FINAL REPORT

For the Florida Department of Transportation

Evaluation of the Dynamic Complex Modulus Test and Indirect Diametral Test for Implementing the AASHTO 2002 Design Guide for Pavement Structures in Florida

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METRIC CONVERSIONS

inches = 25.4 millimeters

feet = 0.305 meters

square inches = 645.1 millimeters squared

square feet = 0.093 meters squared

cubic feet = 0.028 meters cubed

pounds = 0.454 kilograms

poundforce = 4.45 newtons

poundforce per square inch = 6.89 kilopascals

pound per cubic inch = 16.02 kilograms per meters cubed

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16. Abstract

The primary objective of this study was to evaluate the dynamic complex modulus test and indirect tensile test for implementing the AASHTO M-E Design Guide for Pavement Structures in Florida. The specific goals of the study were to develop the dynamic testing capabilities, to perform the dynamic complex modulus test and indirect diametral test, and to establish a database for referencing available resilient modulus and dynamic modulus values for targeted Florida asphalt concrete mixtures. To achieve the objectives and goals, a complete dynamic testing system was purchased to perform the temperature controlled dynamic tests. A laboratory experimental program was also developed to evaluate 20 selected Superpave asphalt concrete mixtures with a range of aggregates and mix designs. One type of asphalt binder, PG 67-22 (AC-30), was used for all mixtures tested. The 20 asphalt concrete mixtures were tested for both dynamic complex modulus and indirect tensile resilient modulus.

The master curves were developed and constructed using the time-temperature superposition principle. The Witczak prediction model was adopted to perform the comparison between predicted and measured dynamic modulus for all mixture series. The comparison indicated that the Witczak prediction model worked very well for the Florida asphalt concrete mixtures tested in this study. A comparative study was also made between the dynamic modulus and resilient modulus test results. The linear regression analysis indicated that the total resilient modulus increased with an increase in dynamic modulus at a specific loading frequency. The resilient modulus values were comparable with the dynamic modulus values at the loading frequency of 4 Hz.

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The laboratory testing program was carried out by Ed Mallory. Ginger Ling assisted in the database development. The PG 67-22 asphalt binder was provided without charge by C. W. Roberts Contracting Company.

EXECUTIVE SUMMARY

The primary objective of this study was to evaluate the dynamic complex modulus test and indirect tensile test for implementing the AASHTO M-E Design Guide for Pavement Structures in Florida. The specific goals of the study were to develop the dynamic testing capabilities, to perform the dynamic complex modulus test and indirect diametral test, and to establish a database for referencing available resilient modulus and dynamic modulus values for targeted Florida asphalt concrete mixtures. To achieve the objectives and goals, a complete dynamic testing system was acquired to perform the temperature controlled dynamic tests to determine the resilient modulus and dynamic modulus for Florida asphalt concrete mixtures. A laboratory experimental program was developed and involved 20 selected Florida Superpave asphalt concrete mixtures with a range of aggregates and mix designs.

The 20 mix designs were contributed by companies involved in the production and use of hot mix asphalt (HMA) in Florida. The 20 mixtures included the following types of aggregates: 14 Georgia granite materials, one Nova Scotia granite, one North Florida limestone, two Central Florida limestone materials, one South Florida oolite, and one Alabama limestone. One type of asphalt binder, PG 67-22 (AC-30), was used for all mixtures tested. To verify the volumetric properties of the mixture, the maximum theoretical specific gravity was measured using Rice maximum specific gravity method for each of the mixtures. The DMT specimens were cored from the 150 mm diameter Superpave samples. The 20 Superpave asphalt concrete mixtures were tested for both dynamic complex modulus and indirect tensile resilient modulus.

The AASHTO TP31 test procedure was generally followed to perform the indirect diametral test. However, the measurement and analysis system developed for SHRP IDT was applied. The deformation measurement system was modified in the SHRP IDT in order to accurately measure Poisson's ratio. The SHRP IDT approach was used to determine the resilient modulus of asphalt concrete. All of the IDT data were processed and stored in a database using Microsoft Access (Appendix B).

The dynamic complex modulus tests were conducted at three temperature levels: 5, 25, and 40°C (41, 77, and 104°F). For all temperatures tested, the following frequencies were used: 25, 10, 5, 1, and 0.5 Hz. All of the dynamic modulus and phase angle test results were also processed and stored in the database (Appendix B).

The master curves for all 20 mixtures were developed and constructed using the time-temperature superposition principle. The Witczak prediction model was adopted to perform the comparison between predicted and measured dynamic modulus for all mixture series. The comparison indicated that the Witczak prediction model worked well for the Florida asphalt concrete mixtures tested in this study.

A comparative study was also made between the dynamic modulus and resilient modulus test results. The linear regression analysis indicated that the total resilient modulus increased with an increase in dynamic modulus at a specific loading frequency. The resilient modulus values were comparable with the dynamic modulus values at the loading frequency of 4 Hz.

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CHAPTER 1

INTRODUCTION

1.1 Background

The new AASHTO Mechanistic-Empirical (M-E) Design Guide research team advocated the use of the dynamic complex modulus ($|E^*|$) as the primary test protocol to characterize the modulus response of asphalt concrete (AC) mixtures. The research team supported the role, selection, and utilization of the dynamic complex modulus test for asphalt concrete mixtures over the indirect tensile resilient modulus (M_r) in the National Cooperative Highway Research Program (NCHRP) 1-37A Project concerning the AASHTO M-E Design Guide for Pavement Structures, which is currently aiming to introduce more rigorous measures of performance into hot mix asphalt (HMA) mixture and pavement design procedures.

Although the NCHRP research team could not endorse the use of the indirect diametral test protocol as the primary means of asphalt concrete modulus characterization in the AASHTO M-E Design Guide, it was the strong opinion of the research team that the indirect diametral test development and enhancement should continue to be worked on. The use of the test was also encouraged as a means of determining the relative moduli response of field cores taken for rehabilitation designs. However, the use of the test to characterize modulus at high temperatures was not recommended.

The difference between a resilient modulus test and a dynamic complex modulus test for AC mixtures is that the former uses loading of any waveform with a given rest period, while the latter applies a sinusoidal or haversine loading with no rest period. The dynamic complex modulus is one of the many methods for describing the stress-strain relationship of viscoelastic materials. The modulus is a complex quantity, of which the real part represents the elastic stiffness and the imaginary part characterize the internal damping of the materials. The absolute value of the complex modulus is commonly referred to as the dynamic modulus.

The Florida Department of Transportation (FDOT) along with many other states is currently using the Superpave HMA design method, which was introduced by the Strategic Highway Research Program (SHRP). The Superpave mix design method incorporates almost solely the volumetric properties of asphalt mixtures. The potential impact of adopting the dynamic complex modulus test for the AASHTO Design Guide is tremendous for the FDOT. While the NCHRP research team claimed that a wealth of historic lab data for both the dynamic modulus and the phase angle had been accumulated over the last thirty years, the dynamic complex modulus test was not at all commonly used in Florida. To the contrary, the indirect tensile resilient modulus test has been used to characterize AC mixtures for pavement design in Florida, and this test method has been shown to be both an expedient and a reliable way of obtaining mixture properties from field cores in Florida. Although an effort has been initiated to develop the dynamic complex modulus testing capability and database for Florida mixtures, this effort is far from completing the characterization of Florida AC mixtures based on the dynamic complex modulus. There needs to be more work to expand the dynamic complex modulus database before implementing the AASHTO M-E Design Guide, to complement the current effort the University of Florida has been doing for FDOT, and to calibrate the database with independent testing results.

1.2 Study Objective

The primary objective of this study was to evaluate the dynamic complex modulus test and indirect diametral test for implementing the AASHTO M-E Design Guide for Pavement Structures in Florida. The research goals were to develop the dynamic testing capabilities, to perform the dynamic complex modulus test and indirect diametral test, and to establish a database for referencing typical available resilient modulus and dynamic modulus values for targeted Florida AC mixtures. A review study of the proposed dynamic modulus predictive model was needed to calibrate the applicability of the model based on available dynamic modulus values for the Florida AC mixtures.

1.3 Scope of Study

The scope of this study included the following tasks:

1) to develop dynamic complex modulus testing capabilities in Florida
2) to perform dynamic complex modulus and indirect diametral tests
3) to evaluate various testing and material effects on the dynamic complex modulus of Florida asphalt mixtures
4) to evaluate how well the proposed dynamic modulus predictive model will work for Florida asphalt concrete mixtures
5) to develop a database (using Microsoft Access) for documenting the dynamic modulus and resilient modulus values of Florida mixtures

1.4 Report Organization

This report summarizes the study to evaluate the dynamic complex modulus test (DMT) and indirect diametral test (IDT) for implementing the AASHTO M-E Design Guide for Pavement Structures in Florida. Both the DMT and IDT were performed for a total of 20 asphalt concrete mixtures, consisting of one RAP with granite mixture, one RAP with limestone mixture, 14 granite mixtures, and four limestone mixtures. As in the first chapter, the background, objective, and scope for the study are introduced. A literature review of the complex modulus and resilient modulus for characterizing the hot mix asphalt concrete mixtures is summarized in Chapter 2. Development of the dynamic testing capabilities for this study is presented in Chapter 3. The laboratory experimental program for the determination of resilient modulus and dynamic modulus of Florida AC mixtures is described in Chapter 4. The materials used and mixture designs are also described in this chapter. Data reduction and analysis procedures for IDT test and resilient modulus test results are presented in Chapter 5. Dynamic complex modulus test results are summarized in Chapter 6. Analyses of experimental results including a comparative study between predicted and measured dynamic modulus for all AC mixtures are discussed in Chapter 7. A summary, conclusions, and recommendations of this study are presented in Chapter 8. The 20 Superpave mix design data sheets are summarized in Appendix A. Dynamic complex modulus and resilient modulus test results are stored in a database using Microsoft Access, which is presented in Appendix B.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The performance of any Hot Mix Asphalt (HMA) is dependent upon the entire pavement structure, and the structural capacity of the pavement layers is dependent of the quality of materials and their compositions in the mixture. Pavement design using elastic layer theory needs two elastic parameters for each material layer used: Young's modulus (stiffness), and Poisson's ratio. The resilient modulus (M_r) has been used in the AASHTO Design Guide (AASHTO, 1993) since 1993. The resilient modulus laboratory test procedure is described in AASHTO TP 31. The test is defined as a repetitive 0.1 second haversine load followed by a 0.9 second rest period, continued at 1 Hz intervals. Many empirical relationships have been developed throughout the years relating M_r to other tests like the California Bearing Ratio (CBR) and the Marshall stability test (AASHTO, 1993), since it has long been considered the defining characteristic for HMA layers. One of the more widely used structural parameters for asphalt cement mixtures used in mechanistic-empirical structural pavement design procedures has been the dynamic (complex) modulus. National Cooperative Highway Research Program (NCHRP) 1-37A mechanistic-empirical design methodology requires the dynamic modulus $|E^*|$ as a primary material input to compute stress, strain, rutting and cracking damage in flexible pavement systems. $|E^*|$ is a fundamental property defining the response of HMA mixtures and strongly influences the performance of asphalt pavement. It is the magnitude of complex modulus $|E^*|$ and determined experimentally as the ratio of the applied stress amplitude to the strain response amplitude under a sinusoidal loading. This stiffness parameter has also been selected to characterize the asphalt materials for the new AASHTO M-E Design Guide for the Design of Pavement Structures, which is under development in the NCHRP 1-37A project. The resilient modulus and dynamic modulus test procedures are further reviewed as follows.

2.2 Indirect Diametral Tensile Test

2.2.1 Original IDT Test

The indirect diametral test is used extensively by state highway and other agencies for routine tests. The 1986 AASHTO Pavement Design Guide, which recommended the use of resilient modulus to characterize pavement materials, has led to accelerated use of this type of test. This test is usually conducted on cylindrical specimens subjected to a compressive load along two opposite generators resulting in a relatively uniform tensile stress acting perpendicular to and along the diametral plane of the applied load. A splitting failure generally occurs as a result along the diametral plane (Figure 2-1). If a repetitive pulsating load is applied diametrically to the sample, the dynamic load results in dynamic deformations across the horizontal diametral plane. The transducers mounted on each side of the horizontal specimen axis record these deformations. The resilient modulus (M_r) of AC mixtures can be determined by the dynamic load and deformation. The indirect diametral test is specified by ASTM D4123-82 Standard Test Method for Indirect Tension Test for Resilient Modulus of Bituminous Mixtures.

After the specimens were well prepared, they were placed in a controlled temperature cabinet and brought to the specified test temperature. The specimen was placed into the loading apparatus and the loading strips were positioned to be parallel and centered on the vertical diametral plane. The specimen was preconditioned by applying a repeated haversine or other suitable waveform load without impact for a minimum period sufficient to obtain uniform deformation readout. Depending upon the loading frequency and temperatures, a minimum of 50 to 200 load repetitions is typical; however, the minimum for a given situation must be determined so that the resilient deformations are stable. Resilient modulus evaluation will usually include tests at three temperatures, for example, 41, 77, and 104°F (5, 25, and 40°C), at one or more loading frequencies. The horizontal and vertical deformations were continuously monitored during the test.

Required test equipment is a loading device capable of applying a load pulse over a range of frequencies, load durations and load levels. Some form of temperature control system is required. The temperature-control system should be capable of control over a temperature range from 41 to 104°F (5 to 40°C). The measurement and recording system should include sensors for measuring and recoding horizontal and vertical deformations. The values of vertical and horizontal deformation can be measured by linear variable differential transducers (LVDTs) or other suitable devices. LVDTs should be at mid-height opposite each other on the specimen's horizontal diameter. A metal loading strip with a concave surface having a radius of curvature equal to the normal radius of the test specimen is required to applied load to the specimen. The specimens should have a height of at least two inches and a minimum diameter of four inches for aggregate up to one inch maximum size, and a height of at least three inches and a minimum diameter of six inches for aggregate up to 1.5 inches maximum size.

The theoretical distribution of stresses for a concentrated load is shown in Figures 2-2 and 2-3. For the horizontal diametral plane, the states of stresses are given by Equations 2-1, 2-2, and 2-3. For the vertical diametral plane (along the load axis), the stresses are shown by Equations 2-4, 2-5, and 2-6.

Horizontal diametral:

$$\sigma_x = \frac{2P}{\pi t d}\left[\frac{d^2 - 4x^2}{d^2 + 4x^2}\right]^2 \tag{2-1}$$

$$\sigma_y = -\frac{2P}{\pi t d}\left[\frac{4d^2}{(d^2 + 4x^2)} - 1\right] \tag{2-2}$$

$$\tau_{xy} = 0 \tag{2-3}$$

Vertical diametral:

$$\sigma_x = \frac{2P}{\pi t d} \tag{2-4}$$

$$\sigma_y = -\frac{2P}{\pi t}\left[\frac{2}{d - 2y} + \frac{2}{d + 2y} - \frac{1}{d}\right] \tag{2-5}$$

$$\tau_{xy} = 0 \tag{2-6}$$

Where

P = total applied load (lb)

t = specimen thickness (inch)

d = specimen diameter (inch)

x, y = coordinate values from center of specimen

The above equations are those derived for an idealized elastic solid. For most engineering materials, initial failure occurs by tensile splitting in accordance with Equation 2-4. Therefore, the tensile strength S_t of the material is given by:

$$S_t = \frac{2P_{\max}}{\pi d} \tag{2-7}$$

Where $P_{\max}$ = ultimate applied load (lb).

Assuming that plane stress conditions are applicable ($\sigma_z = 0$), the resultant strain ε_x is given by:

$$\varepsilon_x = \frac{1}{E}\left[\sigma_x - \mu\sigma_y\right] \tag{2-8}$$

Substitution of Equations 2-1 and 2-2 into Equation 2-8 results in:

$$\varepsilon_x = \frac{2P}{E\pi dt}\left[\frac{d^4(1+5\mu)-8x^2d^2(1-3\mu)+16x^4(1+\mu)}{(d^2+4x^2)^2}\right] \tag{2-9}$$

The deformation across the horizontal diametral ($y = 0$) may be found by integrating Equation (2-9) between $x = -d/2$ and $x = d/2$. This results in the horizontal deformation equal to:

$$\delta_h = \frac{P}{Et}\left[\frac{4}{\pi} + \mu - 1\right] \tag{2-10}$$

Thus, for an applied dynamic load of P in which the resulting horizontal dynamic deformation is measured, the modulus of M_r value is:

$$M_r = \frac{P(\mu + 0.2734)}{t\delta_h} \tag{2-11}$$

A commonly used value of Poisson's ratio (μ) for asphaltic materials is $\mu = 0.35$.

2.2.2 SHRP IDT Test and Modifications

An indirect tensile testing and analysis system was developed as part of the Strategic Highway Research Program (SHRP) to accurately determine the creep compliance and tensile strength of hot mix asphalt mixtures (Figure 2-4). This IDT test and analysis system was selected to become a part of the Superpave mixture design and analysis system. Its primary role was in the evaluation of thermal cracking performance of asphalt pavements. Roque et al. (1993, 1994) showed that the system serves the purpose well. In addition, Roque and Buttlar (1992) also showed that the indirect tensile testing system developed for SHRP overcame many of the problem that have been typically associated with an IDT system traditionally used for asphalt mixture testing.

The modifications of the IDT measurement and analysis procedures developed by Roque and Buttlar (1992) are summarized herein. It only applies for a gauge length to diameter ratio of 1:4 and when the height of the surface mounted LVDT is 0.25 in. from the specimen surface. Horizontal (tensile) deformation is considered to be positive, while vertical (compressive) deformation is considered to be negative for this analysis. The computation procedures are briefly described as follows:

1. Assume Poisson's ratio, μ (usually 0.35 at 77°F).
2. Correct horizontal deformation to account for bulging:

$$H = \left(1.01 - 0.12\mu - 0.05 \cdot \left(\frac{t}{t_{std}}\right)\right) \cdot H_M \quad \text{(2-12)}$$

Where

t = measured specimen thickness

t_{std} = standard specimen thickness

H_M = measured horizontal deformation

3. Correct vertical deformation to account for bulging:

$$Y = (0.994 - 0.128\mu) \times Y_M \tag{2-13}$$

Where Y_M is the measured vertical deformation.

4. Horizontal point strain at the center of specimen is given by

$$\varepsilon_{CTR_x} = 1.07 \frac{H}{GL} \tag{2-14}$$

And the vertical point strain at the center of specimen is given by

$$\varepsilon_{CTR_y} = 0.98 \frac{Y}{GL} \tag{2-15}$$

Where

GL = gage length, in.

H = horizontal deformation, in.

Y = vertical deformation, in.

5. Corrected horizontal point stress at the center of specimen

$$\sigma_{X_{CORR}} = 0.1859 \frac{P}{t_{std}} \tag{2-16}$$

Corrected vertical point stress at the center of specimen

$$\sigma_{Y_{CORR}} = -0.4636 \frac{P}{t_{std}} \tag{2-17}$$

Equations (2-16) and (2-17) are only valid for a thickness to diameter ratio of 0.625 for the specimen and a Poisson's ratio of 0.35.

6. Calculate Poisson's ratio using

$$\mu = \frac{\sigma_{X_{CORR}} - \left(\frac{\varepsilon_{CTR_X}}{\varepsilon_{CTR_Y}} \right) \cdot \sigma_{Y_{CORR}}}{\sigma_{Y_{CORR}} - \left(\frac{\varepsilon_{CTR_X}}{\varepsilon_{CTR_Y}} \right) \cdot \sigma_{X_{CORR}}} \tag{2-18}$$

If Poisson's ratio calculated in this step differs by more than 0.01 with Poisson's ratio in step 1, then replace μ in step 1 by the value calculated in this step and repeat steps 2 through 6, else go on to the next step.

7. The asphalt concrete modulus can then be determined by

$$M_R = \frac{1}{\varepsilon_{CTR_X}} (\sigma_{X_{CORR}} - \mu \cdot \sigma_{Y_{CORR}}) \tag{2-19}$$

Roque et al. (1997) identified the limitations of the SHRP IDT system, including the software developed for use in the SHRP Superpave mixture design and analysis system. Based on the limitations and deficiencies, Roque et al. (1997) designed and developed a testing, data acquisition, and data reduction system for the improvement of the SHRP IDT system.

2.3 Dynamic Modulus in Viscoelastic Asphalt Mixtures

The complex modulus test accounts not only for the instantaneous elastic response, without delayed elastic effects, but also the accumulation of cyclic creep and delayed elastic effects with the number of cycles. The complex modulus test does not allow time for any delayed elastic rebound during the test, which is the fundamental difference from the resilient modulus test. The dynamic complex modulus test is usually conducted on cylindrical specimens subjected to a compressive haversine loading at a given temperature and loading frequency. The dynamic modulus of AC mixtures can be determined by the repeated load triaxial test. The dynamic modulus varies with the loading frequency. A frequency that most closely simulates the actual traffic load should be selected for the test, so the dynamic modulus thus determined is equivalent to the resilient modulus for design purposes. The dynamic modulus test is specified by the ASTM D3497-79 Standard Test Method for the Dynamic Modulus of Asphalt Mixtures.

After the specimens are well prepared, they are placed in a controlled temperature cabinet and brought to the specified test temperature. The conditioned specimen is then placed into the loading apparatus and the strain gage wires are connected to the measurement system. A hardened steel disk is put on both top and bottom of the specimen and centered under the loading apparatus. The electronic measuring system is adjusted and balanced as necessary. A haversine loading is applied to the specimen without impact and with loads varying between 0 and 35 psi (241kpa) for each load application for a minimum of 30 seconds and not exceeding 45 seconds at temperatures of 41, 77, and 104°F (5, 25, and 40°C) and at loading frequencies of 1, 4, and 16 Hz for each temperature. Both the loading stress and axial strain are monitored during the test.

One piece of test equipment that is required is a loading device capable of transmitting haversine waveforms at a frequency range of 0.1 to 20 Hz and a maximum stress of about 100 psi (690 kPa). Because of the desirability to test asphalt mixes at various temperatures, some form of temperature control system is required. This device can be either external or internal to the loading device depending upon how the test is conducted. Strains may be obtained through the use of bonded wire strain gages and a two-channel recording system. When testing, a dummy specimen is usually connected in a Wheatstone circuit to the test (loaded) specimen. Test specimens are usually cylindrical and have a minimum 4-inch diameter and a height-to-diameter ratio of two. A minimum of three specimens is required for testing. A conceptual schematic of dynamic complex modulus test is shown in Figure 2-5.

