.46	13.46

POISSONS RATIO: FROM RESILIENT MODULUS DATA

CYCLE		T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
1	CALCULATED:	0.31	0.31	0.31
	USED:	0.31	0.31	0.31
2	CALCULATED:	0.33	0.33	0.33
	USED:	0.33	0.33	0.33
3	CALCULATED:	0.32	0.32	0.32
	USED:	0.32	0.32	0.32

(**) - Used Poissons Ratio was manually inputted

RESILIENT MODULUS TEST DATA FILE NAMES AND SPECIMEN DIMENSIONS

T1 = 10.0C			T2 = 10.0C			T3 = 10.0C		
Filename	Thickness (in)	Diameter (in)	Filename	Thickness (in)	Diameter (in)	Filename	Thickness (in)	Diameter (in)
4B1.txm	1.53	5.91	4B1.txm	1.53	5.91	4B1.txm	1.53	5.91
7B1.txm	1.58	5.91	7B1.txm	1.58	5.91	7B1.txm	1.58	5.91
7C2.txm	1.64	5.91	7C2.txm	1.64	5.91	7C2.txm	1.64	5.91

NORMALIZED DEFORMATIONS (MICROINCHES)

CYCLE		T1 = 10.0C				T2 = 10.0C				T3 = 10.0C		
	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}
1	3	61	5	75	3	61	5	75	3	61	5	75
	*5	62	*3	86	*5	62	*3	86	*5	62	*3	86
	*2	84	*2	158	*2	84	*2	158	*2	84	*2	158
	*1	109	*1	219	*1	109	*1	219	*1	109	*1	219
	*6	157	*6	329	*6	157	*6	329	*6	157	*6	329
	4	157	4	330	4	157	4	330	4	157	4	330
	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	t3	64	5	78	x3	64	5	78	3	64	5	78
	5	68	*3	98	5	68	*3	98	*5	68	*3	98
	2	95	*2	160	2	95	*2	160	*2	95	*2	160
	*1	118	*1	224	*1	118	*1	224	*1	118	*1	224
	*4	167	*6	350	*4	167	*6	350	*4	167	*6	350
	6	168	4	357	6	168	4	357	6	168	4	357
	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}
2	3	61	5	74	3	61	5	74	3	61	5	74
	*5	67	*3	94	*5	67	*3	94	*5	67	*3	94
	*2	87	*2	149	*2	87	*2	149	*2	87	*2	149
	*1	110	*1	207	*1	110	*1	207	*1	110	*1	207
	*4	156	*4	328	*4	156	*4	328	*4	156	*4	328
	6	157	6	335	6	157	6	335	6	157	6	335
	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	3	67	25	69	3	67	5	69	3	67	5	69
	*5	73	x3	99	*5	73	*3	99	*5	73	*3	99
	*2	91	2	159	*2	91	*2	159	*2	91	*2	159
	*1	119	1	218	*1	119	*1	218	*1	119	*1	218
	*6	168	*6	348	*6	168	*6	348	*6	168	*6	348
	4	170	4	349	4	170	4	349	4	170	4	349
	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}	FACE	H_{INST}	FACE	v_{INST}
3	3	63	5	86	3	63	5	86	3	63	5	86
	*5	69	*3	93	*5	69	*3	93	*5	69	*3	93
	*2	84	*2	154	*2	84	*2	154	*2	84	*2	154
	*1	108	*1	214	*1	108	*1	214	*1	108	*1	214
	*4	152	*6	332	*4	152	*6	332	*4	152	*6	332
	6	154	4	334	6	154	4	334	6	154	4	334
	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	3	69	5	82	3	69	5	82	3	69	5	82
	*5	76	*3	97	*5	76	*3	97	*5	76	*3	97
	*2	93	*2	164	*2	93	*2	164	*2	93	*2	164
	*1	118	*1	235	*1	118	*1	235	*1	118	*1	235
	*6	172	*6	345	*6	172	*6	345	*6	172	*6	345
	4	175	4	353	4	175	74	353	4	175	4	353

INDIRECT TENSILE STRENGTH (MPa)

T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
2.45	2.45	2.45
2.69	2.69	2.69
2.46	2.46	2.46

AVERAGE STRENGTHS (MPa)

2.53	2.53	2.53

POISSONS RATIO: FROM STRENGTH DATA

	T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
Calc:	0.4	0.4	0.4
Used:	0.4	0.4	0.4

NORMALIZED DEFORMATIONS AT 500 SECONDS (MICROINCHES)

T1 = 10.0C				T2 = 10.0C				T3 = 10.0C			
FACE	X	FACE	Y	FACE	X	FACE	Y	FACE	X	FACE	Y
3	418	3	664	3	418	3	664	3	418	3	664
*5	453	*5	751	*5	453	*5	751	*5	453	*5	751
*1	606	*1	899	*1	606	*1	899	*1	606	*1	899
*2	717	*6	1247	*2	717	*6	1247	*2	717	*6	1247
*6	753	*2	1354	*6	753	*2	1354	*6	753	*2	1354
4	937	4	1658	4	937	4	1658	4	937	4	1658

SPECIMEN THICKNESSES AND DIAMETERS (INCHES)

T1 = 10.0C		T2 = 10.0C		T3 = 10.0C	
Thickness	Diameter	Thickness	Diameter	Thickness	Diameter
1.53	5.91	1.53	5.91	1.53	5.91
1.58	5.91	1.58	5.91	1.58	5.91
1.64	5.91	1.64	5.91	1.64	5.91

STRENGTH TEST DATA FILE NAMES

T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
Filename	Filename	Filename
4B1.txs	4B1.txs	4B1.txs
7B1.txs	7B1.txs	7B1.txs
7C2.txs	7C2.txs	7C2.txs

TRIMMED MEAN VALUES

	T1 = **10.0C**	T2 = **10.0C**	T3 = **10.0C**
INITIAL TANGENT MODULUS (GPa)	**3.6**	**3.6**	**3.6**
FAILURE STRAIN (Microstrain)	**3369.73**	**3369.73**	**3369.73**
FRACTURE ENERGY (kJ/m^3)	**6.7**	**6.7**	**6.7**
POISSONS RATIO	**0.4**	**0.4**	**0.4**

INDIVIDUAL VALUES USED TO CALCULATE TRIMMED MEAN VALUES

INITIAL TANGENT MODULUS (GPa)

FACE	T1 = **10.0C**	FACE	T2 = **10.0C**	FACE	T3 = **10.0C**
4	**2.4**	**4**	**2.4**	**4**	**2.4**
***6**	**3.1**	***6**	**3.1**	***6**	**3.1**
***2**	**3.1**	***2**	**3.1**	***2**	**3.1**
***1**	**3.6**	***1**	**3.6**	***1**	**3.6**
***3**	**4.5**	***3**	**4.5**	***3**	**4.5**
5	**4.8**	**5**	**4.8**	**5**	**4.8**

FAILURE STRAIN (Microstrain)

FACE	T1 = **10.0C**	FACE	T2 = **10.0C**	FACE	T3 = **10.0C**
5	**2291.18**	**5**	**2291.18**	**5**	**2291.18**
***6**	**3105.12**	***6**	**3105.12**	***6**	**3105.12**
***3**	**3144.36**	***3**	**3144.36**	***3**	**3144.36**
***1**	**3308.45**	***1**	**3308.45**	***1**	**3308.45**
***2**	**3921.01**	***2**	**3921.01**	***2**	**3921.01**
4	**4721.56**	**4**	**4721.56**	**4**	**4721.56**

FRACTURE ENERGY (kJ/m^3)

FACE	T1 = **10.0C**	FACE	T2 = **10.0C**	FACE	T3 = **10.0C**
5	**4.4**	**5**	**4.4**	**5**	**4.4**
***6**	**5.8**	***6**	**5.8**	***6**	**5.8**
***1**	**6.5**	***1**	**6.5**	***1**	**6.5**
***3**	**6.9**	***3**	**6.9**	***3**	**6.9**
***2**	**7.8**	***2**	**7.8**	***2**	**7.8**
4	**10**	**4**	**10**	**4**	**10**

CREEP COMPLIANCE (1/Gpa)

TIME (SEC)	T1 = **10.0C**	T2 = **10.0C**	T3 = **10.0C**
1	**0.174**	**0.174**	**0.174**
2	**0.238**	**0.238**	**0.238**
5	**0.336**	**0.336**	**0.336**
10	**0.428**	**0.428**	**0.428**
20	**0.611**	**0.611**	**0.611**
50	**1.049**	**1.049**	**1.049**
100	**1.624**	**1.624**	**1.624**
200	**2.397**	**2.397**	**2.397**
500	**4.094**	**4.094**	**4.094**
1000	**6.101**	**6.101**	**6.101**