The complex modulus $| E^* |$ relates the cyclic strain to cyclic stress in a sinusoidal load test. It is calculated using Equation 2-20 (Yoder and Witczak 1975):

$$| \mathrm{E}^* | = \frac{\sigma_0}{\varepsilon_0} \tag{2-20}$$

Where

σ_0 = stress amplitude

ε_0 = strain amplitude

The sinusoidal stress σ is defined as:

$$\sigma = \sigma_0 \cdot \sin(\omega \cdot t) \tag{2-21}$$

Where

ω = angular frequency (rad/sec)

t = time (sec)

The resultant sinusoidal strain ε is:

$$\varepsilon = \varepsilon_0 \cdot \sin(\omega \cdot t - \phi) \tag{2-22}$$

Where ϕ = the phase lag (degrees)

The phase angle ϕ is simply the angle at which the ε_0 lags σ_0:

$$\phi = \frac{t_{lag}}{t_p} \cdot (360^\circ) = t_{lag} \cdot f \cdot (360^\circ) \tag{2-23}$$

Where t_{lag} = time lag between a cycle of sinusoidal stress and a cycle of strain

t_p = time period of a stress cycle (seconds)

f = frequency of the dynamic load (in Hz)

By definition, the complex modulus E^* can be expressed as the following:

$$E^* = E' + iE'' \tag{2-24}$$

Where E' refers to the real part of the complex modulus, it is the storage modulus that describes the elastic component of the complex modulus:

$$E' = |E^*| \cdot \cos(\phi) = \frac{\sigma_0}{\varepsilon_0} \cdot \cos(\phi) \tag{2-25}$$

Where E'' refers to the imaginary part of the complex modulus, it is the loss modulus which describes the viscous component of the complex modulus:

$$E'' = |E^*| \cdot \sin(\phi) = \frac{\sigma_0}{\varepsilon_0} \cdot \sin(\phi) \tag{2-26}$$

The storage and loss moduli can be determined by the measurement of the lag in the response between the applied stress and the measured strains. This lag, referred to as the phase angle ϕ, shown in Figure 2-6, can also be determined by Equation 2-23:

$$\phi = \tan^{-1}\left(\frac{E''}{E'}\right) \tag{2-27}$$

The complex modulus can also be written as:

$$E^* = |E^*| \cdot e^{i \cdot \phi} \tag{2-28}$$

From these equations of relationships, it can be seen obviously that a zero phase angle indicates a purely elastic material and a 90° phase angle means a purely viscous material.

2.4 Prediction Models for Dynamic Modulus

To perform a complex modulus test is relatively difficult and expensive. Efforts were made by asphalt pavement researchers to develop regression equations to estimate the dynamic modulus for a specific hot mix design. One of the most comprehensive mixture dynamic modulus models is the Witczak et al. 2002 |E*| prediction model. It is proposed in the AASHTO M-E Design Guide and the calculations were based on the volumetric properties of a given mixture. In this model, the parameter η (bitumen viscosity) for each dynamic modulus test temperature is determined by:

$$\log(\log\eta) = A + VTS \cdot \log T \qquad (2\text{-}29)$$

Where A is the regression intercept, T is Rankine temperature and VTS is the slope of log-log viscosity vs. temperature relationship. A and VTS parameters are functions of binder type and material characteristics, and they are determined by regression using the experiment data of a binder viscosity versus temperature T.

Witczak's prediction equation is presented as follows:

$$\begin{aligned}\log\left|E^*\right| &= -1.249937 + 0.029232P_{200} - 0.001767(P_{200})^2 \\ &- 0.002841P_4 - 0.058097V_a - 0.802208\frac{V_{beff}}{(V_{beff} + V_a)} \\ &+ \frac{\left[3.871977 - 0.0021P_4 + 0.003958P_{38} - 0.000017(P_{38})^2 + 0.00547P_{34}\right]}{1 + e^{(-0.603313 - 0.313351\log f - 0.393532\log\eta)}}\end{aligned} \qquad (2\text{-}30)$$

Where

$|E^*|$ = dynamic modulus, in 10^5 psi

η = bituminous viscosity, in 10^6 poise (at any temperature, degree of aging)

f = load frequency, in Hz

V_a = percent air voids content, by volume

V_{beff} = percent effective bitumen content, by volume

P_{34} = percent retained on 3/4 -in. sieve, by total aggregate weight (cumulative)

P_{38} = percent retained on 3/8 -in. sieve, by total aggregate weight (cumulative)

P_{4} = percent retained on No. 4 sieve, by total aggregate weight (cumulative)

P_{200} = percent passing on No. 200 sieve, by total aggregate weight (cumulative)

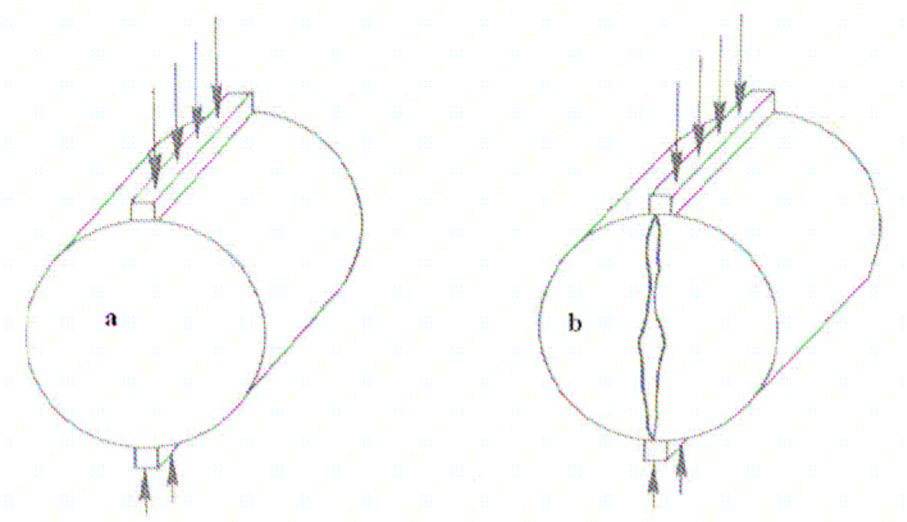
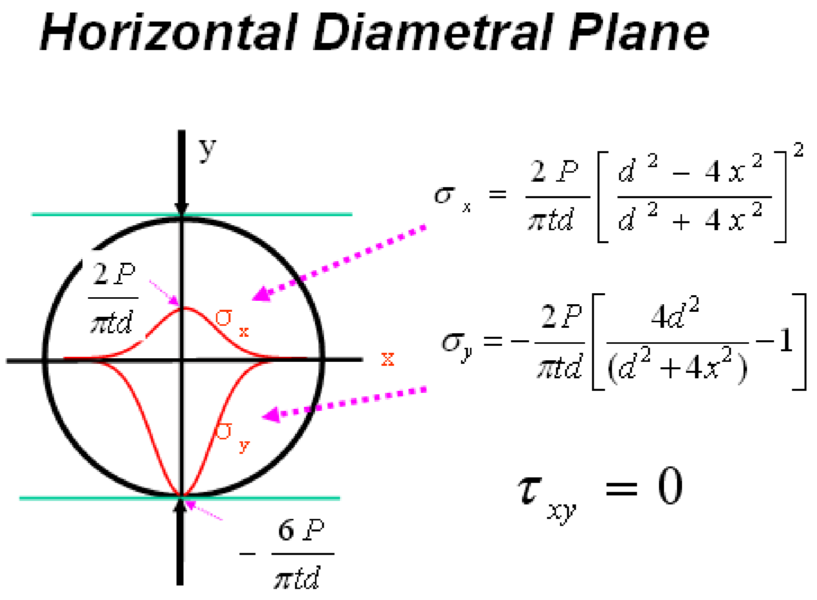


Figure 2 -1. Indirect Diametral Test during Loading and at Failure



$$\sigma_x = \frac{2P}{\pi td}\left[\frac{d^2 - 4x^2}{d^2 + 4x^2}\right]^2$$

$$\sigma_y = -\frac{2P}{\pi td}\left[\frac{4d^2}{(d^2 + 4x^2)} - 1\right]$$

$$\tau_{xy} = 0$$

Figure 2-2. Theoretical Stress Distribution of Horizontal Plane for Indirect Tensile Test

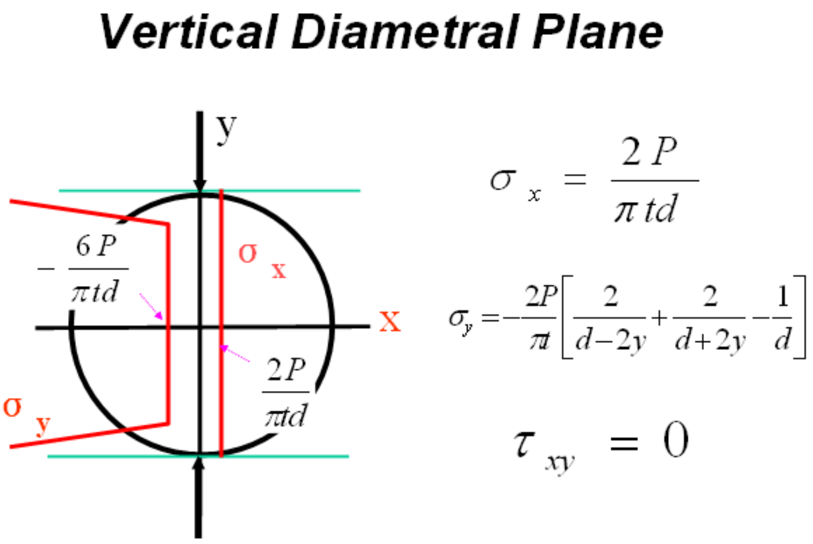


Figure 2-3. Theoretical Stress Distribution of Vertical Diametral Plane for Indirect Tensile Test

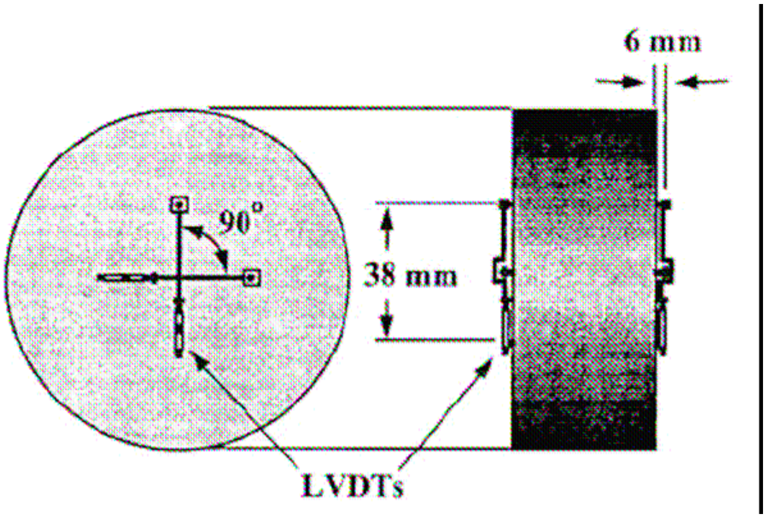


Figure 2-4. Sketch of Indirect Tensile Testing Gage Points (The Asphalt Institute B3)

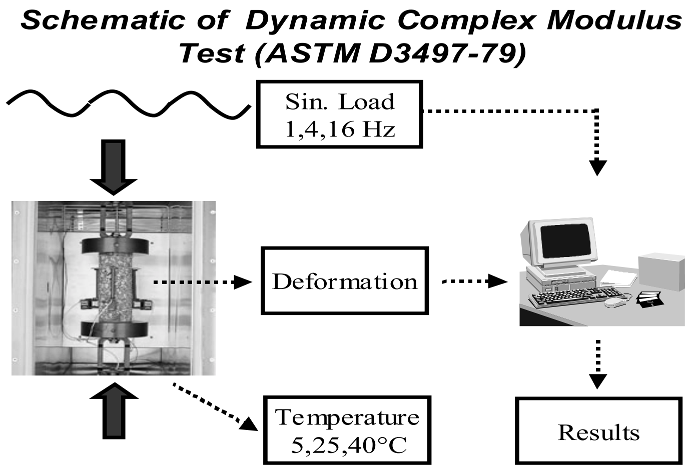


Figure 2-5. Conceptual Schematic of Dynamic Complex Modulus Test

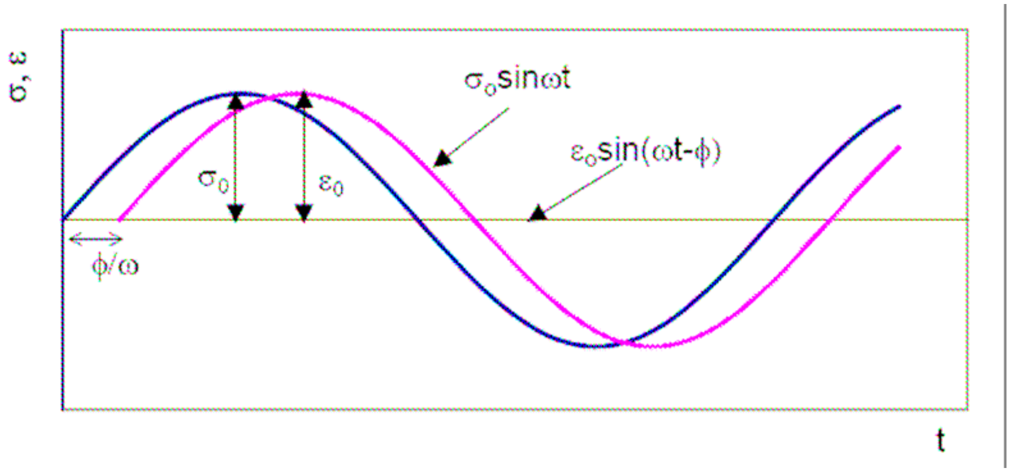


Figure 2-6. Schematic Components of Dynamic Modulus (Pellinen 2001)

CHAPTER 3

DEVELOPMENT OF THE DYNAMIC TESTING CAPABILITIES

3.1 General

The two methods of measuring dynamic properties of HMA in this research study were the triaxial dynamic modulus test (DMT) and indirect diametral tension test (IDT). Both of these tests were described in more detail in Chapter 2. The dynamic modulus test is specified by ASTM D3497-79 Standard Test Method for Dynamic Modulus of Asphalt Mixtures, while the IDT resilient modulus test is specified by AASHTO TP31-94 and ASTM D4123-82. This study was aimed at implementing the resilient modulus test and dynamic modulus test for the design of pavement structures in Florida. A complete dynamic testing system was acquired to perform the temperature controlled dynamic tests for the determination of resilient modulus and dynamic modulus of Florida AC mixtures. In this study, a Servopac Gyratory Compactor and an Interlaken Asphalt Test System were used to compact the asphalt mixture and measure the dynamic response of asphalt concrete respectively. A detail description of the test equipment is as follows.

3.2 Gyratory Compaction Equipment

The gyratory compactor used in this study was supplied by the Industrial Process Controls Ltd. (IPC) Servopac Gyratory Compactor (Figure 3-1). The Servopac is a fully automated, servo-controlled gyratory compactor designed to compact asphalt mixes by means of the gyratory compaction technique. Compaction is achieved by simultaneous action of static compression and the shearing action resulting from the mold being gyrated through an angle about its longitudinal axis.

The Servopac was designed to automatically compensate (under servo-feedback control), to maintain the gyratory angle constant during compaction, and to provide a means to simply and quickly adjust the critical parameters. The servo-feedback control enables it to provide more accurate and consistent results, provides a powerful tool to evaluate optimum parameter settings, and allows ready adjustment for future work.

Since the Servopac uses servo-valves for both gyratory angle and vertical load, the response time is generally faster than systems that use electromechanical drives. The servo-control operation of the machine allows the vertical stress, gyratory angle, and gyration rate to be quickly modified from a hand-held pendant or personal computer (PC). An optional PC 'Windows' interface (Figure 3-2) provides a screen to place data on test parameters and display and plot either height, density, or angle against gyratory cycles in real time. Test data may be stored and retrieved or transferred to other analysis packages.

Since Servopac is designed to comply with SHRP SUPERPAVE asphalt mix design requirements, it is capable of producing gyration angles between zero and three degrees, gyration rates of up to 60 gyrations per minute, and vertical pressures as high as 600 kPa for as many as 999 gyration cycles. In this program, a 1.25 degree gyration angle, 600 kPa vertical stress, and 30 gyrations per minute were followed to meet the SHRP SUPERPAVE requirements.

3.3 Interlaken Integrated Test Frame

The dynamic test equipment used for the DMT and IDT tests of the project was the Interlaken Asphalt Test System. It consists of an integrated load frame which contains its own hydraulic power supply, a triaxial cell, an indirect tensile fixture, an environmental chamber and a control system. The loading is by means of a servo controlled hydraulic actuator with a stroke of two inches and a loading capacity of 3500 lbs, which will meet the requirements for wave form quality and accuracy. A close-loop control system is used for confining pressure. Forced air circulation is provided for heating and cooling within the enclosure. An extensometer set is included that can be used for axial deformation measurements in the triaxial cell and radial deformation measurements on the indirect tensile specimens. The system is fully computer controlled using an industrial PC with a Windows based user interface. Control of the hydraulic actuator and pneumatic pressure system is through a dedicated servo controller with separate processors. All transducer measurements can be monitored and recorded.

This system (Figure 3-3) is based on a test frame with integrated hydraulics so external hoses are not required. Also, it is air cooled eliminating the need for cooling water. The actuator capacity ranges from 3,500 to 22,000 lbs. To assure precision control and measurement of confining pressure, a servo controlled pressure system is included. The pressure transducer used for feedback and measurement has an accuracy of 0.25 % of full scale (the normal full scale calibration is 100 psi). System dimensions are 30" wide by 50" deep by 84" high and test space dimensions are 22" wide by 30" high. The compact size allows it to be moved easily. The performance is equal to that of systems with separate test frames and power supplies. Standard system which meets the requirements for standard ASTM and AASHTO tests have been developed.

3.4 Environmental Chamber

Controlling the temperature accurately is critical to asphalt property measurements. The Interlaken environmental chamber (Figure 3-4) with mechanical and CO_2 cooling offers a wide temperature range of -40 °C to 150 °C to accurately perform asphalt property measurements. Cascade temperature control provides the maximum amount of stability. Also the air temperature fluctuations can be limited. The chamber accommodates other fixtures in addition to the Indirect Tensile Fixture and there is ample space for the preconditioning of other specimens (Figure 3-5). A cart to support the chamber with mechanical refrigeration is also included.

3.5 Indirect Tensile Fixture

The Interlaken Indirect Tensile Fixture (Figure 3-6) aligns the upper and lower loading strips with rugged bearings and columns. The upper loading strip pivots on a high quality bearing for uniform load distribution. Side rails restrain the broken specimens. Two loading strips, 100 mm and 150 mm, are provided.

3.6 Biaxial Extensometer Set

Interlaken 3910B Snap-On Extensometers (Figure 3-7) simplify the creep compliance and resilient modulus testing with easy to use extensometers. Problems with rocking will be eliminated. They are completely assembled and the only thing required before testing is removal of alignment pins. They do not apply any force beyond their own weight. The standard travel is 20,000 micro inches or 0.5 mm. Since they can be quickly switched between specimens, changes of temperature in the environmental system are minimized. Calibration is easily maintained since they remain assembled and can be easily checked at any time. The steel gauge points are mounted in the alignment fixture holders where they are retained magnetically. After the adhesive has been applied the holder is pressed against the specimen until it sets. Then the holder is simply pulled away.

3.7 Triaxial Cell

The Triaxial Cell (Figure 3-7) is the heart of a soil testing system. It can be used in asphalt testing applications requiring confinement such as the procedures developed in the NCHRP 9-19 programs for Flow Time, Flow Number and Dynamic Modulus. The standard cell is configured for air as the confining media, and is ported for confining pressure and pore pressure. The external shell is transparent so the specimen can be monitored visually. The internal load cell is placed on top of the upper platen. When the anticipated loads are higher than the capacity of the internal cell, the system load cell is used. A platen set includes the upper and lower platens, matching porous stones, O rings and a set twelve membranes.

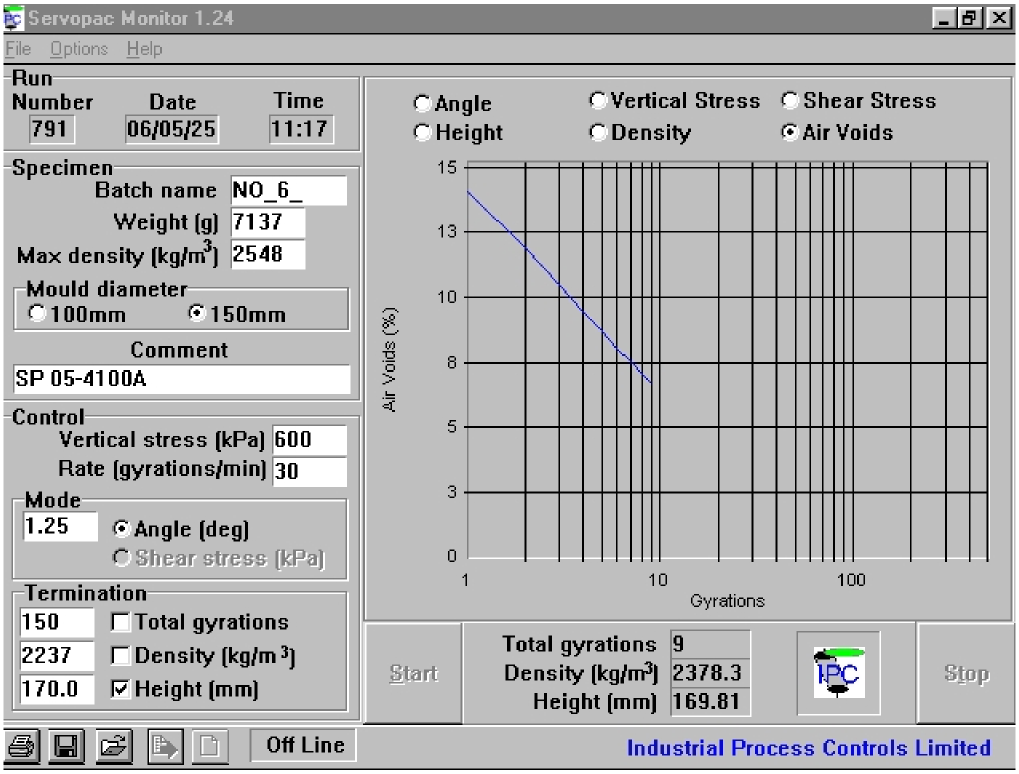
3.8 Control System

The Interlaken Series 2000 UniTest Control System features a 16 bit control and data acquisition section along with a Window Based Graphical User Interface. A main operator’s screen (Figure 3-8), which displays the status of command and feedback of each control channel as well as the status of the hydraulic system and safety interlocks, is the central control screen which is always displayed to the user. In addition, a scope screen (Figure 3-9) is normally opened which can graphically display up to six channels vs. time (y-t) or up to six channels vs. another channel (x-y). A drop down menu provides a simple and intuitive setup access. Watch boxes provide a digital display of data and a wizard prompts operators through each test. All the data may be stored in excel file or text file format.

3.9 Test Builder

Test Builder is used to configure the machine to step through user defined sequences that make up a test. This feature adds great flexibility to the control of the machine. By left clicking on the step number box on the test builder main screen (Figure 3-10), the user will have the choice of inserting a step above or below the current step, or deleting the current step. By double clicking on the control channel column of an existing step, the function builder window will appear. This window allows several types of actions (such as Ramp Function, Sin Function, Pulse Function, Dwell Function…etc.) to be defined. By double clicking on the events column of an existing step, the Define Events window will appear. This window allows several types of events to be defined. After the test is programmed, checked and saved, it should be ready to run.

Figure 3-1. Servopac Gyratory Compactor



Run

Number 791

Date 06/05/25

Time 11:17

Specimen

Batch name NO_6_

Weight (g) 7137

Max density (kg/m^3) 2548

Mould diameter ○ 100mm ● 150mm

Comment SP 05-4100A

Control

Vertical stress (kPa) 600

Rate (gyrations/min) 30

Mode 1.25 ● Angle (deg) ○ Shear stress (kPa)

Termination

150 ☐ Total gyrations

2237 ☐ Density (kg/m^3)

170.0 ☑ Height (mm)

Total gyrations 9

Density (kg/m^3) 2378.3

Height (mm) 169.81

Figure 3-2. Servopac Gyratory Compactor PC Window

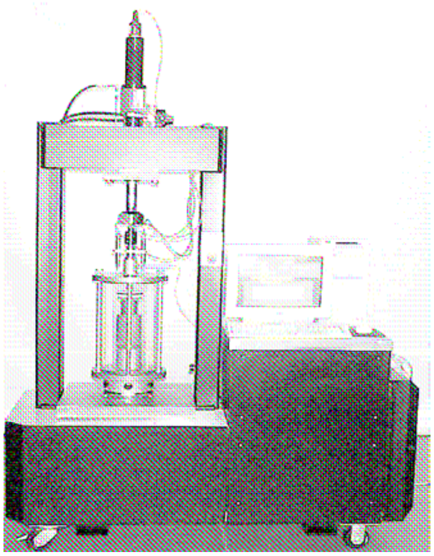


Figure 3-3. Interlaken Asphalt Test System

Figure 3-4. Environmental Chamber

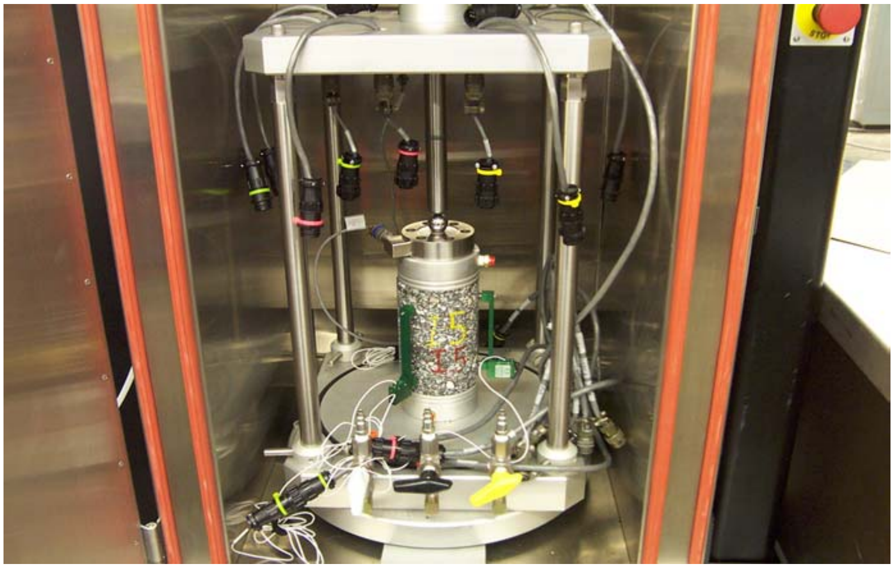


Figure 3-5. Dynamic Modulus Testing

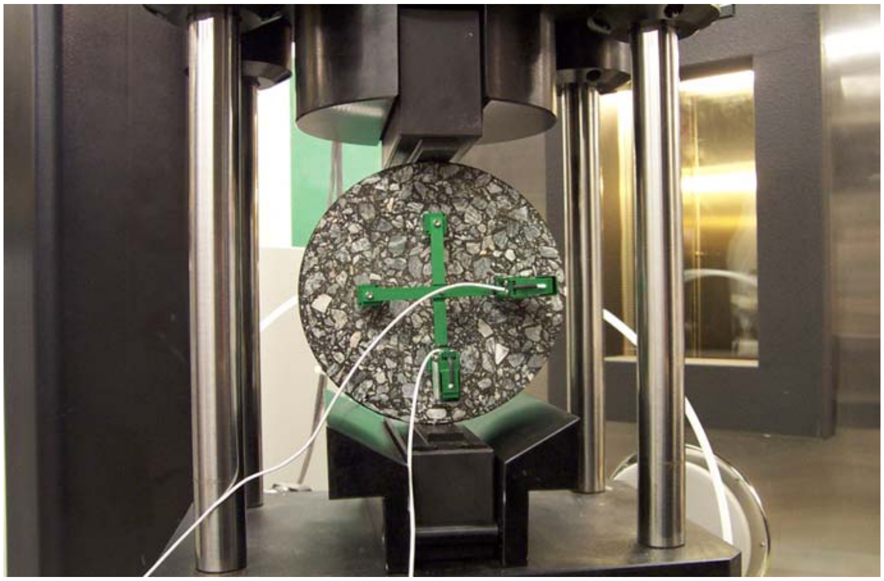


Figure 3-6. Indirect Tensile Fixture and Biaxial Extensometer Set

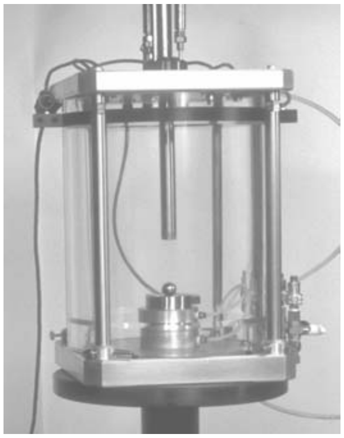
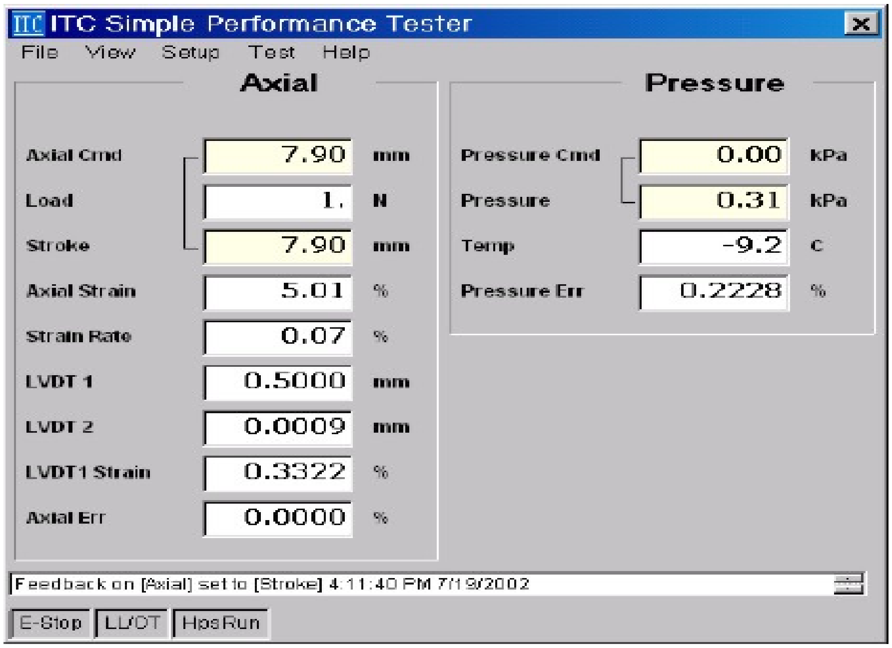


Figure 3-7. Triaxial Cell



Axial

Axial Cmd 7.90 mm
Load 1. N
Stroke 7.90 mm
Axial Strain 5.01 %
Strain Rate 0.07 %
LVDT 1 0.5000 mm
LVDT 2 0.0009 mm
LVDT1 Strain 0.3322 %
Axial Err 0.0000 %

Pressure

Pressure Cmd 0.00 kPa
Pressure 0.31 kPa
Temp -9.2 C
Pressure Err 0.2228 %

Feedback on [Axial] set to [Stroke] 4:11:40 PM 7/19/2002

Figure 3-8. UniTest Main Panel

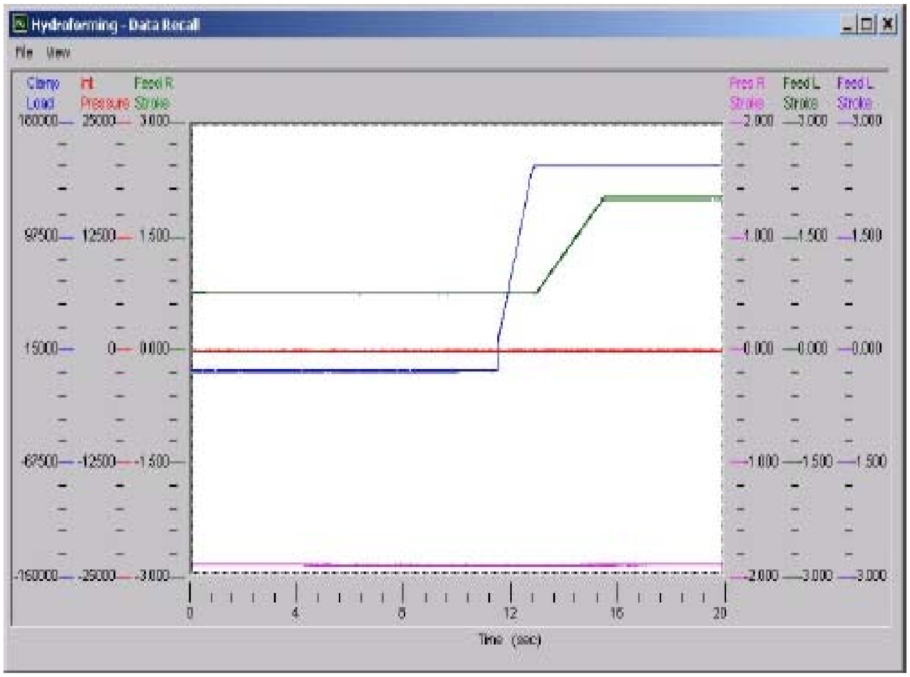
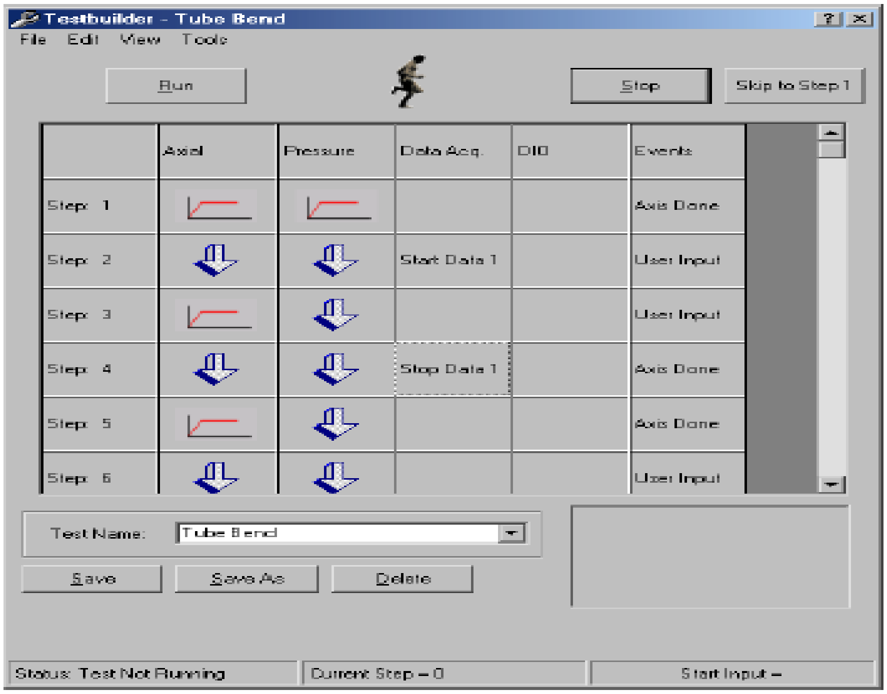


Figure 3-9. UniTest Scope Window



	Axial	Pressure	Data Acq.	DIO	Events
Step 1	⟋	⟋			Axis Done
Step 2	⇩	⇩	Start Data 1		User Input
Step 3	⟋	⇩			User Input
Step 4	⇩	⇩	Stop Data 1		Axis Done
Step 5	⟋	⇩			Axis Done
Step 6	⇩	⇩			User Input

Test Name: Tube Bend

Status: Test Not Running

Current Step = 0

Start Input =

Figure 3-10. UniTest Test Builder Main Screen

CHAPTER 4

EXPERIMENTAL PROGRAM

4.1 General

A laboratory experimental program was developed and conducted to determine resilient modulus and dynamic modulus of Florida AC mixtures. The overall experimental program involved 20 selected Florida HMA Superpave mixtures and involved a range of aggregates and mix designs. The physical properties of the materials used are also presented in this chapter, including their aggregate physical properties, aggregate gradation, asphalt binder characteristics, and mixture design series selected from the references. A description of the experimental program follows.

4.2 Overview of Mix Designs

A summary of 20 selected mix designs is presented in Table 4-1 for information. These mix designs were contributed by companies involved in the production and use of HMA in Florida. The summary table consists of 20 mix designs in the format of 19 columns each. The data presented in the table were sorted by mix design series number. Below is a description of each column:

1. The test series number related to the whole project
2. The mix design number used by the FLDOT for reference
3. The nominal maximum aggregate sizes, which are 19.0, 12.5, or 9.5 millimeters.
4. The type of the design mix, coarse or fine, determined by which side of the forbidden zone the mix passes when plotted on the 0.45Power chart.

5. The load level the design represents; Superpave has 5 levels, A-E.
6. The design applied either to a structural or friction course; different qualities are desired for the two types of courses.

7 – 18. Columns 7-18 list the materials used in the design. The numbers are FDOTs reference number for sources.

19. The type of asphalt used in the design.

4.3 Asphalt Binder

The grade of asphalt cement used in mixtures is one important factor that can affect the strength of asphalt concrete and amount of rutting which occurs in the mix. In this study, only one type of unmodified asphalt cement, PG67-22 (AC-30), which is commonly used in Florida, was used for all mixtures tested. The asphalt binder PG67-22 grading report is summarized in Table 4-2.

4.4 Aggregates

The type of aggregates, aggregate gradations, and combination of various aggregates used in this study are described in this section. The nominal maximum aggregate sizes for the mixtures tested are 19.0 mm, 12.5 mm, and 9.5 mm, respectively. The Superpave mixture designs were selected as they are commonly used FDOT gradations and are known to perform well in the field. The types of aggregates used are as follows:

- Granite
  - Georgia-553
  - Georgia-206
  - Nova Scotia Granite (NS)

- Reclaimed Asphalt Pavement (RAP)
- Limestone
  - North Florida Limestone (NFL)
  - Mid Florida Limestone (MFL)
  - South Florida Oolite/Limestone (SFL)
  - Alabama Limestone (AL)

A summary of the 20 mix designs and the aggregate types is presented in Table 4-3. The 20 mixtures were tested for both complex modulus and indirect tensile resilient modulus. The gradations of all mix designs, sorted by the mix design series number and used in this study, are summarized in Tables 4-4, 4-5, 4-6, and 4-7. The corresponding gradation charts for all mix design series (sieve size raised to 0.45 power mm) are presented in Figures 4-1 through 4-8 for illustration.

4.5 HMA Mix Designs

The mixture design process was verified for the mixture volumetric properties before the production of test specimens. The original Superpave design procedure was used for all the mixture designs. The Servopac Superpave gyratory compactor was used in the process.

Table 4-8 displays the Superpave compaction requirements for specified traffic level as a guide for the design of asphalt paving mixtures. The mixture's volumetric properties are calculated based on the design number of gyrations (Ndes). At this number of gyrations, a specified air voids level of 4% provided the optimum design asphalt content. The Ndes number depended on the traffic level at which the mixture was designed. The Servopac compaction parameters used for the design were 150 mm diameter mold, a 1.25° gyratory angle, 600-kPa ram pressure, and 30 gyrations per minute.

To verify the volumetric properties of the mixtures, the maximum theoretical specific gravity was measured using Rice maximum theoretical specific gravity method specified in AASHTO T 209/ASTM D 2041 standards. In this case, the mixtures were allowed to cool down in the loose state. Table 4-9 to 4-12 show the volumetric properties of all the mixtures used in this research project.

4.6 Specimen Preparation

The sample preparation was based on the conclusions of an extensive study on sample geometry and aggregate size conducted during NCHRP Project 9-19. Results show that (1) a minimum height-to-diameter ratio of 1.5 was required in order to ensure that the response of a sample evaluated in either the dynamic modulus or permanent deformation test repeated load tests represented a fundamental engineering property; (2) a minimum sample diameter of 4 in. (100 mm) was satisfactory for all HMA mixtures up to a maximum aggregate size of 1.5 in. (37.5 mm); and (3) smooth, parallel specimen ends were needed to eliminate end friction and violation of the theoretical boundary effects of the specimen during the test. Another factor discouraging the use of the 6-in.-diameter specimens was that numerous studies have illustrated the large degree of non-homogeneity of air voids within the larger gyratory-compacted specimens. This variability, and its subsequent impact upon the variability of the Simple Performance Test (SPT) results, was significantly larger than the variability found when the smaller 4-in.-diameter cored-and-sawn specimens were used.

Test specimens with dimensions of 150 mm (~ 6 in.) in diameter by 165 mm (6.5 in.) in high were first prepared on the required air void content (4%) using a Servopac Gyratory Compactor for targeted Florida AC mixtures. The nominal 100 mm (4in.) diameter test specimens were cored from the center of the gyratory specimens (Figure 4-9) and were subsequently cut to 150 mm (6 in.) in height (Figure 4-10). Dynamic modulus testing was performed on the 100 mm (4 in.) in diameter by 150 mm (6 in.) in height test specimens.

The sample preparation for the IDT test was based on the findings from the NCHRP Project 1-28A, "Harmonized Test Methods for Laboratory Determination of Resilient Modulus for Flexible Pavement Design". Test specimens of 150 mm (6 in.) in diameter by 128 mm (5 in.) in height were first prepared on the required air void content (4%) using a Servopac Gyratory Compactor for targeted Florida AC mixtures. At least 6 mm was sawed off both sides of each test specimen to provide smooth, parallel surfaces for mounting the measurement gauges. The testing specimen was then sawed to the required thickness (two specimens out of each compacted pill). This sample preparation procedure was done to make three samples for each AC mixture and the air voids were measured on the finished test specimens. Resilient modulus testing was performed on 150 mm (6 in.) in diameter by 50 mm (2 in.) thick test specimens.

4.7 Test Procedures

The laboratory testing program conducted in this project included dynamic modulus testing and indirect tension testing. Both types of testing were conducted in unconfined condition. The Interlaken dynamic test system was used to load the specimens.

4.7.1 IDT Testing Procedures

After the specimens were well prepared, they were placed in a controlled temperature cabinet and brought to the specified test temperature. The specimens were placed into the loading apparatus; the loading strips were positioned in a parallel format and centered on the vertical diametral plane. Tests were performed at temperatures of 5, 25, and 40ºC and at 1.0 Hz frequency. Testing began with the lowest temperature and proceeded to the highest.

On the night before testing, extensometers were placed on the test specimen using glue. The specimen was then placed in a controlled temperature cabinet overnight at 5ºC to ensure temperature equilibrium. On the morning of testing, the specimen was placed in the environmental chamber at 5ºC and allowed to equilibrate for two hours.

To begin testing, the extensometers were zeroed, and a minimal contact load was applied to the specimen. Each stress cycle was made up of a 0.1 second haversine pulse followed by 0.9 second hold cycle to simulate moving wheel loads. The data acquisition system was set up to record the last six cycles at each frequency with about 200 points per cycle. The raw force and displacement data were manipulated to obtain the resilient modulus for each specimen.

After the entire cycle of testing was complete at 5ºC, the environmental chamber was set to the next temperature. After two hours of conditioning, the above steps were repeated until completion of the entire sequence of temperatures.

4.7.2 DMT Testing Procedures

The dynamic moduli and phase angle were measured by applying compressive sinusoidal (haversine) loading. The deformations were measured through three LVDTs (Linear Variable Differential Transducers). These LVDTs were placed vertically on diametrically symmetric specimen sides. On the night before testing, parallel studs were glued 100 mm (4") apart and located approximately 25 mm (1") from the top and bottom of the specimen. They were used to secure the LVDTs in place. The diameter of the specimens was 100 mm (4”) and height was 150 mm (6”), cut and cored form the raw gyratory compacted pills with 150 mm (6”) in diameter and 165 mm in height (Figure 4-9 and Figure 4-10). The specimens were then placed in a controlled temperature cabinet overnight at 5ºC to ensure temperature equilibrium. On the morning of testing, the specimen was placed in the environmental chamber at 5ºC and allowed to equilibrate for two hours. All testing was conducted using this temperature controlled chamber capable of holding temperatures from -16 to 60°C (3.2 to 140°F). Tests were performed at temperatures of 5, 25, and 40 ºC and frequencies of 25, 10, 5, 1, and 0.5Hz. Testing began with the lowest temperature and proceeded to the highest temperature. At a given temperature level, the testing began with the highest frequency of loading and proceeded to the lowest. This temperature-frequency sequence was carried out to cause minimum damage to the specimens before the next sequential test (Pellinen 2001).

To begin testing, the extensometers were zeroed, and a minimal contact load was applied to the specimens. A sinusoidal axial compressive load was applied to the specimens without impact in a cyclic manner. The load was adjusted in each case to attempt to keep the axial strains between 50 and 150 micro-strains. The first step was to apply a preconditioning load to the specimens with 200 cycles at 25 Hz. Testing continued with different numbers of cycles for each frequency as shown in Table (4-13). The data acquisition system was set up to record the last six cycles at each frequency with about 200 points per cycle. The raw force and displacement data were manipulated to obtain the dynamic modulus and phase angle for each specimen. After the entire cycle of testing was complete at 5ºC, the environmental chamber was set to the next temperature. After two hours of conditioning, the above steps were repeated until completion of the entire sequence of temperatures and frequencies.

4.8 Testing Program

The HMA mixtures were compacted in the laboratory and the specimens were prepared for the IDT and DMT. In general, for each test series, four to six IDT specimens and three DMT specimens were tested to determine the resilient modulus and dynamic modulus of each mix design. The number of specimens for each test series and each test procedure are listed in Table 4-14. If any of the specimens had air voids outside of the 3.5 to 4.5 percent range, the specimen was discarded and new specimens were prepared and compacted. This procedure was followed as much as possible; however, in some cases the DMT specimens were extremely difficult to have the cored 4-in. specimens with approximately 4.0 percent air voids. A flow chart is shown in Figure 4-11 to illustrate the complete testing program for this study.