POISSONS RATIO: FROM CREEP DATA

	T1 = 10.0C	T2 = 10.0C	T3 = 10.0C
CALCULATED:	0.24	0.24	0.24
USED:	0.24	0.24	0.24

(**) - Used Poissons Ratio was manually inputted

NORMALIZED DEFORMATIONS AT 500 SECONDS (MICROINCHES)

	T1 = 10.0C				T2 = 10.0C				T3 = 10.0C		
FACE	X	FACE	Y	FACE	X	FACE	Y	FACE	X	FACE	Y
5	39	5	21	5	39	5	21	5	39	5	21
*3	140	*3	184	*3	140	*3	184	*3	140	*3	184
*1	193	*1	208	*1	193	*1	208	*1	193	*1	208
*6	285	*2	439	*6	285	*2	439	*6	285	*2	439
*2	290	*6	513	*2	290	*6	513	*2	290	*6	513
4	333	4	604	4	333	4	604	4	333	4	604

CREEP TEST DATA FILE NAMES AND AVERAGE CREEP LOADS (LBS)

T1 = 10.0C		T2 = 10.0C		T3 = 10.0C	
Filename	Load	Filename	Load	Filename	Load
4B1.txc	55.9	4B1.txc	55.9	4B1.txc	55.9
7B1.txc	40.9	7B1.txc	40.9	7B1.txc	40.9
7C2.txc	49.4	7C2.txc	49.4	7C2.txc	49.4

SPECIMEN THICKNESSES AND DIAMETERS (INCHES)

T1 = 10.0C		T2 = 10.0C		T3 = 10.0C	
Thickness	Diameter	Thickness	Diameter	Thickness	Diameter
1.53	5.91	1.53	5.91	1.53	5.91
1.58	5.91	1.58	5.91	1.58	5.91
1.64	5.91	1.64	5.91	1.64	5.91

Calculating D_1 and m-value from a fixed D_0

Temp (ºC)	Time (s)	D(t) (1/Gpa)	Fitted D (1/Gpa)	Diff square (#)
	1	**0.174**	0.151	5.40E-04
	2	**0.238**	0.203	1.25E-03
	5	**0.336**	0.313	5.11E-04
	10	**0.428**	0.448	3.81E-04
	20	**0.611**	0.650	1.49E-03
10.0C	50	**1.049**	1.081	1.05E-03
	100	**1.624**	1.604	3.91E-04
	200	**2.397**	2.392	2.91E-05
	500	**4.094**	4.075	3.68E-04
	1000	**6.101**	6.113	1.33E-04
		SUM OF DIFF SQUARED		**0.006**

Set 1 Fitted Solution

	(1/GPa)	(1/psi)
D_0 **(fixed)**	4.83E-02	3.33E-07
D_1	**1.02E-01**	**7.06E-07**
m-value	**0.590798**	**0.590798**