Table 4-1. Superpave Mix Designs Sorted by Test Series

Series	Mix Design	Size	Type	Load	Application	Rap	# 7	# 67	S-1-A	S-1-B	# 78	#89	5/16"	W-10	M-10	Stone	Sand	Asphalt
				Level			Stone	Stone	Stone	Stone	Stone	Stone	Stone	Screenings	Screenings	Screenings		
S-1	SP 03-2460A	12.5		C	Structural	A0704					43	51		20			CWR	AC-30?
						A0704-3					GA-553	GA-553		GA-553			Quincy	
S-2	LD 00-2502A	12.5	Fine	D	Structural				41	51				20			Starvation Hill	PG 67-22
S-3	LD 02-2529A	12.5	Coarse	D	Structural				41	51				20				PG 67-22
S-4	SP 02-2180A	9.5	Fine	B	Structural							51		20	21		A/C	PG 67-22
												GA-553		GA-553	GA-553		Mayo	
S-5	SP 03-2921A	9.5	Coarse	D	Structural							51		20	21			PG 67-22
												GA-553		GA-553	GA-553			
S-6	SP 03-2922A	19.0	Coarse	D	Structural			42			43	51			21			PG 67-22
								GA-553			GA-553	GA-553			GA-553			
S-7	SP 04-3034A	12.5	Coarse	D	Structural			42			43	51		20	21			PG 67-22
								GA-553			GA-553	GA-553		GA-553	GA-553			
S-8	SP 03-2610A	12.5	Fine	C	Structural					52		51				20		PG 67-22
										AL-149		AL-149				AL-149		
S-9	SP 03-2627A	12.5	Fine	C	Structural				42	51						20		PG 67-22
									87-145	87-145						87-145		
S-10	SP 04-3225A	12.5	Fine	C	Structural						43	51	21				TM-35	PG 67-22
											GA-553	GA-553	GA-206				Hill	

S-11	SP 02-2194A	12.5	Coarse	D	Structural		44					54				22		PG 67-22
							NS-315					NS-315				NS-315		
S-12	SP 03-2452A	12.5	Coarse	D	Structural						54			21	22			PG 67-22
											GA-383			GA-383	GA-383			
S-13	SP 03-2941A	19.0	Fine	C	Structural			42			43	51		20			JCH	PG 67-22
								GA-553			GA-553	GA-553		GA-553			Ruben	
S-14	SP 03-2351A	12.5	Fine	B	Structural						43	51		20			A/C	PG 67-22
											GA-553	GA-553		GA-553			Sunny Hills	
S-15	SP 05-4015A	12.5	Fine	C	Structural						43	51		20			A/C	PG 67-22
											GA-553	GA-553		GA-553			Grandin	
S-16	SPM 05-4044A	9.5	Fine	B	Structural							51		20	21		A/C	PG 67-22
												GA-553		GA-553	GA-554		Compass Lake	
S-17	SPM 05-4051A	9.5	Fine	C	Structural							51		20			A/C	PG 67-22
												GA-553		GA-553			Compass Lake	
S-18	SP 05-4061A	12.5	Fine	C	Structural	A0638		41				53		20			A/C	PG 67-22
								38-286				38-268		GA-553			Quincy	
S-19	SP 05-4100A	12.5	Fine	C	Structural						43	51		20			A/C	PG 67-22
											GA-553	GA-553		GA-553			Quincy	
S-20	SP 02-2052A	12.5	FC	C	Friction						43	51		20			A/C	PG 67-22
											GA-553	GA-553		GA-553			Quincy	

Table 4-2. Performance Grade Binder Grading Report

Project	FSU Dynamic Modulus Testing	Date Received	02-17-05
Submitted By	Dr. Ping (from C. W. Roberts)	Date Tested	02-22 thru 02-24-05
Tested By	Hill & Stickles	Date Reported	02-24-05

Test	Test Temp.	Test Result	P / F	Florida Specification
Spot Test	n/a	Negative	P	Negative
Solubility, %	n/a	99.71	P	Minimum 99.0%
Smoke Point COC, °C	n/a	174	P	Minimum 125°C
Flash Point COC, °C	n/a	316	P	Minimum 230°C
Absolute Viscosity, poises	60°C	3329	P	2400 – 3600 poises
Rotational Viscosity, Pa•s	135°C	0.58	P	Maximum 3.0 Pa•s
Original Dynamic Shear, G*/sinδ, kPa	67°C	1.32	P	Minimum 1.0 kPa
	70°C	0.87	F	
The initial High Temperature Grade is PG 67				
RTF Mass Loss, %	163°C	0.293	P	Maximum 0.500%
RTF Dynamic Shear, G*/sinδ, kPa	67°C	2.82	P	Minimum 2.20 kPa
	70°C	1.88	F	
The final High Temperature Grade is PG 67				
PAV Dynamic Shear, G*sinδ, kPa	25°C	3260	P	Maximum 5000 kPa
	22°C	5361	F	
The initial Low Temperature Grade is -22				
Creep Stiffness S, MPa	-12	154	P	S Maximum 300 MPa
Creep Stiffness, M-value	-12	0.346	P	
Creep Stiffness S, MPa	-18	369	F	M-value Minimum 0.300
Creep Stiffness, M-value	-18	0.275	F	
This sample graded out to a final grade of PG 67-22				

Note: When heated and stirred there was a granular texture to the asphalt. The Solubility test revealed what appears to be very fine ground tire rubber but the percentage is within acceptable parameters specified by the State of Florida Department of Transportation.

Table 4-3. Summary of Mix Designs and Aggregates

Test	SP	RAP	Ga-553	Ga-206	Nova Sco.	North Fl	Central Fl	South Fl	Alabama
Series	Spec #		Granite	Granite	Granite	Limestone	Limestone	Oolite	Limestone
S-1	2460	🟩	🟩						
S-2	2502						🟩		
S-3	2529						🟩		
S-4	2180		🟩						
S-5	2921		🟩						
S-6	2922		🟩						
S-7	3034		🟩						
S-8	2610								🟩
S-9	2627							🟩	
S-10	3225		🟩	🟩					
S-11	2194				🟩				
S-12	2452		🟩						
S-13	2941		🟩						
S-14	2351		🟩						
S-15	4015		🟩						
S-16	4044		🟩						
S-17	4051		🟩						
S-18	4061	🟩				🟩			
S-19	4100		🟩						
S-20	2052		🟩						

Table 4-4. Aggregate gradations for series 1 ~ 5

Sieve Size (mm)	S-1	S-2	S-3	S-4	S-5
19	100	100	100	100	100
12.5	100	93	94	100	100
9.5	89	89	89	100	100
4.75	67	71	56	74	71
2.36	50	53	30	48	42
1.18	37	42	20	39	28
0.6	27	35	15	28	18
0.3	14	22	10	16	13
0.15	8	9	6	7	9
0.075	5.6	4.5	4.3	4.5	6.9

Table 4-5. Aggregate gradations for series 6 ~ 10

Sieve Size (mm)	S-6	S-7	S-8	S-9	S-10
19	100	100	100	100	100
12.5	90	95	96	96	98
9.5	77	84	90	88	90
4.75	51	52	72	69	57
2.36	32	32	52	54	40
1.18	22	21	34	38	34
0.6	16	15	24	27	28
0.3	12	9	11	19	16
0.15	9	6	6	12	4
0.075	6.4	5.2	4.5	4.5	4.5

Table 4-6. Aggregate gradations for series 11 ~ 15

Sieve Size (mm)	S-11	S-12	S-13	S-14	S-15
19	100	100	100	100	100
12.5	98	99	90	100	99
9.5	89	75	79	90	90
4.75	58	44	61	55	61
2.36	38	29	44	40	42
1.18	24	19	35	34	33
0.6	16	13	26	28	26
0.3	10	9	18	16	18
0.15	5	6	8	4	7
0.075	4.5	4.5	4.4	2.9	2.8

Table 4-7. Aggregate gradations for series 16 ~ 20

Sieve Size (mm)	S-16	S-17	S-18	S-19	S-20
19	100	100	100	100	100
12.5	100	100	91	100	98
9.5	100	100	83	90	90
4.75	74	75	68	60	59
2.36	50	48	51	43	40
1.18	39	40	39	34	34
0.6	31	30	30	27	26
0.3	23	16	16	19	11
0.15	9	6	8	7	4
0.075	5.6	3.0	4.8	3.0	3.5

Table 4-8. Superpave Design Gyratory Compaction Effort

Traffic Level	N initial	N design	N maximum
A	6	50	75
B	7	75	115
C	7	75	115
D	8	100	160
E	9	125	205

Table 4-9. Volumetric Properties of mixture design series 1 ~ 5

Property	Symbol	S1	S2	S3	S4	S5
Maximum theoretical density	G_{mm}	2.543	2.276	2.253	2.550	2.563
Specific gravity of asphalt	G_b	1.035	1.035	1.035	1.035	1.035
Bulk specific gravity of compacted mix	G_{mb}	2.441	2.185	2.162	2.448	2.460
Asphalt content	P_b	5.3	8.2	8.2	5.3	5.8
Bulk specific gravity of aggregate	G_{sb}	2.725	2.346	2.311	2.745	2.776
Effective specific gravity of aggregate	G_{se}	2.769	2.549	2.518	2.778	2.819
Asphalt absorption	P_{ba}	0.6	3.514	3.676	0.442	0.572
Effective asphalt content in the mixture	P_{be}	4.7	4.97	4.8	4.9	5.2
Percent VMA in compacted mix	VMA	15.2	14.5	14.1	15.5	16.5
Percent air voids in compacted mix	V_a	4.0	4.0	4.0	4.0	4.0
Percent VFA in compacted mix	VFA	74	72	72	74	76
Dust/asphalt ratio	D/A	1.2	0.9	0.9	0.9	1.3

Table 4-10. Volumetric Properties of mixture design series 6 ~ 10

Property	Symbol	S6	S7	S8	S9	S10
Maximum theoretical density	G_{mm}	2.603	2.589	2.494	2.313	2.554
Specific gravity of asphalt	G_b	1.035	1.035	1.035	1.035	1.035
Bulk specific gravity of compacted mix	G_{mb}	2.499	2.485	2.393	2.220	2.452
Asphalt content	P_b	4.5	5.0	5.7	7.5	5.3
Bulk specific gravity of aggregate	G_{sb}	2.781	2.775	2.689	2.389	2.729
Effective specific gravity of aggregate	G_{se}	2.803	2.811	2.726	2.570	2.783
Asphalt absorption	P_{ba}	0.293	0.480	0.527	3.056	0.730
Effective asphalt content in the mixture	P_{be}	4.2	4.5	5.2	4.68	4.61
Percent VMA in compacted mix	VMA	14.2	14.9	16.1	14.0	14.9
Percent air voids in compacted mix	V_a	4.0	4.0	4.0	4.0	4.0
Percent VFA in compacted mix	VFA	72	73	75	71	73
Dust/asphalt ratio	D/A	1.5	1.2	0.9	1.0	1.0

Table 4-11. Volumetric Properties of mixture design series 11 ~ 15

Property	Symbol	S11	S12	S13	S14	S15
Maximum theoretical density	G_{mm}	2.420	2.555	2.571	2.570	2.557
Specific gravity of asphalt	G_b	1.035	1.035	1.035	1.035	1.035
Bulk specific gravity of compacted mix	G_{mb}	2.322	2.454	2.468	2.467	2.455
Asphalt content	P_b	6.0	5.4	5.0	4.8	5.0
Bulk specific gravity of aggregate	G_{sb}	2.604	2.701	2.763	2.752	2.764
Effective specific gravity of aggregate	G_{se}	2.646	2.789	2.789	2.778	2.772
Asphalt absorption	P_{ba}	0.631	1.206	0.347	0.348	0.101
Effective asphalt content in the mixture	P_{be}	5.41	4.26	4.6	4.4	4.9
Percent VMA in compacted mix	VMA	16.2	14.1	15.1	14.7	15.6
Percent air voids in compacted mix	V_a	4.0	4.0	4.0	4.0	4.0
Percent VFA in compacted mix	VFA	75	72	74	73	74
Dust/asphalt ratio	D/A	0.8	1.1	1.0	0.7	0.6

Table 4-12. Volumetric Properties of mixture design series 16 ~ 20

Property	Symbol	S16	S17	S18	S19	S20
Maximum theoretical density	G_{mm}	2.550	2.535	2.445	2.567	2.539
Specific gravity of asphalt	G_b	1.035	1.035	1.035	1.035	1.035
Bulk specific gravity of compacted mix	G_{mb}	2.448	2.434	2.348	2.464	2.438
Asphalt content	P_b	5.2	6.0	6.4	5.0	5.3
Bulk specific gravity of aggregate	G_{sb}	2.750	2.748	2.572	2.756	2.757
Effective specific gravity of aggregate	G_{se}	2.773	2.793	2.696	2.784	2.764
Asphalt absorption	P_{ba}	0.307	0.612	1.853	0.376	0.092
Effective asphalt content in the mixture	P_{be}	4.9	5.4	4.6	4.6	5.2
Percent VMA in compacted mix	VMA	15.6	16.7	14.6	15.1	16.3
Percent air voids in compacted mix	V_a	4.0	4.0	4.0	4.0	4.0
Percent VFA in compacted mix	VFA	74	76	73	74	75
Dust/asphalt ratio	D/A	1.2	0.8	1.2	0.7	0.7

Table 4-13. Cycles for Test Sequence

Frequency, Hz	Number of Cycles
Preconditioning (25)	200
25	50
10	50
5	50
1	25
0.5	6

Table 4-14. Summary of Specimens Tested

Test Series	Specimens Tested for IDT	Specimens Tested for DMT
S-1 SP 03-2460A (TL-C)	S-1-2B S-1-5B	S-1-8 S-1-9 S-1-10
S-2 LD 00-2502A (TL-D)	S-2-11A, S-2-11B S-2-12A, S-2-12B	S-2-8 S-2-9 S-2-10
S-3 LD 02-2529A (TL-D)	S-3-8A, S-3-8B S-3-9A, S-3-9B	S-3-3 S-3-4
S-4 SP 02-2180A (TL-B)	S-4-13B S-4-14A S-4-14B	S-4-3 S-4-4 S-4-5
S-5 SP 03-2921A (TL-D)	S-5-3A, S-5-3B S-5-4A S-5-9A, S-5-9B	S-5-10 S-5-11
S-6 SP 03-2922A (TL-D)	S-6-5A S-6-6B	S-6-7 S-6-8
S-7 SP 04-3034A (TL-D)	S-7-4A S-7-5A S-7-5B	S-7-7 S-7-8 S-7-9
S-8 SP 03-2610A (TL-C)	S-8-4A S-8-4B S-8-5B	S-8-7 S-8-8 S-8-9
S-9 SP 03-2627A (TL-C)	S-9-4A S-9-5A S-9-5B	S-9-6 S-9-7 S-9-8
S-10 SP 04-3225A (TL-C)	S-10-5B S-10-6A S-10-6B	S-10-7 S-10-8 S-10-9

Table 4-14. Summary of Specimens Tested (Cont.)

Test Series	Specimens Tested for IDT	Specimens Tested for DMT
S-11 SP 02-2194A (TL-D)	S-11-3A S-11-3B S-11-4B	S-11-7 S-11-8 S-11-9
S-12 SP 03-2452A (TL-D)	S-12-3B S-12-4A S-12-4B	S-12-6 S-12-7 S-12-8
S-13 SP 03-2941A (TL-C)	S-13-3B S-13-5A S-13-5B	S-13-6 S-13-7 S-13-8
S-14 SP 03-2351A (TL-B)	S-14-3B S-14-4B S-14-5A	S-14-6 S-14-7 S-14-8
S-15 SP 05-4015A (TL-C)	S-15-4B S-15-5A S-15-5B	S-15-6 S-15-7
S-16 SPM 05-4044A (TL-C)	S-16-3A S-16-5A S-16-5B	S-16-6 S-16-7 S-16-8
S-17 SPM 05-4051A (TL-C)	S-17-3A S-17-3B S-17-5A	S-17-6 S-17-7 S-17-8
S-18 SP 05-4061A (TL-C)	S-18-4A S-18-4B S-18-5A	S-18-6 S-18-7 S-18-8
S-19 SP 05-4100A (TL-C)	S-19-3A S-19-4A S-19-5B	S-19-6 S-19-7 S-19-8
S-20 SP 02-2052A (TL-B)	S-20-3B S-20-4A S-20-4B	S-20-6 S-20-7 S-20-8

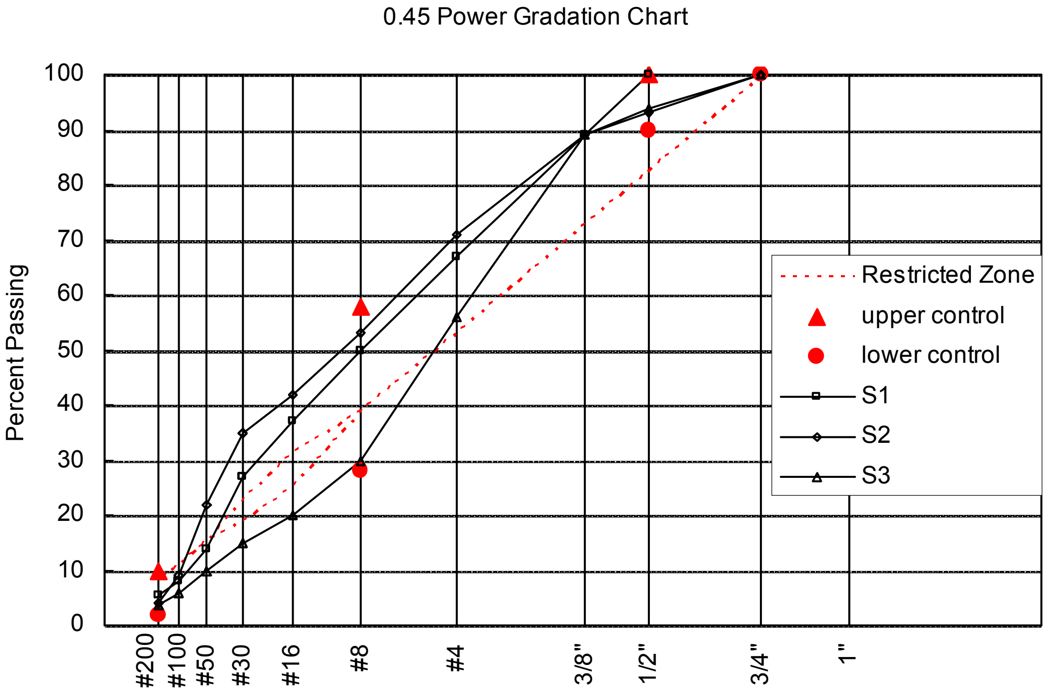


Figure 4-1. Gradation chart for S1 to S3

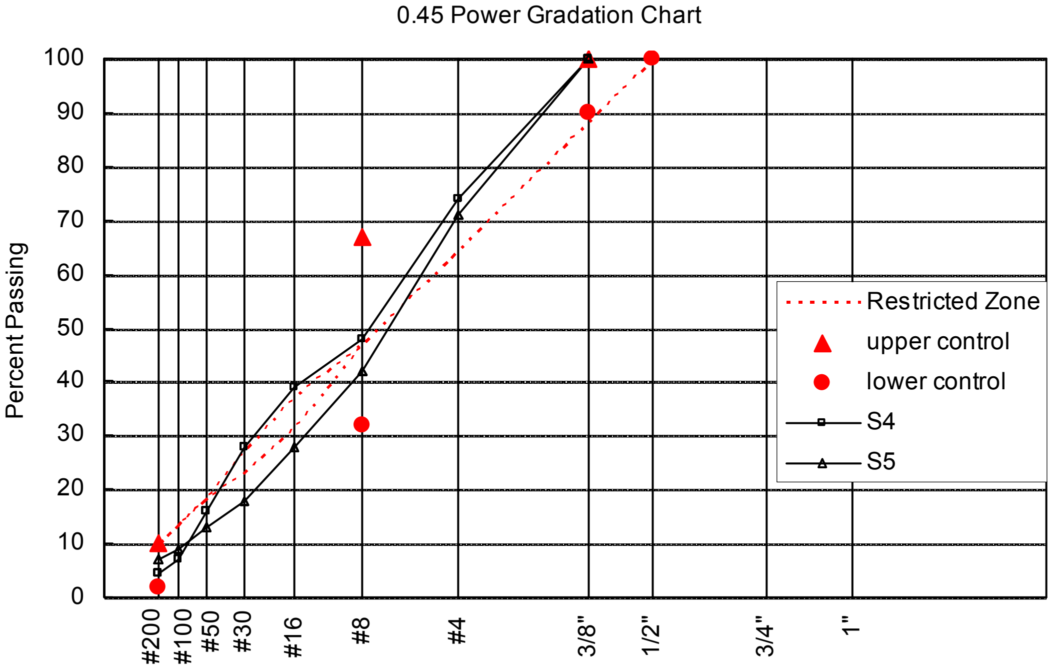


Figure 4-2. Gradation chart for S4 and S5

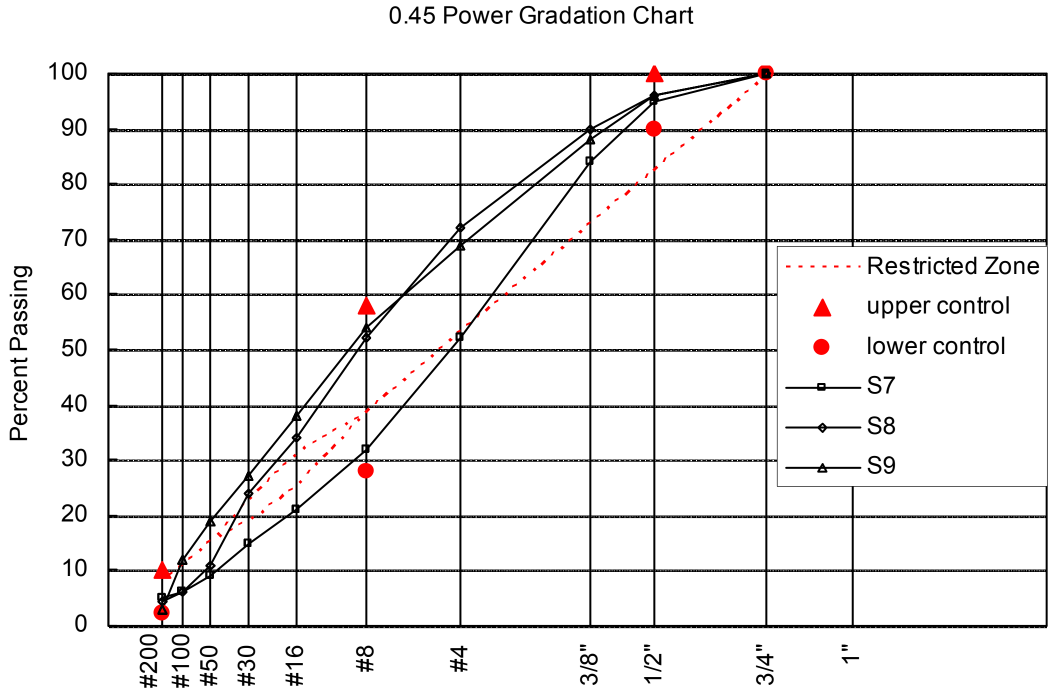


Figure 4-3. Gradation chart for S7 to S9

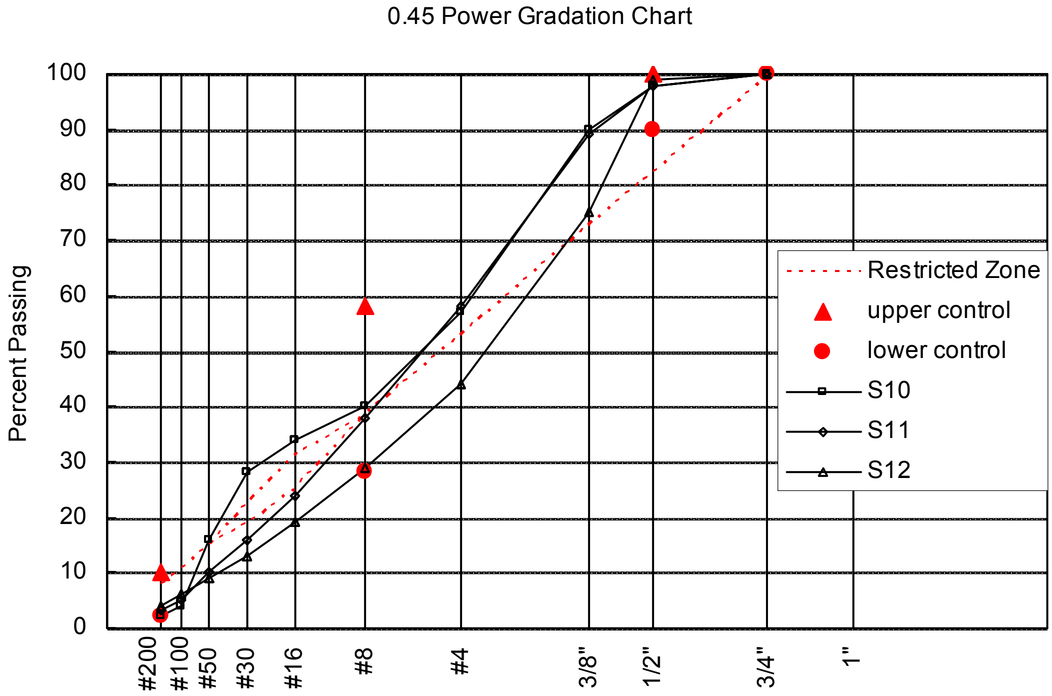


Figure 4-4. Gradation chart for S10 to S12

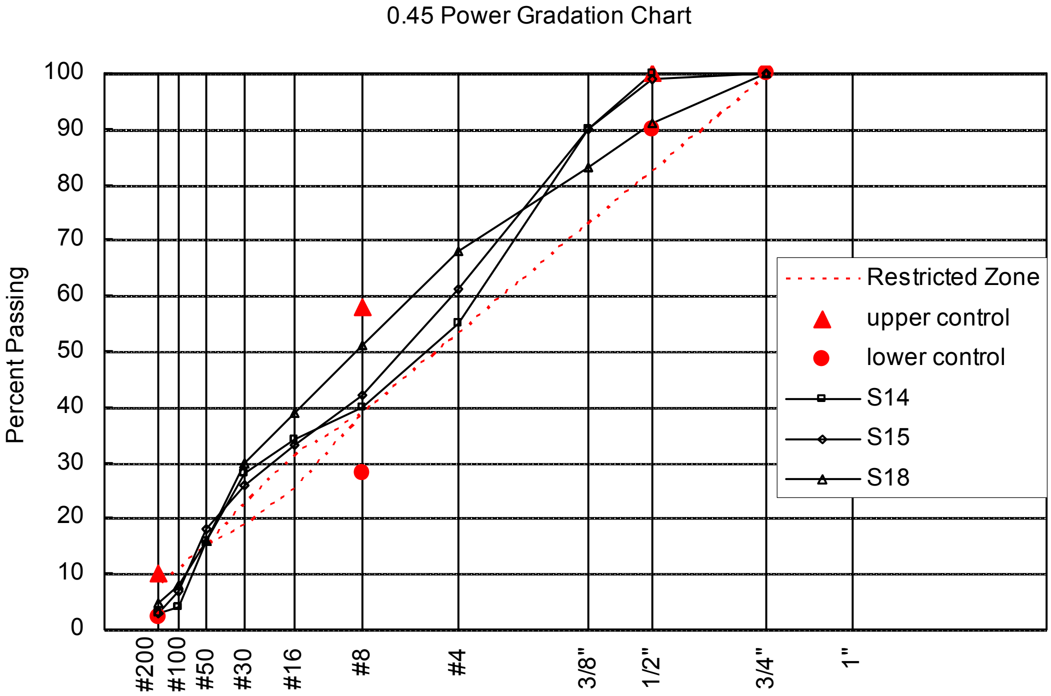


Figure 4-5. Gradation chart for S14, S15, and S18

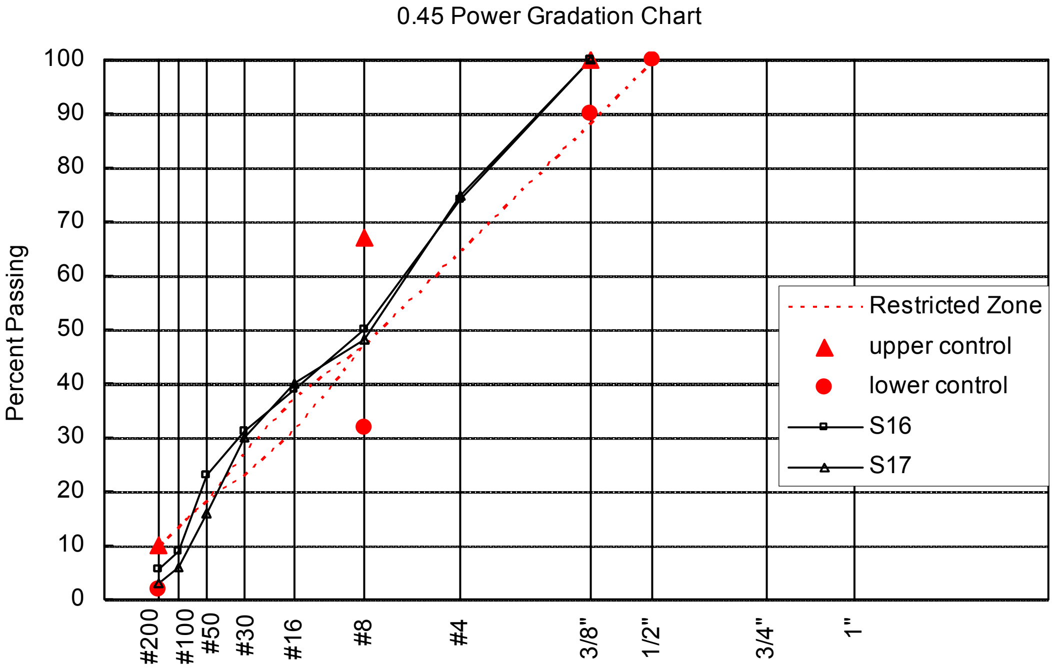


Figure 4-6. Gradation chart for S16 and S17

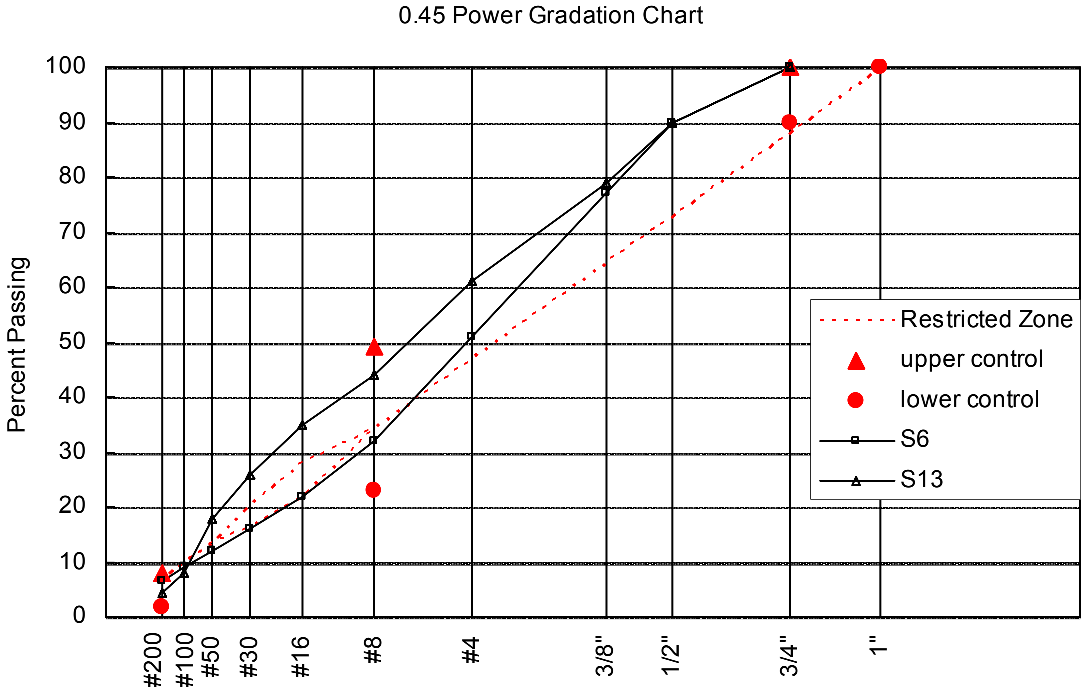


Figure 4-7. Gradation chart for S6 and S13

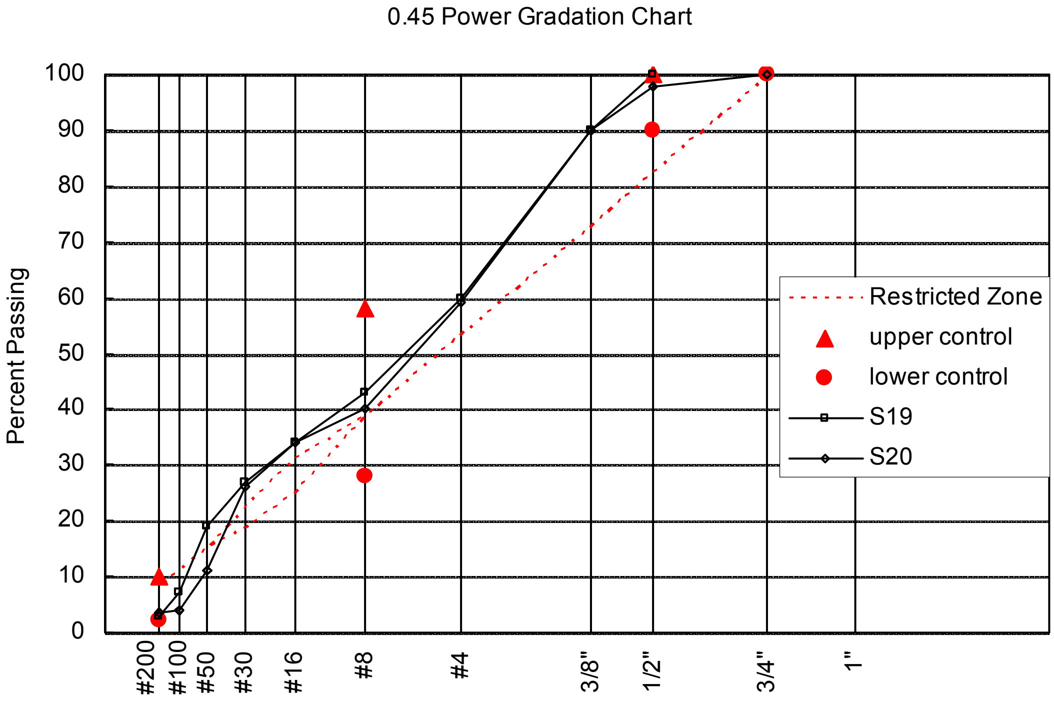


Figure 4-8. Gradation chart for S19 and S20

Figure 4-9. Coring of the Superpave Specimen

Figure 4-10. Cutting of the Dynamic Modulus Specimen

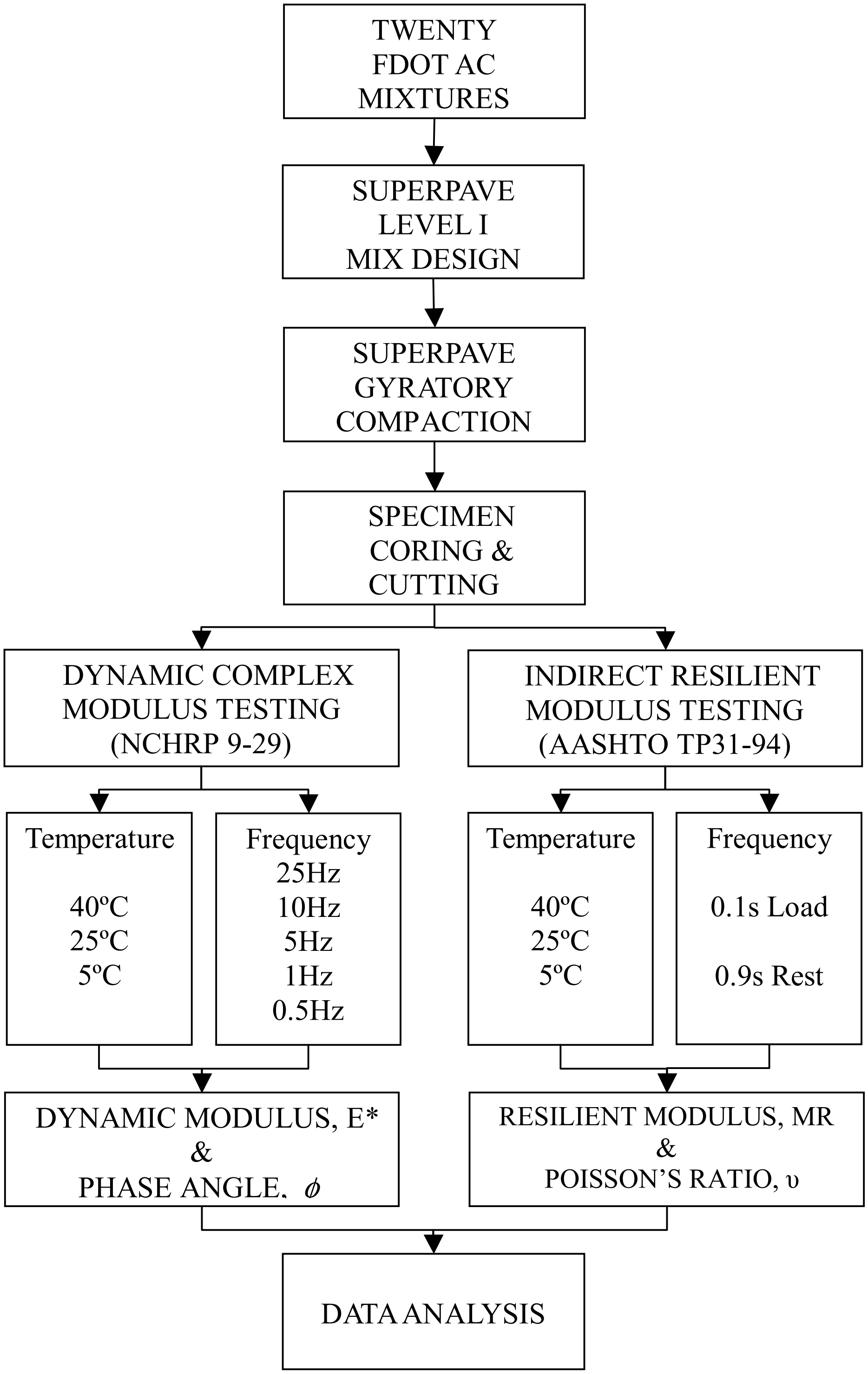


Figure 4-11. Flowchart of the Experimental Program

CHAPTER 5

PRESENTATION OF THE INDIRECT DIAMETRAL TEST RESULTS

5.1 General

The indirect diametral test results are presented in this chapter. A total of 20 mix design series were tested and the measured data were processed for each test. The resilient modulus data files were stored in a database using Microsoft Access (see Appendix B). Data processing and presentation of the test results are described as follows.

5.2 Data Processing and Analysis Procedures

The AASHTO TP31 test procedure (AASHTO 1996) was generally followed to perform the indirect tensile test. However, the measurement and analysis system developed for the SHRP indirect tensile test (IDT) (Roque and Buttlar 1992) was also applied. The SHRP IDT could obtain an accurate determination of tensile properties of asphalt mixtures at lower temperatures, with an accurate measuring of Poisson's ratio. The deformation measurement mounting system was modified in the SHRP IDT in order to accurately measure Poisson's ratio. The SHRP IDT was also used to determine the resilient modulus of asphalt concrete.

5.2.1 Resilient Modulus and Tensile Strength

The resilient modulus of asphalt mixture is a stress-strain relationship which can be defined as follows:

$$M_r = \sigma_r / \varepsilon_r \tag{5-1}$$

Where, σ_r = repeated stress

ε_r = recoverable axial strain

The indirect tensile test for resilient modulus of a bituminous mixture recommended by AASHTO TP31 was conducted by applying a haversine waveform load along the vertical diametral plane of a cylindrical specimen of the asphalt mixture. The resilient modulus of the asphalt mixture was calculated by using the measured horizontal deformation and either an assumed Poisson's ratio, or a Poisson's ratio determined from platen-to-platen measurements. The instantaneous resilient modulus was calculated by using the recoverable deformation that occurs instantaneously during the unloading portion of each cycle. The total resilient modulus was calculated by using the total recoverable deformation, which included both the instantaneous recoverable and the time-dependent recoverable deformation during the unloading and rest-period portion of each cycle. Typical load and deformation outputs that form a resilient modulus test are shown in Figure 5-1. The two dimensional plane stress equations for calculating the resilient modulus and Poisson's ratio are:

$$M_{RI} = \frac{P(\mu_{RI} + 0.27)}{t\Delta H_I} \tag{5-2}$$

$$M_{RT} = \frac{P(\mu_{RT} + 0.27)}{t\Delta H_T} \tag{5-3}$$

$$\mu_{RI} = \frac{3.59\Delta H_I}{\Delta V_I} - 0.27 \tag{5-4}$$

$$\mu_{RT} = \frac{3.59\Delta H_T}{\Delta V_T} - 0.27 \tag{5-5}$$

Where

M_{RI} : Instantaneous resilient modulus, psi or MPa

M_{RT} : Total resilient modulus, psi or MPa

μ_{RI} : Instantaneous resilient Poisson's ratio

μ_{RT} : Total resilient Poisson's ratio

P : Repeated load, lbf or N

t : Thickness of a specimen, in. or mm

ΔH_I : Instantaneous recoverable horizontal deformation, in. or mm

ΔH_T : Total recoverable horizontal deformation, in. or mm

ΔV_I : Instantaneous recoverable vertical deformation, in. or mm

ΔV_T : Total recoverable horizontal deformation, in. or mm

The indirect tensile strength may be calculated utilizing the following equation:

$$S_t = \frac{50.127 \cdot P_0}{t}\left[\sin\left(\frac{1455.313}{d}\right) - \frac{12.7}{d}\right] \tag{5-6}$$

Where

S_t : Indirect tensile strength, kPa ($6.896 \times psi$)

P_0 : Maximum load sustained by the specimen, N ($4.448 \times lbf$)

t : Specimen thickness, mm ($25.4 \times in.$)

d : Specimen diameter, mm ($25.4 \times in.$)

5.2.2 Corrected Data Processing Procedure

The measurement and analysis procedures developed by Roque and Buttlar (1992) for SHRP were used. The procedure calls for application of a gauge length to diameter ratio of

1:4 and the height of the surface mounted LVDT 0.25 in. from the specimen surface. A horizontal (tensile) deformation is considered to be positive, while a vertical (compressive) deformation is considered to be negative for this analysis. The computation procedures are briefly described as follows:

1. Assume Poisson's ratio, μ (usually 0.35 at 25°C).
2. Correct horizontal deformation to account for bulging:

$$H = \left(1.01 - 0.12\mu - 0.05 \cdot \left(\frac{t}{t_{std}}\right)\right) \cdot H_M \tag{5-7}$$

Where

t = measured specimen thickness

t_{std} = standard specimen thickness

H_M = measured horizontal deformation

3. Correct vertical deformation to account for bulging:

$$Y = (0.994 - 0.128\mu) \times Y_M \tag{5-8}$$

Where Y_M is the measured vertical deformation.

4. Horizontal point strain at the center of specimen is given by

$$\varepsilon_{CTR_x} = 1.07 \frac{H}{GL} \tag{5-9}$$

And the vertical point strain at the center of specimen is given by

$$\varepsilon_{CTR_y} = 0.98 \frac{Y}{GL} \tag{5-10}$$

Where

GL = gage length, in.

H = horizontal deformation, in.

Y = vertical deformation, in.

5. Corrected horizontal point stress at the center of specimen:

$$\sigma_{X_{CORR}} = \frac{2 \cdot P}{\pi t d} \cdot C_{\sigma_x CTR} \tag{5-11}$$

Corrected vertical point stress at the center of specimen:

$$\sigma_{Y_{CORR}} = \frac{6 \cdot P}{\pi t d} \cdot C_{\sigma_y CTR} \tag{5-12}$$

Where

$\sigma_{X_{CORR}}$ = corrected horizontal point stress

$\sigma_{Y_{CORR}}$ = corrected vertical point stress

$C_{\sigma_x CTR}$ = correction factor applied to the horizontal point stress

$C_{\sigma_y CTR}$ = correction factor applied to the vertical point stress

P : total load applied to the specimen

t : measured specimen thickness

d : specimen diameter

The correction factors for both the horizontal and the vertical stress are given in Table (5-1) (Roque and Buttlar 1992).

6. Calculate Poisson's ratio using

$$\mu = \frac{\sigma_{X_{CORR}} - \left(\frac{\varepsilon_{CTR_X}}{\varepsilon_{CTR_Y}}\right) \cdot \sigma_{Y_{CORR}}}{\sigma_{Y_{CORR}} - \left(\frac{\varepsilon_{CTR_X}}{\varepsilon_{CTR_Y}}\right) \cdot \sigma_{X_{CORR}}} \tag{5-13}$$

If Poisson's ratio calculated in this step differs by more than 0.01 with Poisson's ratio in step 1, then replace μ in step 1 by the value calculated in this step and repeat steps 2 through 6, or else go on to the next step.

7. The asphalt concrete modulus can then be determined by

$$M_R = \frac{1}{\varepsilon_{CTR_X}} (\sigma_{X_{CORR}} - \mu \cdot \sigma_{Y_{CORR}}) \tag{5-14}$$

Following the foregoing procedures, the Poisson's ratio (total and instantaneous) and the resilient modulus (total and instantaneous) were determined for the indirect diametral tests. The static tensile strength was calculated using Equation 5-6.

5.3 IDT Test Results

The resilient modulus and Poisson's ratio test results are summarized in Table 5-2 for the 20 Superpave AC mixtures. The Poisson's ratio and resilient modulus test results are also shown in Figures 5-2 through 5-41 for the S-1 through S-20 AC mixtures, respectively. The static tensile strength test results are presented in Table 5-3 for each of the 20 mixtures with selected specimens.