Solve
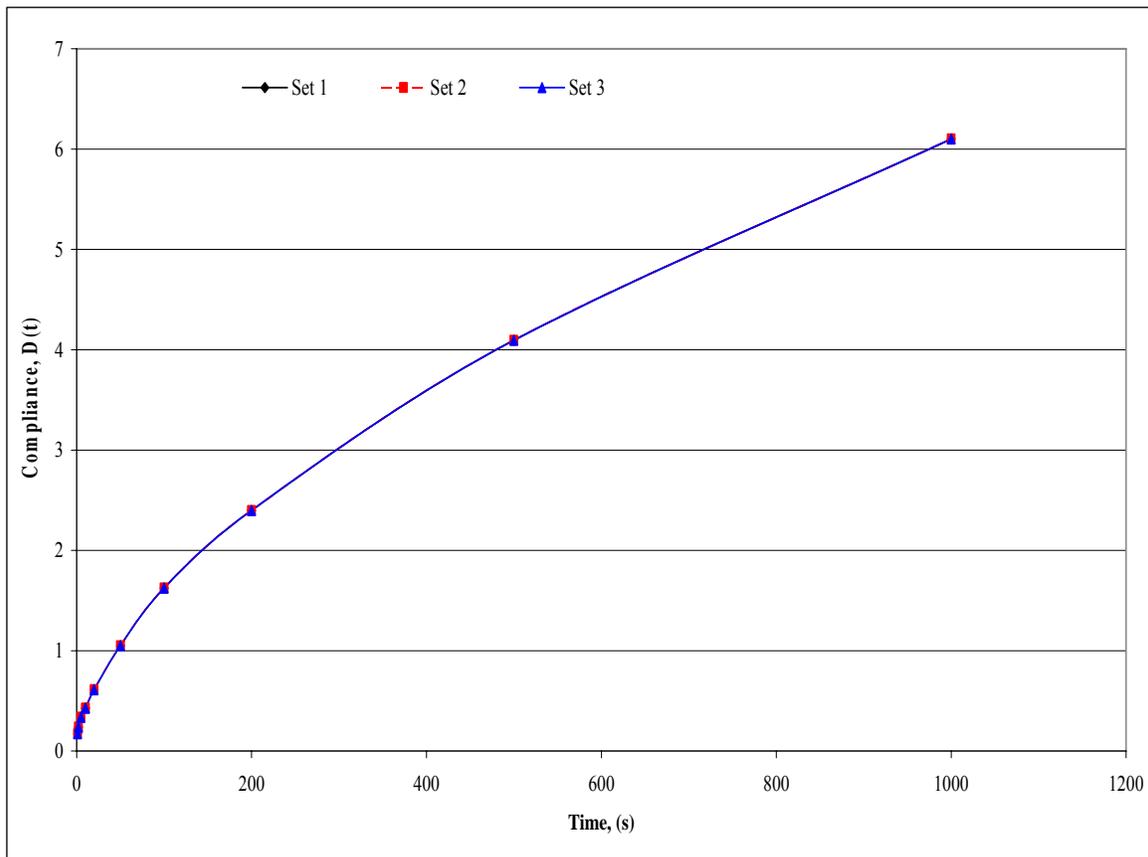
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ENERGY RATIO

Project Name	m-value	D_1	S_t (Mpa)	M_R (Gpa)	FE (kJ/m^3)	DCSE$_{HMA}$ (kJ/m^3)	Stress (psi)	a	DCSE$_{MIN}$ (kJ/m^3)	ER
Set 1	0.591	7.06E-07	2.53	13.50	6.7	6.5	150	4.60E-08	3.202	2.02
Set 2	0.591	7.06E-07	2.53	13.50	6.7	6.5	150	4.60E-08	3.202	2.02
Set 3	0.591	7.06E-07	2.53	13.50	6.7	6.5	150	4.60E-08	3.202	2.02

UF Tests at 20°C

INSTANTANEOUS

RESILIENT MODULUS (GPa)

CYCLE	T1= 20.0C	T2= 20.0C	T3= 20.0C
1	7.54	7.54	7.54
2	7.7	7.7	7.7
3	7.67	7.67	7.67

POISSONS RATIO: FROM RESILIENT MODULUS DATA

CYCLE		T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
1	CALCULATED:	0.27	0.27	0.27
	USED:	0.27	0.27	0.27
2	CALCULATED:	0.25	0.25	0.25
	USED:	0.25	0.25	0.25
3	CALCULATED:	0.25	0.25	0.25
	USED:	0.25	0.25	0.25

(**) - Used Poissons Ratio was manually inputted

TOTAL

RESILIENT MODULUS (GPa)

CYCLE	T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
1	6.88	6.88	6.88
2	6.85	6.85	6.85
3	6.81	6.81	6.81

POISSONS RATIO: FROM RESILIENT MODULUS DATA

CYCLE		T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
1	CALCULATED:	0.24	0.24	0.24
	USED:	0.24	0.24	0.24
2	CALCULATED:	0.23	0.23	0.23
	USED:	0.23	0.23	0.23
3	CALCULATED:	0.24	0.24	0.24
	USED:	0.24	0.24	0.24

(**) - Used Poissons Ratio was manually inputted

RESILIENT MODULUS TEST DATA FILE NAMES AND SPECIMEN DIMENSIONS

T1 = 20.0C			T2 = 20.0C			T3 = 20.0C		
Filename	Thickness (in)	Diameter (in)	Filename	Thickness (in)	Diameter (in)	Filename	Thickness (in)	Diameter (in)
1A1.txm	1.59	5.91	1A1.txm	1.59	5.91	1A1.txm	1.59	5.91
1A2.txm	1.6	5.91	1A2.txm	1.6	5.91	1A2.txm	1.6	5.91
7C1.txm	1.55	5.91	7C1.txm	1.55	5.91	7C1.txm	1.55	5.91

NORMALIZED DEFORMATIONS (MICROINCHES)

CYCLE	FACE	T1 = 20.0C H_{INST}	FACE	V_{INST}	FACE	T2 = 20.0C H_{INST}	FACE	V_{INST}	FACE	T3 = 20.0C H_{INST}	FACE	V_{INST}
1	3	80	5	160	3	80	5	160	3	80	5	160
	*5	92	*2	169	*5	92	*2	169	*5	92	*2	169
	*2	96	*4	187	*2	96	*4	187	*2	96	*4	187
	*6	99	*1	197	*6	99	*1	197	*6	99	*1	197
	*1	106	*3	217	*1	106	*3	217	*1	106	*3	217
	4	112	6	242	4	112	6	242	4	112	6	242

CYCLE	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	t3	84	5	180	x3	84	5	180	3	84	5	180
	5	96	*2	185	5	96	*2	185	*5	96	*2	185
	2	102	*4	202	2	102	*4	202	*2	102	*4	202
	*6	104	*1	218	*6	104	*1	218	*6	104	*1	218
	*1	112	*3	239	*1	112	*3	239	*1	112	*3	239
	4	121	6	263	4	121	6	263	4	121	6	263

CYCLE	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}
2	3	82	5	169	3	82	5	169	3	82	5	169
	*5	92	*2	174	*5	92	*2	174	*5	92	*2	174
	*2	95	*4	187	*2	95	*4	187	*2	95	*4	187
	*6	96	*1	199	*6	96	*1	199	*6	96	*1	199
	*1	104	*3	223	*1	104	*3	223	*1	104	*3	223
	4	117	6	233	4	117	6	233	4	117	6	233

CYCLE	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	3	85	15	183	3	85	5	183	3	85	5	183
	*5	99	x2	191	*5	99	*2	191	*5	99	*2	191
	*2	104	4	209	*2	104	*4	209	*2	104	*4	209
	*6	105	1	218	*6	105	*1	218	*6	105	*1	218
	*1	113	*3	252	*1	113	*3	252	*1	113	*3	252
	4	126	6	269	4	126	6	269	4	126	6	269

CYCLE	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}	FACE	H_{INST}	FACE	V_{INST}
3	3	82	5	177	3	82	5	177	3	82	5	177
	*5	93	*2	177	*5	93	*2	177	*5	93	*2	177
	*2	95	*1	194	*2	95	*1	194	*2	95	*1	194
	*6	98	*4	195	*6	98	*4	195	*6	98	*4	195
	*1	105	*3	224	*1	105	*3	224	*1	105	*3	224
	4	118	6	239	4	118	6	239	4	118	6	239

CYCLE	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}	FACE	H_{TOTAL}	FACE	V_{TOTAL}
	3	87	5	196	3	87	5	196	3	87	5	196
	*5	101	*2	196	*5	101	*2	196	*5	101	*2	196
	*2	104	*4	210	*2	104	*4	210	*2	104	*4	210
	*6	108	*1	225	*6	108	*1	225	*6	108	*1	225
	*1	112	*3	244	*1	112	*3	244	*1	112	*3	244
	4	127	6	266	4	127	76	266	4	127	6	266

INDIRECT TENSILE STRENGTH (MPa)

T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
1.34	1.34	1.34
1.26	1.26	1.26
1.26	1.26	1.26

AVERAGE STRENGTHS (MPa)

1.29	1.29	1.29

POISSONS RATIO: FROM STRENGTH DATA

	T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
Calc:	0.33	0.33	0.33
Used:	0.33	0.33	0.33

NORMALIZED DEFORMATIONS AT 500 SECONDS (MICROINCHES)

T1 = 20.0C				T2 = 20.0C				T3 = 20.0C			
FACE	X	FACE	Y	FACE	X	FACE	Y	FACE	X	FACE	Y
3	528	1	1050	3	528	1	1050	3	528	1	1050
*1	604	*4	1055	*1	604	*4	1055	*1	604	*4	1055
*6	694	*2	1195	*6	694	*2	1195	*6	694	*2	1195
*5	708	*5	1286	*5	708	*5	1286	*5	708	*5	1286
*2	712	*3	1391	*2	712	*3	1391	*2	712	*3	1391
4	757	6	1456	4	757	6	1456	4	757	6	1456