Table 5-1. Correction Factors for Horizontal and Vertical Stress

(Roque and Buttlar 1992)

		Diameter to Thickness Ratio, (t / d)				
$d = 4"\ \ or\ \ 6"$	μ	0.167	0.333	0.500	0.625	0.750
$C_{\sigma_x CTR}$	0.20	0.9471	0.9773	1.0251	1.0696	1.1040
	0.35	0.9561	1.0007	1.0871	1.1682	1.2321
	0.45	0.9597	1.0087	1.1213	1.2307	1.3171
$C_{\sigma_y CTR}$	0.20	-0.9648	-0.9754	-0.9743	-0.9693	-0.9611
	0.35	-0.9732	-0.9888	-0.9844	-0.9710	-0.9538
	0.45	-0.9788	-0.9971	-0.9864	-0.9646	-0.9395

Table 5-2. Summary of Resilient Modulus and Poisson’s Ratio Test Results

Mix	Temp. (°C)	Sample ID	*M_R (ksi)*				Poisson’s Ratio			
			Total		Instantaneous		Total		Instantaneous	
			Total	Avg.	Inst.	Avg.	Total	Avg.	Inst.	Avg.
S-1	5	S-1-2B	1625	1522	1599	1537	0.39	0.34	0.36	0.34
		S-1-5B	1419		1474		0.28		0.32	
	25	S-1-2B	576	521	570	516	---	0.34	---	0.35
		S-1-5B	465		462		0.34		0.35	
	40	S-1-2B	165	174	215	216	---	0.35	---	0.32
		S-1-5B	183		217		0.35		0.32	
S-2	5	S-2-11A	1279	1172	1507	1350	0.33	0.31	0.37	0.34
		S-2-11B	1113		1180		0.25		0.28	
		S-2-12A	1283		1490		0.37		0.37	
		S-2-12B	1012		1223		0.29		0.36	
	25	S-2-11A	---	428	---	524	---	0.33	---	0.32
		S-2-11B	439		549		0.27		0.30	
		S-2-12A	406		505		0.37		0.35	
		S-2-12B	438		519		0.36		0.32	
	40	S-2-11A	185	179	210	215	0.46	0.31	0.46	0.35
		S-2-11B	168		205		0.20		0.27	
		S-2-12A	184		229		0.28		0.33	
		S-2-12B	---		---		---		---	
S-3	5	S-3-8A	1035	1136	1208	1305	0.22	0.27	0.23	0.28
		S-3-8B	1194		1357		0.26		0.29	
		S-3-9A	1194		1357		0.26		0.29	
		S-3-9B	1122		1298		0.32		0.32	
	25	S-3-8A	---	451	---	584	---	0.29	---	0.34
		S-3-8B	467		605		0.28		0.35	
		S-3-9A	410		543		0.24		0.30	
		S-3-9B	475		604		0.35		0.38	
	40	S-3-8A	178	186	214	229	0.28	0.33	0.25	0.31
		S-3-8B	---		---		---		---	
		S-3-9A	164		209		0.32		0.34	
		S-3-9B	218		263		0.38		0.33	

Table 5-2. Summary of Resilient Modulus and Poisson’s Ratio Test Results (Cont.)

Mix	Temp. (°C)	Sample ID	M_R *(ksi)*				Poisson’s Ratio			
			Total		Instantaneous		Total		Instantaneous	
			Total	Avg.	Inst.	Avg.	Total	Avg.	Inst.	Avg.
S-4	5	S-4-13B	---	1180	---	1389	---	0.30	---	0.32
		S-4-14A	1272		1464		0.28		0.33	
		S-4-14B	1089		1313		0.31		0.31	
	25	S-4-13B	367	390	447	485	0.28	0.26	0.25	0.25
		S-4-14A	---		---		---		---	
		S-4-14B	414		524		0.23		0.25	
	40	S-4-13B	---	94	---	122	---	0.22	---	0.23
		S-4-14A	94		122		0.22		0.23	
		S-4-14B	---		---		---		---	
S-5	5	S-5-3A	2392	2674	2620	2958	0.33	0.32	0.33	0.33
		S-5-3B	2732		2953		0.33		0.30	
		S-5-4A	2443		2768		0.31		0.28	
		S-5-5A	2845		3122		0.33		0.34	
		S-5-5B	2957		3320		0.34		0.36	
	25	S-5-3A	672	789	942	1040	0.29	0.32	0.26	0.32
		S-5-3B	833		1004		0.30		0.29	
		S-5-4A	717		912		0.38		0.32	
		S-5-5A	855		1079		0.27		0.34	
		S-5-5B	870		1261		0.37		0.40	
	40	S-5-3A	245	237	329	336	0.29	0.33	0.31	0.37
		S-5-3B	313		411		0.35		0.39	
		S-5-4A	253		305		0.40		0.35	
		S-5-9A	296		181		0.25		0.34	
		S-5-9B	194		339		0.33		0.47	
S-6	5	S-6-5A	3312	3134	3505	3337	0.30	0.24	0.27	0.21
		S-6-6B	2955		3170		0.17		0.16	
	25	S-6-5A	1204	1282	1378	1464	0.38	0.37	0.38	0.34
		S-6-6B	1361		1550		0.35		0.31	
	40	S-6-5A	279	333	451	508	0.31	0.31	0.30	0.31
		S-6-6B	387		564		0.31		0.32	

Table 5-2. Summary of Resilient Modulus and Poisson’s Ratio Test Results (Cont.)

Mix	Temp. (°C)	Sample ID	M_R (ksi)				Poisson’s Ratio			
			Total		Instantaneous		Total		Instantaneous	
			Total	Avg.	Inst.	Avg.	Total	Avg.	Inst.	Avg.
S-7	5	S-7-4B	2264	1999	2536	2223	0.20	0.20	0.20	0.20
		S-7-5A	2303		2564		0.25		0.25	
		S-7-5B	1430		1570		0.16		0.15	
	25	S-7-4B	718	629	977	858	0.27	0.24	0.26	0.23
		S-7-5A	681		957		0.29		0.31	
		S-7-5B	486		641		0.16		0.13	
	40	S-7-4B	196	162	298	257	0.34	0.28	0.35	0.31
		S-7-5A	167		276		0.31		0.33	
		S-7-5B	122		197		0.18		0.24	
S-8	5	S-8-4A	1952	1827	2178	2041	0.17	0.21	0.18	0.20
		S-8-4B	1723		1929		0.22		0.21	
		S-8-5B	1805		2015		0.23		0.22	
	25	S-8-4A	542	513	804	734	0.23	0.27	0.27	0.29
		S-8-4B	590		785		0.41		0.40	
		S-8-5B	407		613		0.17		0.19	
	40	S-8-4A	175	152	280	244	0.35	0.35	0.39	0.40
		S-8-4B	136		220		0.36		0.40	
		S-8-5B	145		232		0.34		0.42	
S-9	5	S-9-4A	1797	1776	1985	1955	0.22	0.21	0.22	0.21
		S-9-5A	1991		2165		0.22		0.22	
		S-9-5B	1538		1715		0.19		0.20	
	25	S-9-4A	690	566	836	711	0.24	0.22	0.22	0.21
		S-9-5A	523		675		0.21		0.21	
		S-9-5B	483		621		0.19		0.20	
	40	S-9-4A	227	187	375	303	0.28	0.23	0.34	0.26
		S-9-5A	172		275		0.22		0.24	
		S-9-5B	161		258		0.19		0.21	

Table 5-2. Summary of Resilient Modulus and Poisson's Ratio Test Results (Cont.)

Mix	Temp. (°C)	Sample ID	M_R (ksi)				Poisson's Ratio			
			Total		Instantaneous		Total		Instantaneous	
			Total	Avg.	Inst.	Avg.	Total	Avg.	Inst.	Avg.
S-10	5	S-10-5B	2070	2136	2270	2353	0.26	0.22	0.24	0.21
		S-10-6A	1993		2210		0.19		0.20	
		S-10-6B	2344		2580		0.20		0.19	
	25	S-10-5B	584	616	780	803	0.31	0.27	0.30	0.25
		S-10-6A	612		805		0.26		0.26	
		S-10-6B	651		824		0.23		0.18	
	40	S-10-5B	175	174	445	336	0.40	0.29	0.46	0.36
		S-10-6A	177		269		0.28		0.37	
		S-10-6B	170		293		0.19		0.25	
S-11	5	S-11-3A	1936	1996	2146	2193	0.24	0.22	0.25	0.21
		S-11-3B	2017		2213		0.19		0.19	
		S-11-4B	2036		2222		0.21		0.19	
	25	S-11-3A	557	532	801	770	0.35	0.29	0.35	0.29
		S-11-3B	486		742		0.23		0.24	
		S-11-4B	553		766		0.30		0.27	
	40	S-11-3A	180	171	301	280	0.14	0.22	0.19	0.25
		S-11-3B	166		271		0.24		0.27	
		S-11-4B	167		267		0.29		0.30	
S-12	5	S-12-3B	2427	2161	2738	2425	0.24	0.21	0.24	0.22
		S-12-4A	1953		2148		0.19		0.18	
		S-12-4B	2103		2388		0.20		0.24	
	25	S-12-3B	579	541	862	768	0.22	0.22	0.23	0.23
		S-12-4A	510		676		0.25		0.27	
		S-12-4B	532		765		0.20		0.23	
	40	S-12-3B	112	126	171	200	0.25	0.26	0.24	0.28
		S-12-4A	125		197		0.24		0.26	
		S-12-4B	142		231		0.30		0.34	

Table 5-2. Summary of Resilient Modulus and Poisson’s Ratio Test Results (Cont.)

Mix	Temp. (° C)	Sample ID	*M_R (ksi)*				Poisson’s Ratio			
			Total		Instantaneous		Total		Instantaneous	
			Total	Avg.	Inst.	Avg.	Total	Avg.	Inst.	Avg.
S-13	5	S-13-3B	2315	2459	2564	2733	0.21	0.20	0.22	0.21
		S-13-5A	2702		2979		0.15		0.17	
		S-13-5B	2359		2657		0.23		0.24	
	25	S-13-3B	903	931	1081	1095	0.29	0.23	0.29	0.22
		S-13-5A	1059		1167		0.22		0.17	
		S-13-5B	831		1038		0.18		0.20	
	40	S-13-3B	238	253	385	417	0.25	0.27	0.30	0.33
		S-13-5A	292		487		0.26		0.34	
		S-13-5B	228		376		0.29		0.34	
S-14	5	S-14-3B	1993	2176	2170	2384	0.23	0.23	0.21	0.23
		S-14-4B	2561		2783		0.28		0.29	
		S-14-5A	1974		2198		0.20		0.20	
	25	S-14-3B	625	722	997	1011	0.25	0.26	0.33	0.28
		S-14-4B	942		1131		0.34		0.27	
		S-14-5A	600		904		0.20		0.25	
	40	S-14-3B	154	209	247	335	0.29	0.27	0.38	0.34
		S-14-4B	327		518		0.35		0.39	
		S-14-5A	146		240		0.17		0.24	
S-15	5	S-15-4B	2937	2509	3222	2744	0.33	0.25	0.33	0.25
		S-15-5A	2311		2550		0.25		0.25	
		S-15-5B	2277		2459		0.18		0.17	
	25	S-15-4B	889	790	1088	1045	0.37	0.29	0.30	0.27
		S-15-5A	674		911		0.26		0.25	
		S-15-5B	807		1137		0.24		0.25	
	40	S-15-4B	265	242	422	375	0.34	0.34	0.33	0.35
		S-15-5A	206		336		0.33		0.39	
		S-15-5B	254		367		0.36		0.34	

Table 5-2. Summary of Resilient Modulus and Poisson’s Ratio Test Results (Cont.)

Mix	Temp. (° C)	Sample ID	M_R *(ksi)*				Poisson’s Ratio			
			Total		Instantaneous		Total		Instantaneous	
			Total	Avg.	Inst.	Avg.	Total	Avg.	Inst.	Avg.
S-16	5	S-16-3A	2153	2084	2344	2308	0.24	0.20	0.23	0.20
		S-16-5A	2016		2257		0.18		0.19	
		S-16-5B	2084		2322		0.18		0.19	
	25	S-16-3A	746	656	985	890	0.31	0.24	0.30	0.25
		S-16-5A	601		815		0.22		0.22	
		S-16-5B	622		869		0.19		0.24	
	40	S-16-3A	216	208	355	334	0.23	0.21	0.28	0.27
		S-16-5A	198		314		0.21		0.26	
		S-16-5B	209		334		0.19		0.27	
S-17	5	S-17-3A	2147	1977	2403	2186	0.31	0.22	0.33	0.23
		S-17-3B	1928		2089		0.17		0.16	
		S-17-5A	1855		2066		0.18		0.19	
	25	S-17-3A	886	766	1029	931	0.35	0.26	0.31	0.23
		S-17-3B	753		976		0.20		0.20	
		S-17-5A	659		789		0.22		0.18	
	40	S-17-3A	285	266	411	403	0.31	0.29	0.31	0.31
		S-17-3B	265		396		0.29		0.31	
		S-17-5A	247		401		0.28		0.32	
S-18	5	S-18-4A	2631	2626	2835	2848	0.24	0.23	0.25	0.25
		S-18-4B	2551		2787		0.19		0.21	
		S-18-5A	2696		2923		0.26		0.28	
	25	S-18-4A	1702	1464	1809	1608	0.48	0.31	0.43	0.30
		S-18-4B	1343		1475		0.19		0.19	
		S-18-5A	1347		1540		0.28		0.28	
	40	S-18-4A	807	743	919	941	0.38	0.31	0.35	0.37
		S-18-4B	783		936		0.25		0.28	
		S-18-5A	640		968		0.31		0.47	

Table 5-2. Summary of Resilient Modulus and Poisson’s Ratio Test Results (Cont.)

Mix	Temp. (° C)	Sample ID	M_R *(ksi)*				Poisson’s Ratio			
			Total		Instantaneous		Total		Instantaneous	
			Total	Avg.	Inst.	Avg.	Total	Avg.	Inst.	Avg.
S-19	5	S-19-3A	2102	2073	2324	2274	0.13	0.12	0.13	0.12
		S-19-4A	2040		2243		0.10		0.10	
		S-19-5B	2076		2255		0.12		0.12	
	25	S-19-3A	907	785	1025	932	0.21	0.20	0.22	0.20
		S-19-4A	713		891		0.13		0.14	
		S-19-5B	735		880		0.27		0.25	
	40	S-19-3A	224	202	353	317	0.27	0.25	0.27	0.25
		S-19-4A	174		274		0.16		0.17	
		S-19-5B	209		324		0.30		0.30	
S-20	5	S-20-3B	1838	1995	2046	2203	0.15	0.17	0.15	0.17
		S-20-4A	2070		2281		0.17		0.17	
		S-20-4B	2077		2283		0.19		0.19	
	25	S-20-3B	493	578	736	882	0.19	0.22	0.19	0.23
		S-20-4A	653		1004		0.20		0.20	
		S-20-4B	588		907		0.28		0.29	
	40	S-20-3B	141	131	224	210	0.24	0.28	0.25	0.29
		S-20-4A	132		205		0.26		0.28	
		S-20-4B	122		199		0.34		0.35	

Table 5-3. Summary of Tensile Strength Test Results

Series	Mix Design	Size	Type	Load Level	Specimen	Height (in.)	V_a	Applied Load (lbs)	Strength (psi)
S-1	SP 03-2460A	12.5		C	S-1-2B	1.145	3.8	1631	152.1
					S-1-5B	1.205	3.8	1464	129.7
S-2	LD 00-2502A	12.5	Fine	D	S-2-11B	2.55	3.9	4808	201.3
					S-2-12A	2.54	4.0	4988	209.6
S-3	LD 02-2529A	12.5	Coarse	D	S-3-8A	2.56	2.71	3884	162.0
					S-3-9B	2.56	2.6	4023	167.8
S-4	SP 02-2180A	9.5	Fine	B	S-4-13A	2.54	3.9	4414	185.5
					S-4-14A	2.56	3.6	4509	188.0
S-5	SP 03-2921A	9.5	Coarse	D	S-5-3	2.57	3.7	3442	143.0
S-6	SP 03-2922A	19.0	Coarse	D	S-6-5A	2.53	4.1	2734	115.4
S-7	SP 04-3034A	12.5	Coarse	D	S-7-6A	2.48	4.7	2925	125.9
S-8	SP 03-2610A	12.5	Fine	C	S-8-4B	2.59	4.7	3255	134.2
S-9	SP 03-2627A	12.5	Fine	C	S-9-5A	2.056	3.6	4434	230.2
S-10	SP 04-3225A	12.5	Fine	C	S-10-6B	2.48	4.0	4429	190.6
S-11	SP 02-2194A	12.5	Coarse	D	S-11-3A	2.39	4.6	2235	99.8
					S-11-3B	2.47	3.9	2038	88.1
					S-11-4A	2.43	4.8	2181	95.8
					S-11-4B	2.48	3.8	2018	86.9
					S-11-6A	2.42	4.2	2505	110.5
					S-11-6B	2.44	4.0	2536	110.9

Table 5-3. Summary of Tensile Strength Test Results (Cont.)

Series	Mix Design	Size	Type	Load Level	Specimen	Height (in.)	V_a	Applied Load (lbs)	Strength (psi)
S-12	SP 03-2452A	12.5	Coarse	D	S-12-3A	2.35	4.5	2038	92.6
					S-12-3B	2.4	3.6	2181	97.0
					S-12-4A	2.34	4.4	2018	92.1
					S-12-4B	2.42	4.3	2116	93.3
					S-12-5A	2.38	4.9	2068	92.8
S-13	SP 03-2941A	19.0	Fine	C	S-13-2A	2.57	4.4	2695	111.9
					S-13-3A	2.57	4.4	2695	111.9
S-14	SP 03-2351A	12.5	Fine	B	S-14-2	2.5	4.4	2836	121.1
					S-14-3B	2.74	5.1	3973	154.8
S-15	SP 05-4015A	12.5	Fine	C	S-15-2	2.53	3.8	4800	202.5
					S-15-4A	2.54	4.1	4982	209.4
S-16	SPM 05-4044A	9.5	Fine	B	S-16-2	2.5	3.7	4956	211.6
					S-16-3B	2.48	4.3	4907	211.2
S-17	SPM 05-4051A	9.5	Fine	C	S-17-4A	2.76	4.1	6375	246.6
S-18	SP 05-4061A	12.5	Fine (RAP)	C	S-18-4B	2.72	3.6	8952	351.3
S-19	SP 05-4100A	12.5	Fine	C	S-19-5B	2.54	3.1	4946	207.9
S-20	SP 02-2052A	12.5	FC	C	S-20-4A	2.59	3.1	4788	197.3

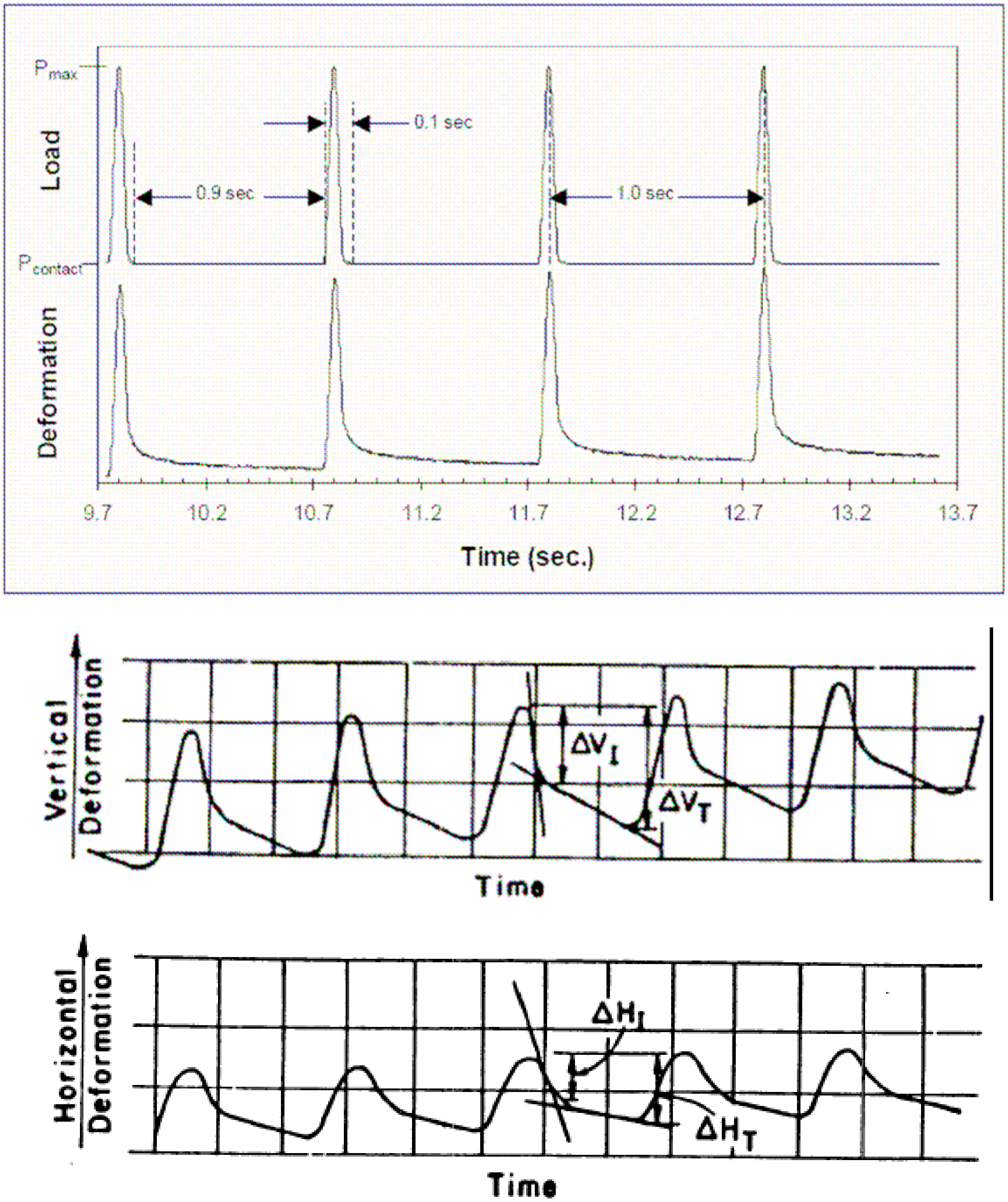


Figure 5-1. Load, Deformations (Vertical and Horizontal)

versus Time Relationship in a Repeated-Load Indirect Tension Test

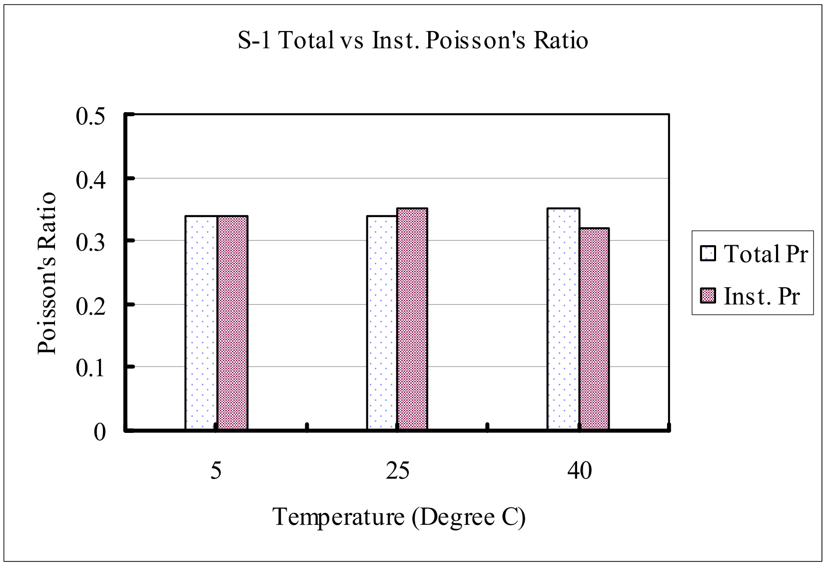


Figure 5-2. Total vs. Inst. Poisson’s Ratio for S-1 Mixture (RAP & Ga-553)