SPECIMEN THICKNESSES AND DIAMETERS (INCHES)

T1 = 20.0C		T2 = 20.0C		T3 = 20.0C	
Thickness	Diameter	Thickness	Diameter	Thickness	Diameter
1.59	5.91	1.59	5.91	1.59	5.91
1.6	5.91	1.6	5.91	1.6	5.91
1.55	5.91	1.55	5.91	1.55	5.91

STRENGTH TEST DATA FILE NAMES

T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
Filename	Filename	Filename
1A1.txs	1A1.txs	1A1.txs
1A2.txs	1A2.txs	1A2.txs
7C1.txs	7C1.txs	7C1.txs

TRIMMED MEAN VALUES

	T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
INITIAL TANGENT MODULUS (GPa)	1.4	1.4	1.4
FAILURE STRAIN (Microstrain)	4649.91	4649.91	4649.91
FRACTURE ENERGY (kJ/m^3)	4.7	4.7	4.7
POISSONS RATIO	0.33	0.33	0.33

INDIVIDUAL VALUES USED TO CALCULATE TRIMMED MEAN VALUES

INITIAL TANGENT MODULUS (GPa)

FACE	T1 = 20.0C	FACE	T2 = 20.0C	FACE	T3 = 20.0C
4	1.3	4	1.3	4	1.3
*2	1.3	*2	1.3	*2	1.3
*6	1.4	*6	1.4	*6	1.4
*5	1.5	*5	1.5	*5	1.5
*3	1.5	*3	1.5	*3	1.5
1	1.7	1	1.7	1	1.7

FAILURE STRAIN (Microstrain)

FACE	T1 = 20.0C	FACE	T2 = 20.0C	FACE	T3 = 20.0C
1	3207.68	1	3207.68	1	3207.68
*5	4198.5	*5	4198.5	*5	4198.5
*6	4690.47	*6	4690.47	*6	4690.47
*4	4853.93	*4	4853.93	*4	4853.93
*2	4856.75	*2	4856.75	*2	4856.75
3	5565.71	3	5565.71	3	5565.71

FRACTURE ENERGY (kJ/m^3)

FACE	T1 = 20.0C	FACE	T2 = 20.0C	FACE	T3 = 20.0C
1	3.3	1	3.3	1	3.3
*5	4.2	*5	4.2	*5	4.2
*6	4.7	*6	4.7	*6	4.7
*4	4.9	*4	4.9	*4	4.9
*2	5.2	*2	5.2	*2	5.2
3	5.7	3	5.7	3	5.7

CREEP COMPLIANCE (1/Gpa)

TIME (SEC)	T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
1	0.282	0.282	0.282
2	0.368	0.368	0.368
5	0.581	0.581	0.581
10	0.905	0.905	0.905
20	1.42	1.42	1.42
50	2.347	2.347	2.347
100	3.869	3.869	3.869
200	6.216	6.216	6.216
500	11.629	11.629	11.629
1000	18.561	18.561	18.561

POISSONS RATIO: FROM CREEP DATA

	T1 = 20.0C	T2 = 20.0C	T3 = 20.0C
CALCULATED:	0.77	0.77	0.77
USED:	0.5	0.5	0.5

(**) - Used Poissons Ratio was manually inputted

NORMALIZED DEFORMATIONS AT 500 SECONDS
(MICROINCHES)

T1 = 20.0C				T2 = 20.0C				T3 = 20.0C			
FACE	X	FACE	Y	FACE	X	FACE	Y	FACE	X	FACE	Y
1	293	2	268	1	293	2	268	1	293	2	268
*2	368	*4	301	*2	368	*4	301	*2	368	*4	301
*3	413	*1	316	*3	413	*1	316	*3	413	*1	316
*5	449	*5	321	*5	449	*5	321	*5	449	*5	321
*4	460	*3	497	*4	460	*3	497	*4	460	*3	497
6	559	6	617	6	559	6	617	6	559	6	617

CREEP TEST DATA FILE NAMES AND AVERAGE CREEP LOADS (LBS)

T1 = 20.0C		T2 = 20.0C		T3 = 20.0C	
Filename	Load	Filename	Load	Filename	Load
1A1.txc	20.5	1A1.txc	20.5	1A1.txc	20.5
1A2.txc	21.1	1A2.txc	21.1	1A2.txc	21.1
7C1.txc	22	7C1.txc	22	7C1.txc	22

SPECIMEN THICKNESSES AND DIAMETERS (INCHES)

T1 = 20.0C		T2 = 20.0C		T3 = 20.0C	
Thickness	Diameter	Thickness	Diameter	Thickness	Diameter
1.59	5.91	1.59	5.91	1.59	5.91
1.6	5.91	1.6	5.91	1.6	5.91
1.55	5.91	1.55	5.91	1.55	5.91

Calculating D_1 and m-value from a fixed D_0

Temp	Time	D(t)	Fitted D	Diff square		Set 1 Fitted Solution		
(ºC)	(s)	(1/Gpa)	(1/Gpa)	(#)			(1/GPa)	(1/psi)
	1	**0.282**	0.215	4.47E-03		D_0 (fixed)	4.83E-02	3.33E-07
	2	**0.368**	0.316	2.71E-03		D_1	**1.67E-01**	**1.15E-06**
	5	**0.581**	0.548	1.08E-03		m-value	**0.68182**	**0.68182**
	10	**0.905**	0.850	3.02E-03				
20.0C	20	**1.420**	1.334	7.33E-03				
	50	**2.347**	2.450	1.07E-02		**Solve**		
	100	**3.869**	3.902	1.06E-03				
	200	**6.216**	6.230	1.86E-04				
	500	**11.629**	11.594	1.25E-03				
	1000	**18.561**	18.569	6.04E-05				
		SUM OF DIFF SQUARED		**0.032**				