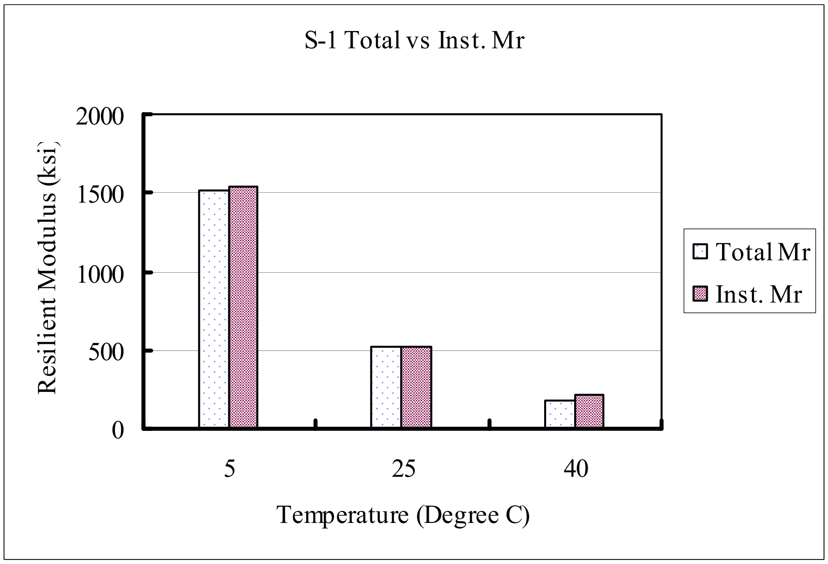


Figure 5-3. Total vs. Inst. MR for S-1 Mixture (RAP & Ga-553)

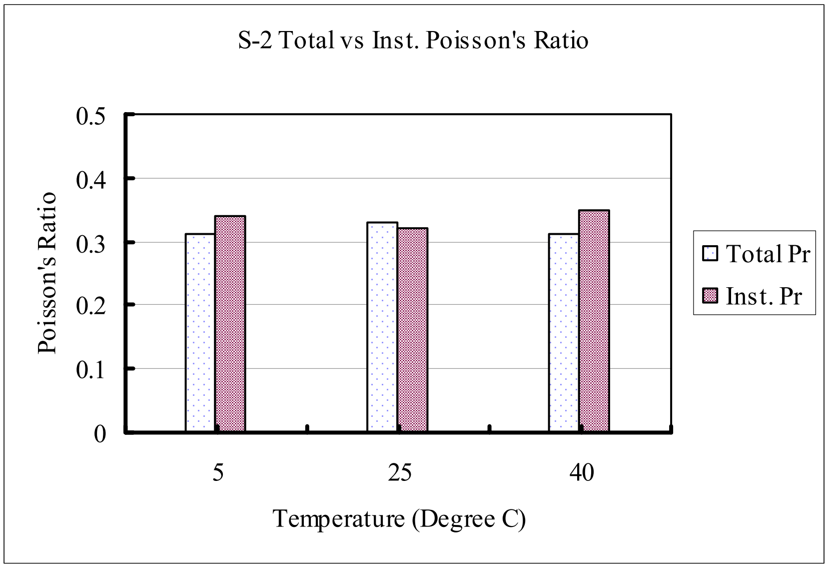


Figure 5-4. Total vs. Inst. Poisson’s Ratio for S-2 Mixture (CFL)

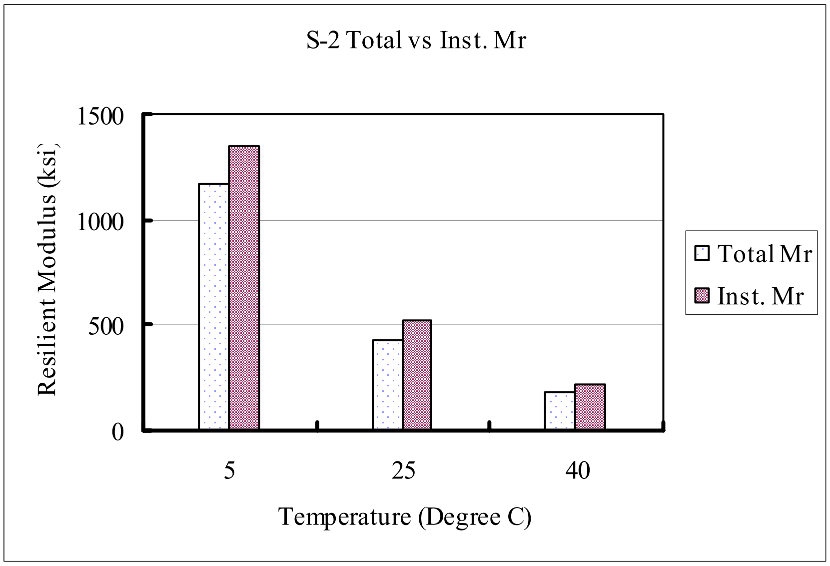


Figure 5-5. Total vs. Inst. MR for S-2 Mixture (CFL)

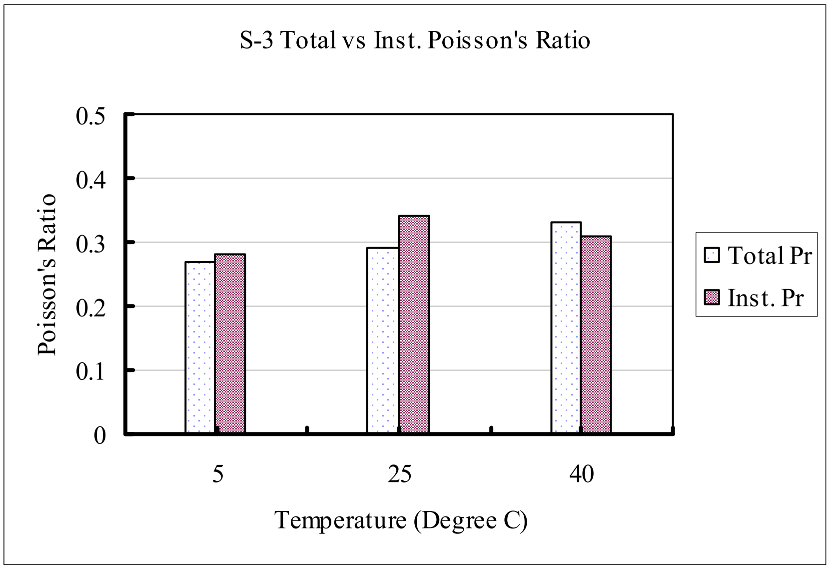


Figure 5-6. Total vs. Inst. Poisson’s Ratio for S-3 Mixture (CFL)

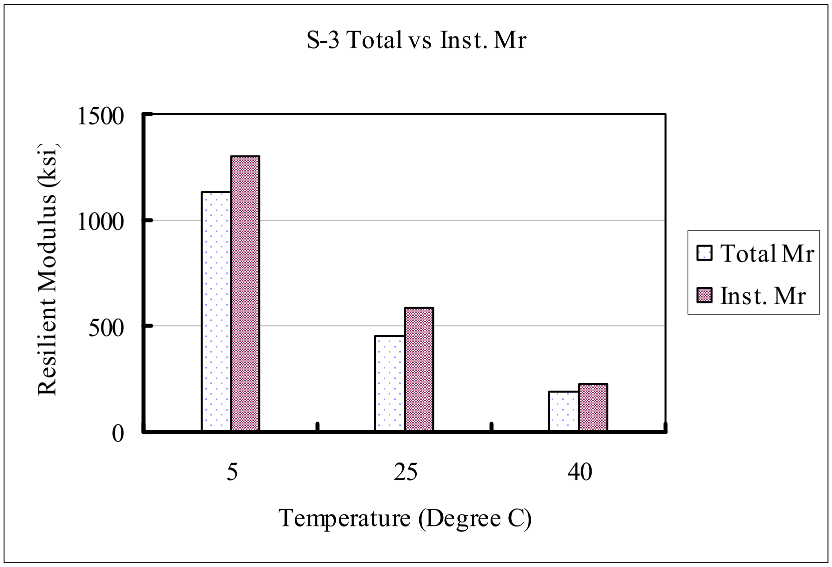


Figure 5-7. Total vs. Inst. MR for S-3 Mixture (CFL)

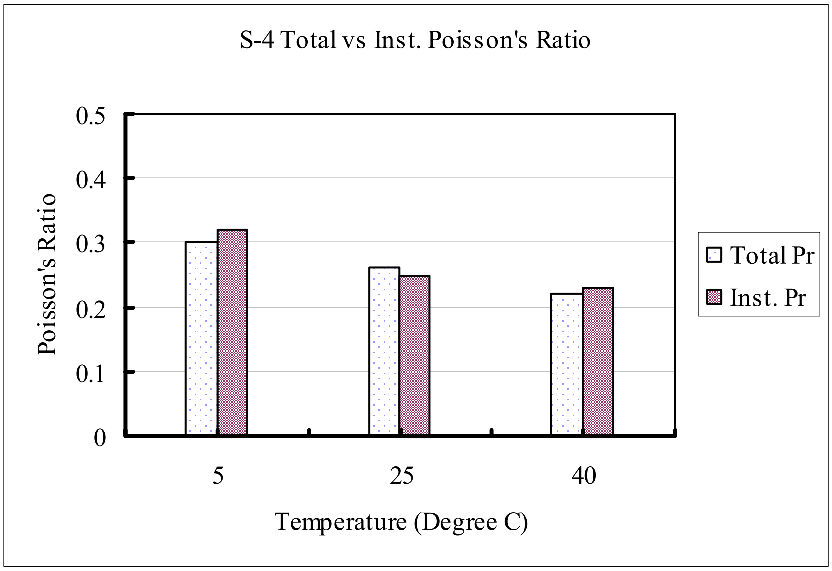


Figure 5-8. Total vs. Inst. Poisson’s Ratio for S-4 Mixture (Ga-553)

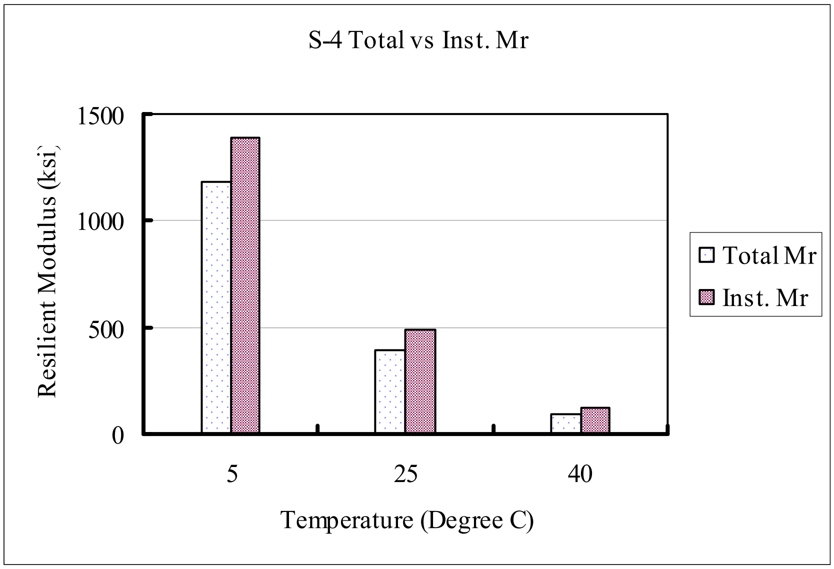


Figure 5-9. Total vs. Inst. MR for S-4 Mixture (Ga-553)

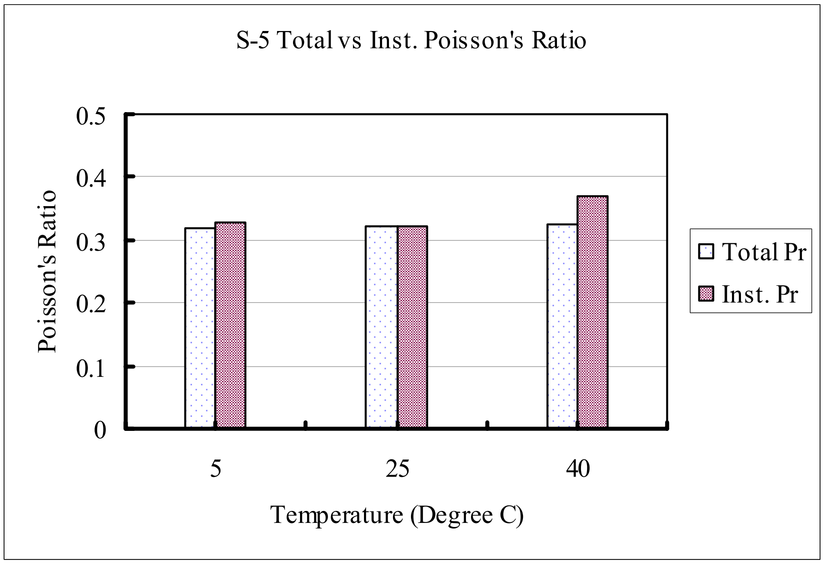


Figure 5-10. Total vs. Inst. Poisson’s Ratio for S-5 Mixture (Ga-553)

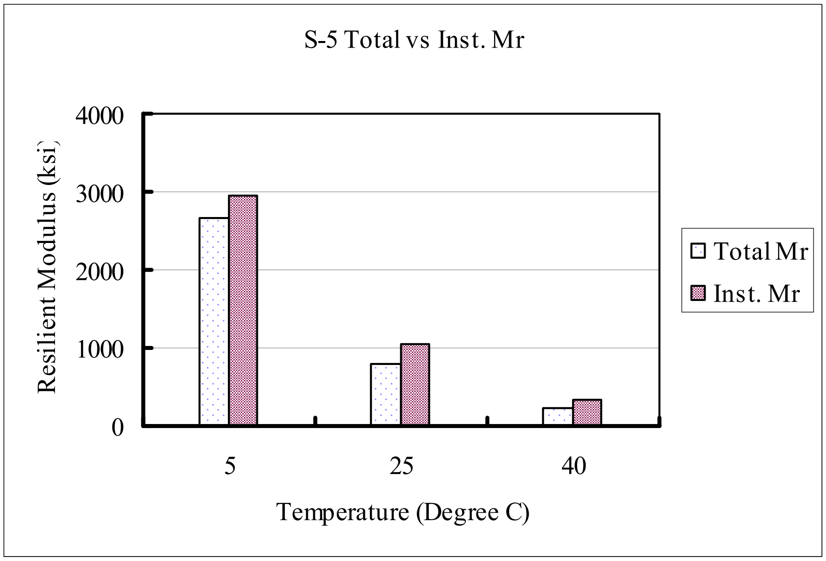


Figure 5-11. Total vs. Inst. MR for S-5 Mixture (Ga-553)

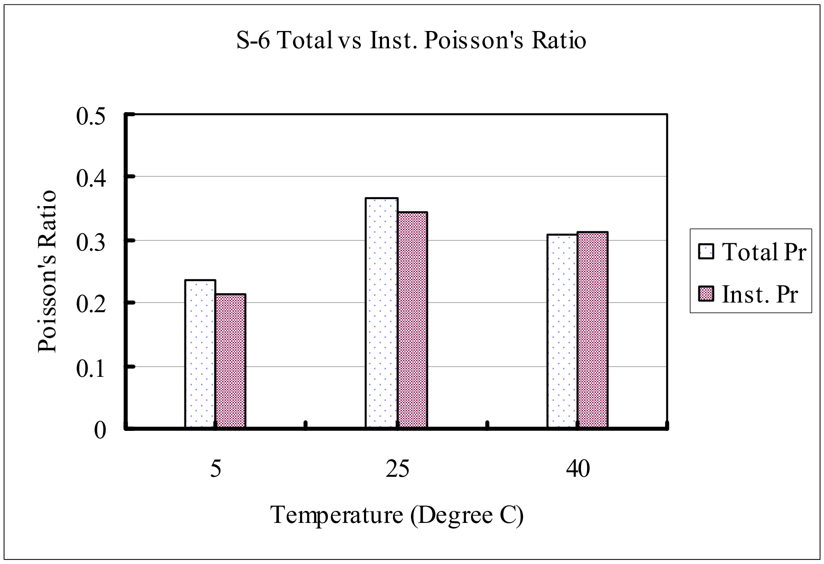


Figure 5-12. Total vs. Inst. Poisson’s Ratio for S-6 Mixture (Ga-553)

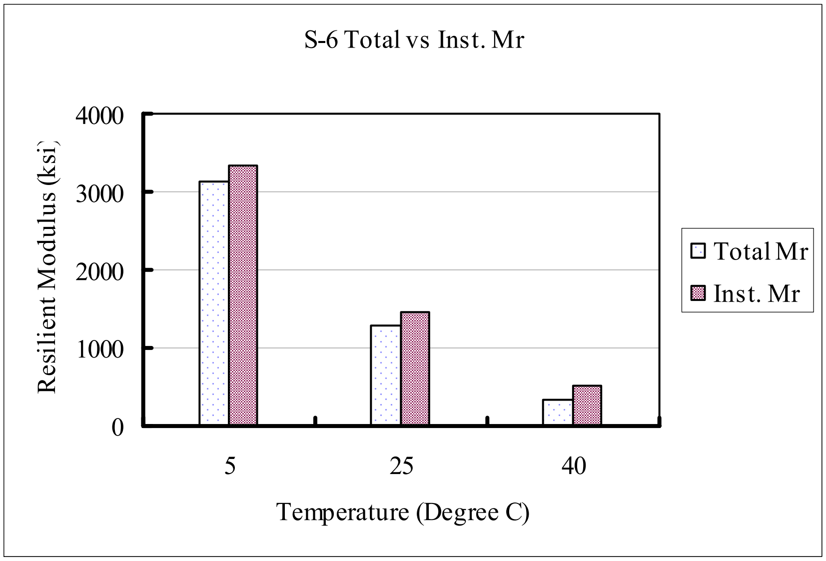


Figure 5-13. Total vs. Inst. MR for S-6 Mixture (Ga-553)

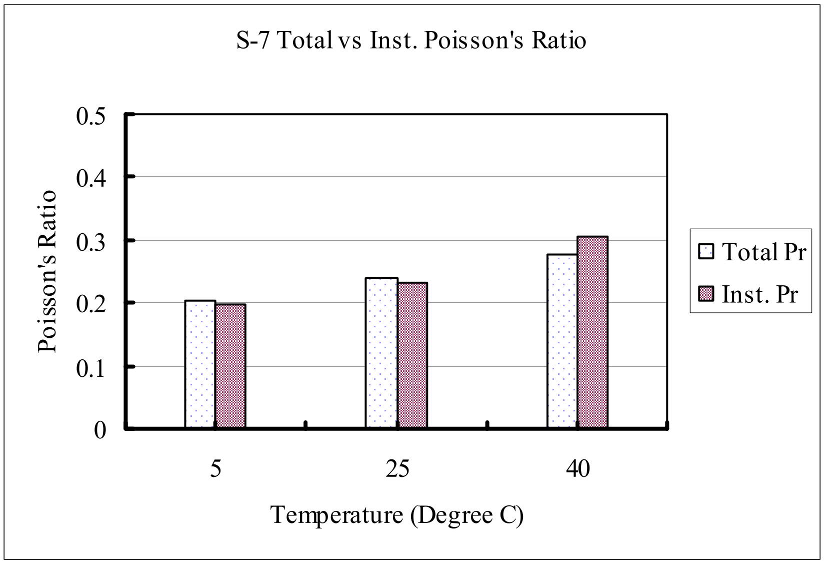


Figure 5-14. Total vs. Inst. Poisson’s Ratio for S-7 Mixture (Ga-553)

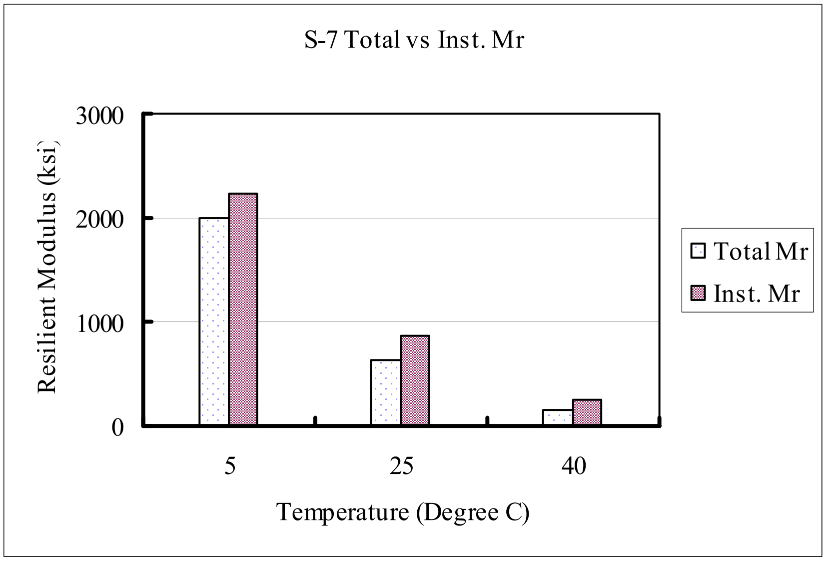


Figure 5-15. Total vs. Inst. MR for S-7 Mixture (Ga-553)

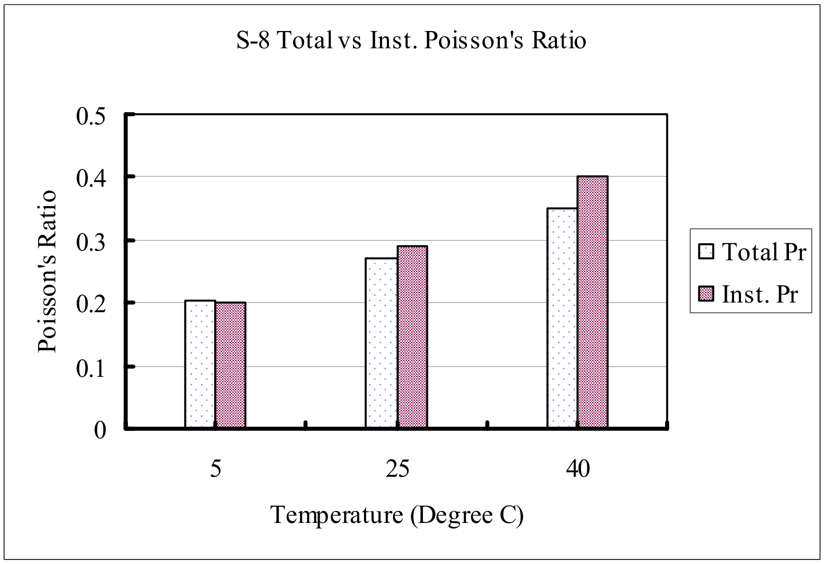


Figure 5-16. Total vs. Inst. Poisson’s Ratio for S-8 Mixture (AL)