135
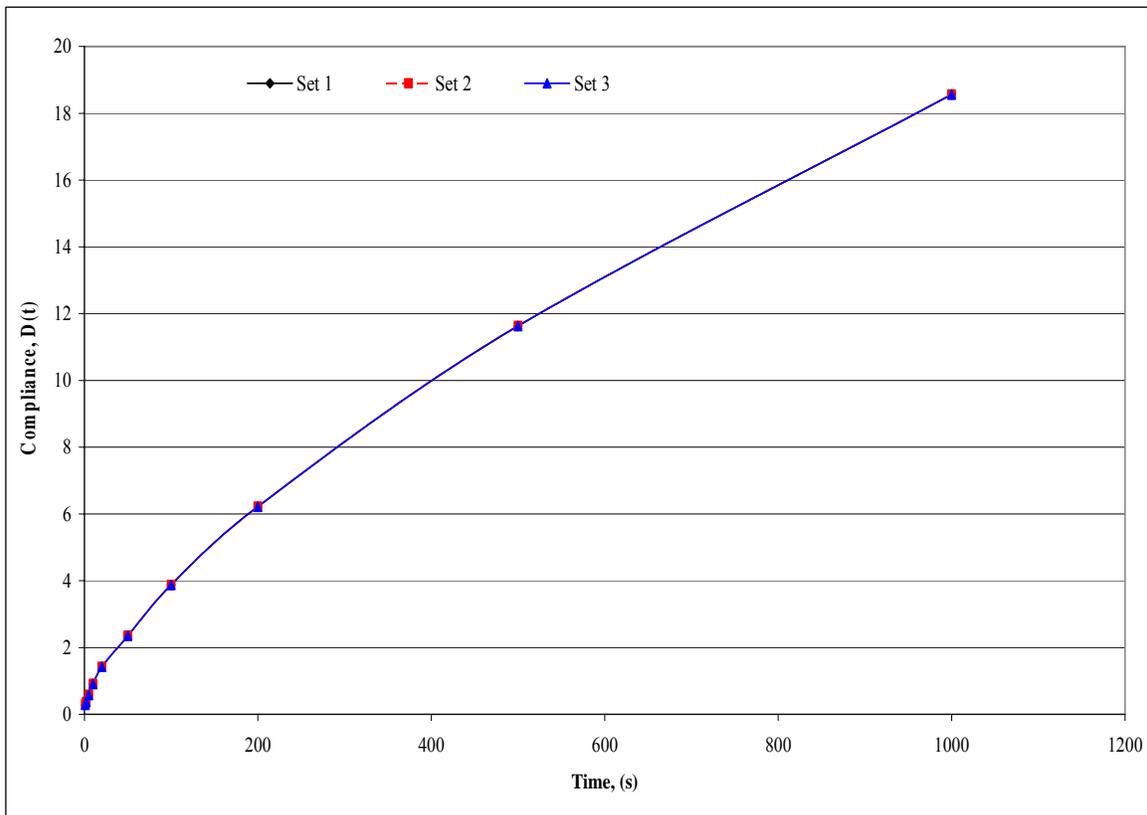
ENERGY RATIO

Project Name	m-value	D_1	S_t (Mpa)	M_R (Gpa)	FE (kJ/m^3)	DCSE$_{HMA}$ (kJ/m^3)	Stress (psi)	a	DCSE$_{MIN}$ (kJ/m^3)	ER
Set 1	0.682	1.15E-06	1.29	6.85	4.7	4.6	150	5.29E-08	6.948	0.66
Set 2	0.682	1.15E-06	1.29	6.85	4.7	4.6	150	5.29E-08	6.948	0.66
Set 3	0.682	1.15E-06	1.29	6.85	4.7	4.6	150	5.29E-08	6.948	0.66

APPENDIX D

Simple IDT

Sensor

Calibration

	Simple IDT Calibration	Sensor Gain	Indirect 1 25.36	
	Displacement			
	mm	**in**	**Reading**	**Error**
IN	0.500	0.019685	0.019705	0.000020
	0.400	0.015748	0.015764	0.000016
	0.300	0.011811	0.011823	0.000012
	0.200	0.007874	0.007864	-0.000010
	0.100	0.003937	0.003960	0.000023
ZERO	0.000	0.000000	0.000000	0.000000
OUT	-0.100	-0.003937	-0.003972	-0.000035
	-0.200	-0.007874	-0.007864	0.000010
	-0.300	-0.011811	-0.011796	0.000015
	-0.400	-0.015748	-0.015728	0.000020
	-0.500	-0.019685	-0.019660	0.000025

H1 Error

	Simple IDT Calibration	Sensor Gain	Indirect 2 25.27	
	Displacement			
	mm	**in**	**Reading**	**Error**
IN	0.500	0.019685	0.019640	-0.000045
	0.400	0.015748	0.015752	0.000004
	0.300	0.011811	0.011773	-0.000038
	0.200	0.007874	0.007851	-0.000023
	0.100	0.003937	0.003912	-0.000025
ZERO	0.000	0.000000		0.000000
OUT	-0.100	-0.003937	-0.003970	-0.000033
	-0.200	-0.007874	-0.007861	0.000013
	-0.300	-0.011811	-0.011842	-0.000031
	-0.400	-0.015748	-0.015727	0.000021
	-0.500	-0.019685	-0.019658	0.000027

H2 Error

	Simple IDT Calibration	Sensor Gain	Direct 1 49.05	
	Displacement			
	mm	**in**	**Reading**	**Error**
IN	1.000	0.039370	0.039164	-0.000206
	0.800	0.031496	0.031363	-0.000133
	0.600	0.023622	0.023511	-0.000111
	0.400	0.015748	0.015691	-0.000057
	0.200	0.007874	0.007854	-0.000020
ZERO	0.000	0.000000	0.000000	0.000000
OUT	-0.200	-0.007874	-0.007862	0.000012
	-0.400	-0.015748	-0.015765	-0.000017
	-0.600	-0.023622	-0.023640	-0.000018
	-0.800	-0.031496	-0.031570	-0.000074
	-1.000	-0.039370	-0.039485	-0.000115

V1 Error

	Simple IDT Calibration	Sensor Gain	Direct 2 50.82	
	Displacement			
	mm	**in**	**Reading**	**Error**
IN	1.000	0.039370	0.039241	-0.000129
	0.800	0.031496	0.031370	-0.000126
	0.600	0.023622	0.023526	-0.000096
	0.400	0.015748	0.015700	-0.000048
	0.200	0.007874	0.007864	-0.000010
ZERO	0.000	0.000000	0.000000	0.000000
OUT	-0.200	-0.007874	-0.007891	-0.000017
	-0.400	-0.015748	-0.015749	-0.000001
	-0.600	-0.023622	-0.023658	-0.000036
	-0.800	-0.031496	-0.031593	-0.000097
	-1.000	-0.039370	-0.039444	-0.000074

V2 Error