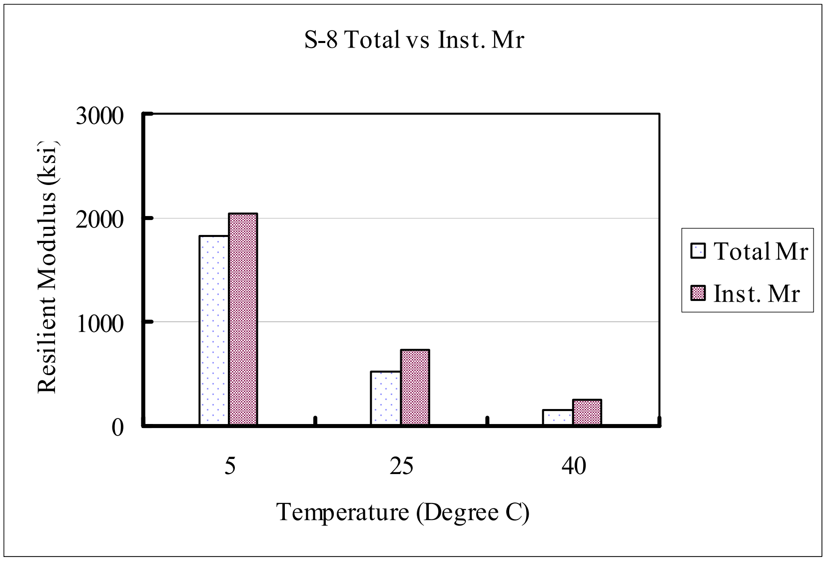


Figure 5-17. Total vs. Inst. MR for S-8 Mixture (AL)

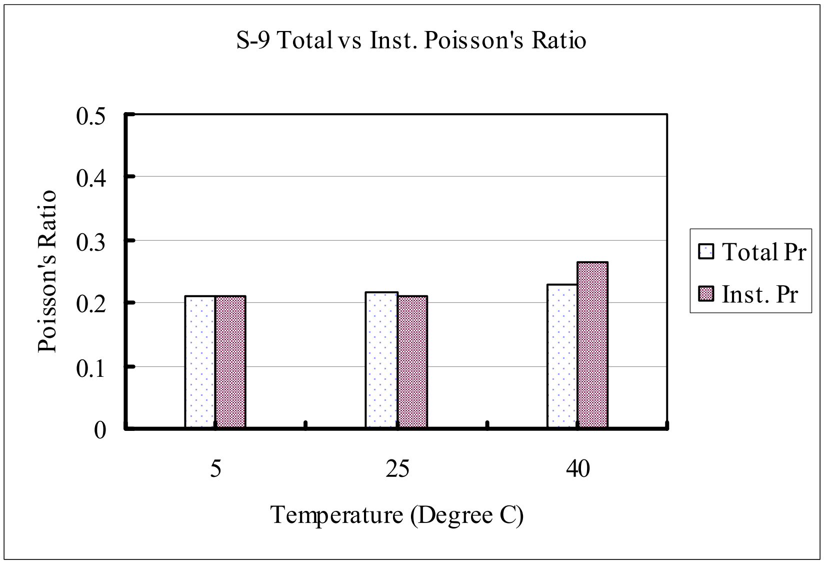


Figure 5-18. Total vs. Inst. Poisson’s Ratio for S-9 Mixture (SFOO)

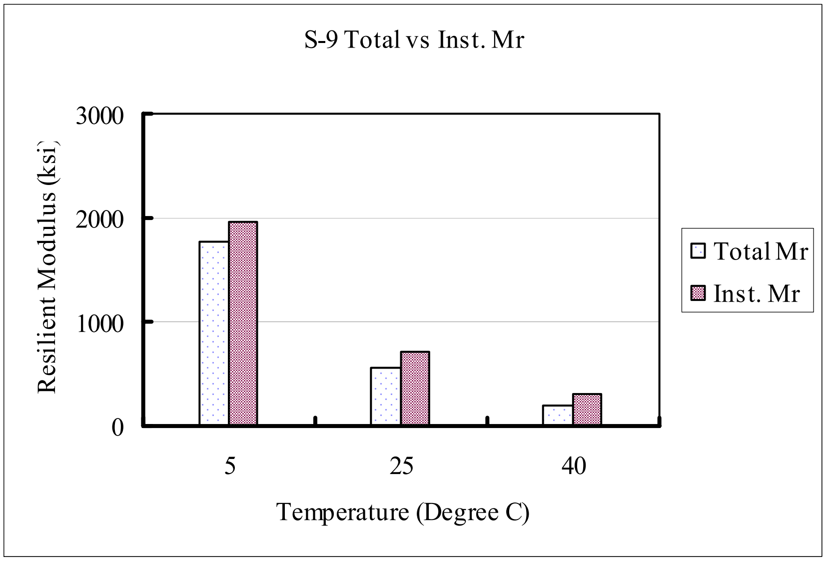


Figure 5-19. Total vs. Inst. MR for S-9 Mixture (SFOO)

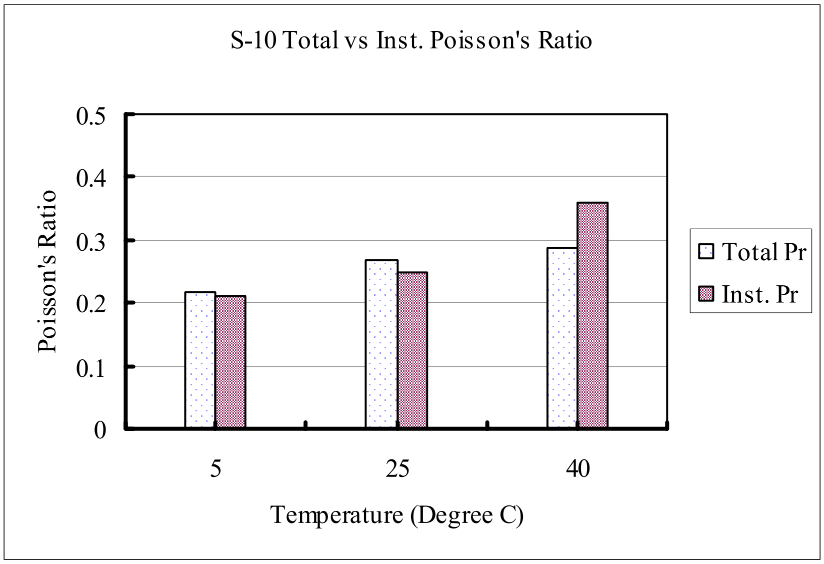


Figure 5-20. Total vs. Inst. Poisson’s Ratio for S-10 Mixture (Ga-553 & GA-206)

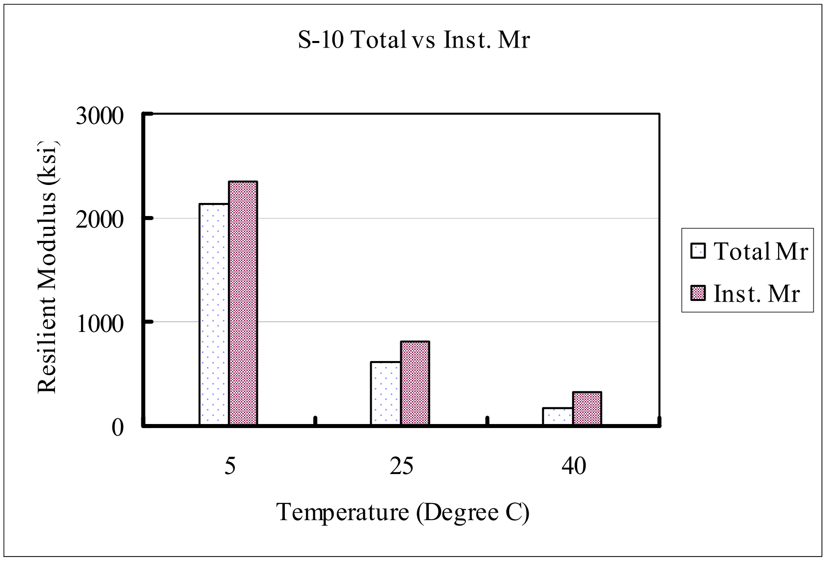


Figure 5-21. Total vs. Inst. MR for S-10 Mixture (Ga-553 & Ga-206)

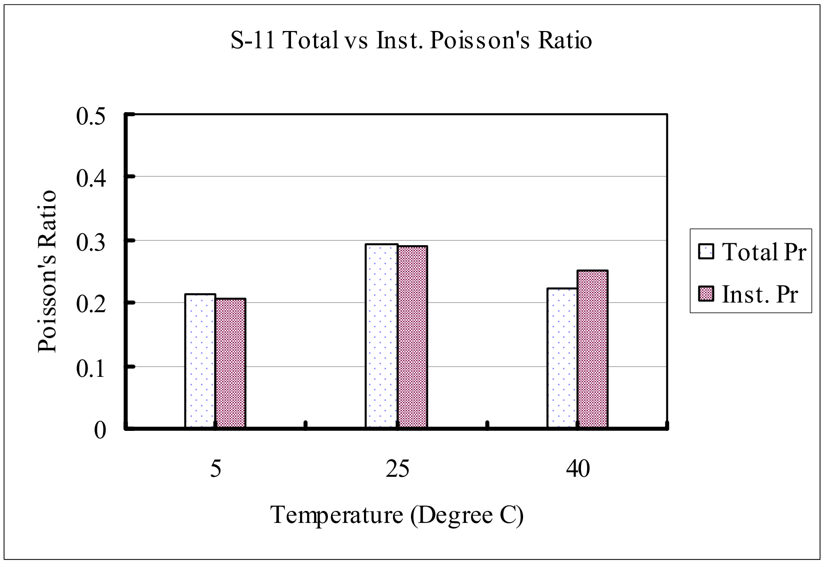


Figure 5-22. Total vs. Inst. Poisson’s Ratio for S-11 Mixture (NS)

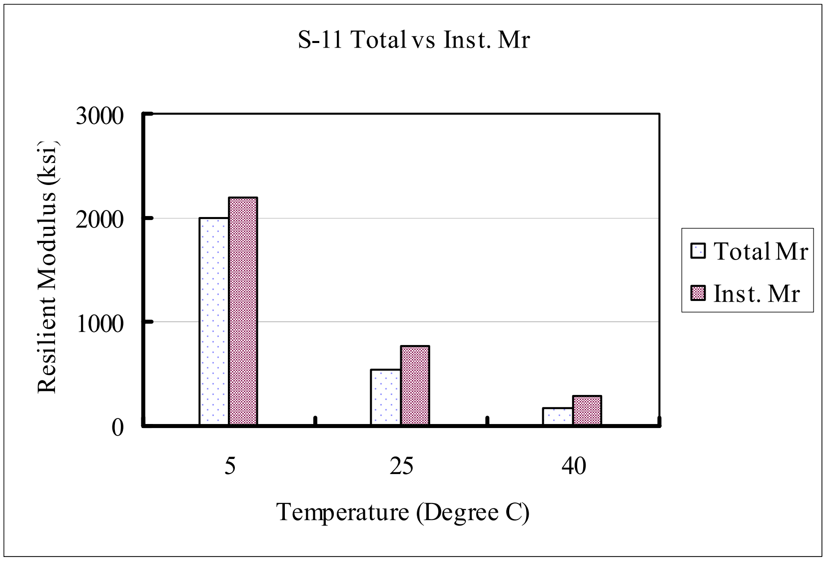


Figure 5-23. Total vs. Inst. MR for S-11 Mixture (NS)

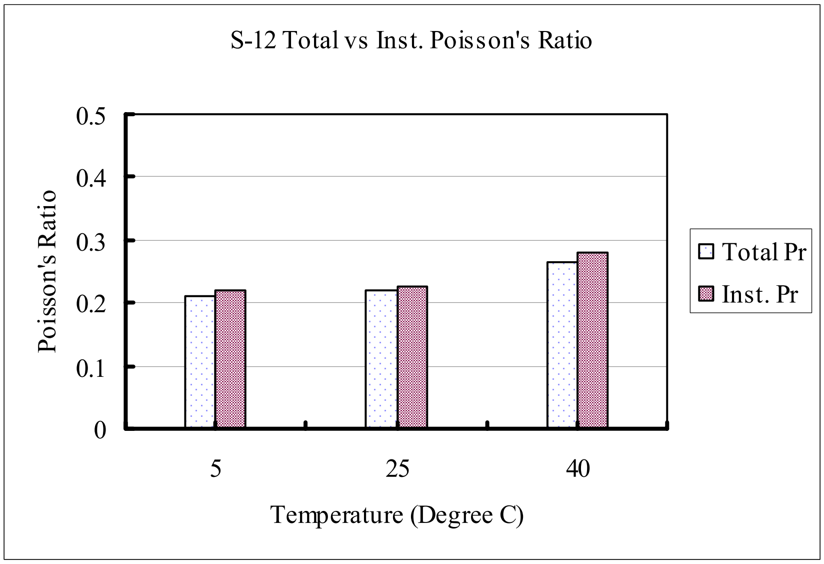


Figure 5-24. Total vs. Inst. Poisson’s Ratio for S-12 Mixture (Ga-553)

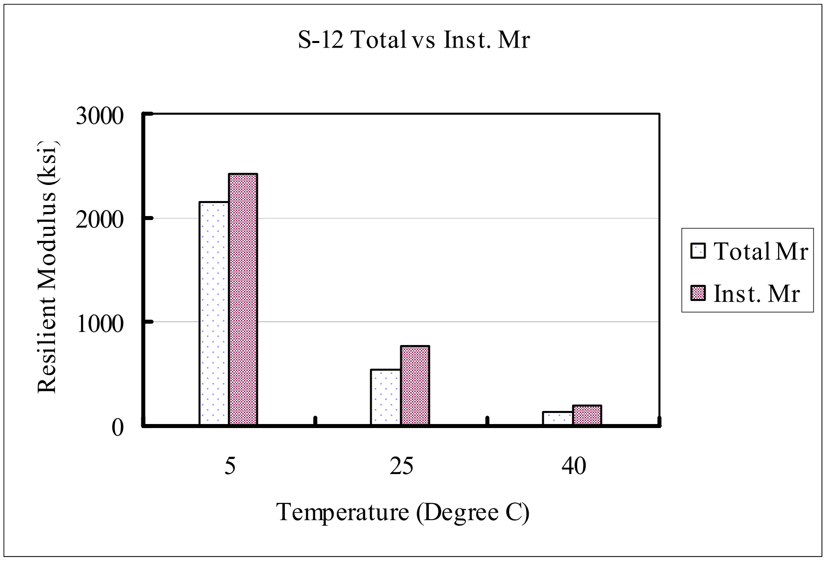


Figure 5-25. Total vs. Inst. MR for S-12 Mixture (Ga-553)

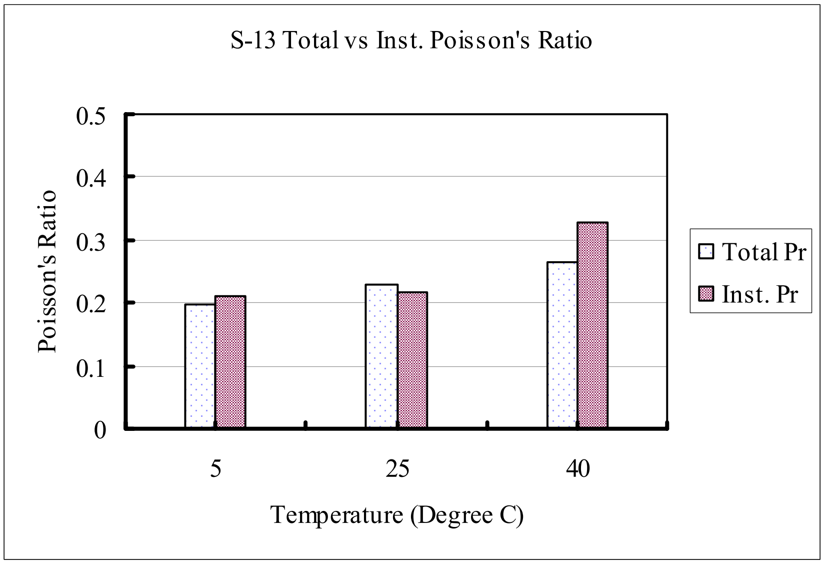


Figure 5-26. Total vs. Inst. Poisson's Ratio for S-13 Mixture (Ga-553)

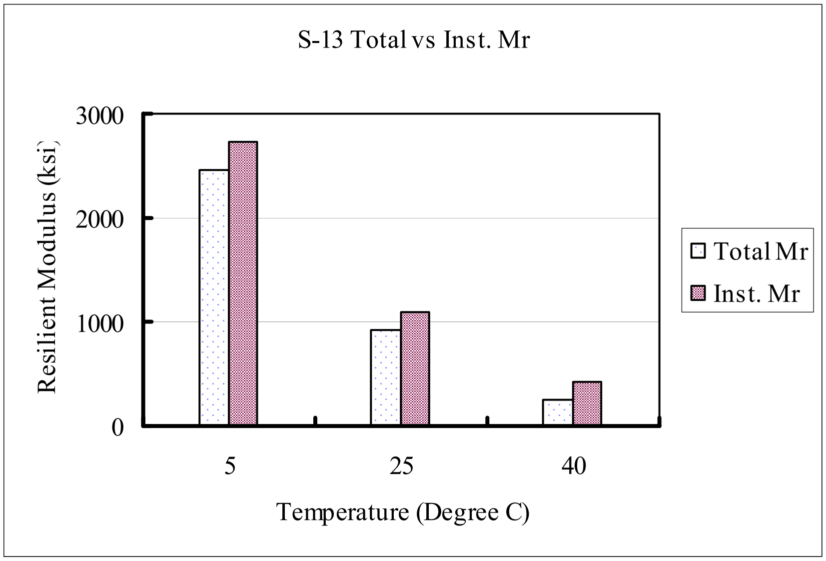


Figure 5-27. Total vs. Inst. MR for S-13 Mixture (Ga-553)

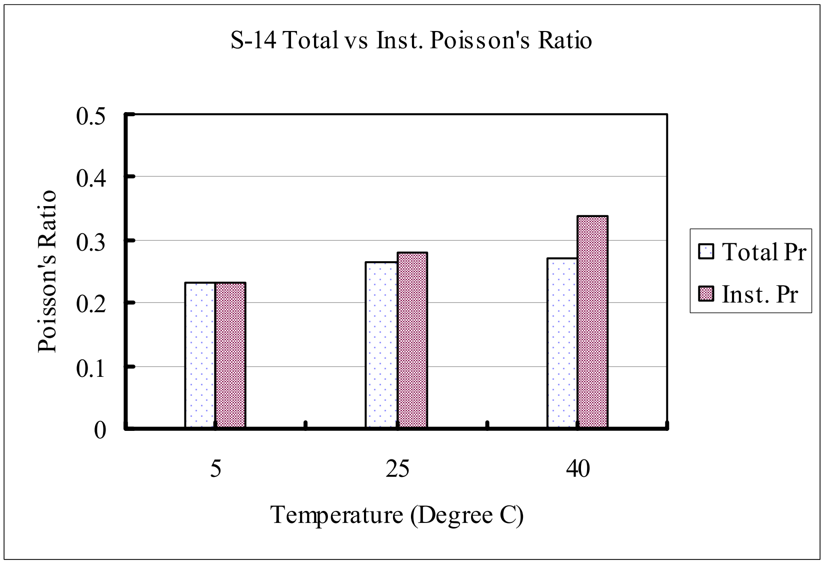


Figure 5-28. Total vs. Inst. Poisson's Ratio for S-14 Mixture (Ga-553)

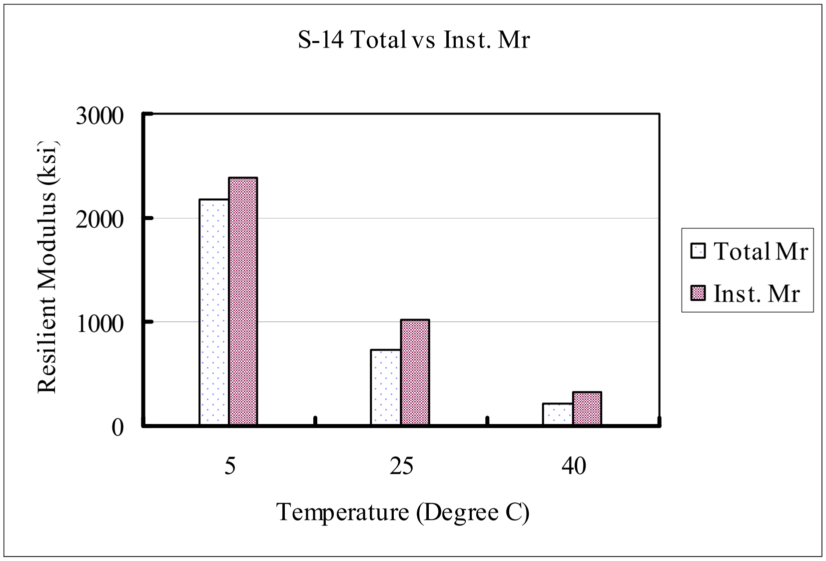


Figure 5-29. Total vs. Inst. MR for S-14 Mixture (Ga-553)

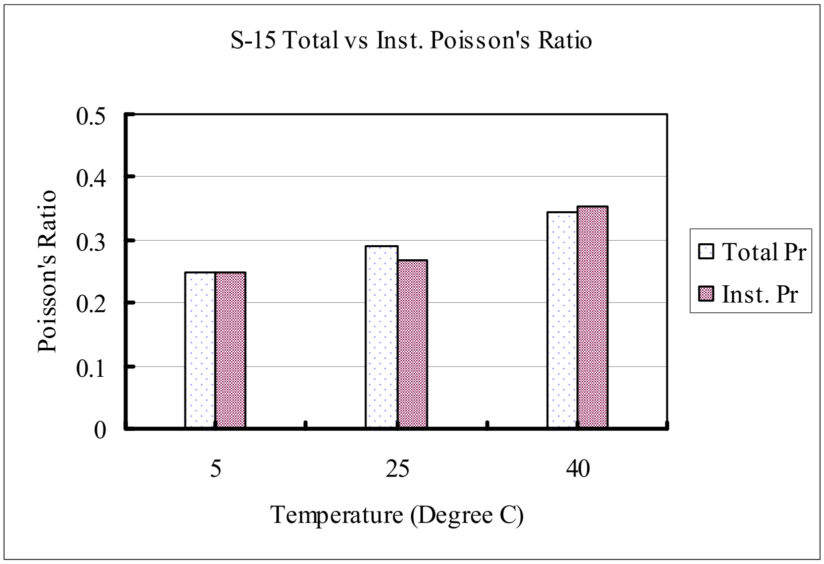


Figure 5-30. Total vs. Inst. Poisson’s Ratio for S-15 Mixture (Ga-553)

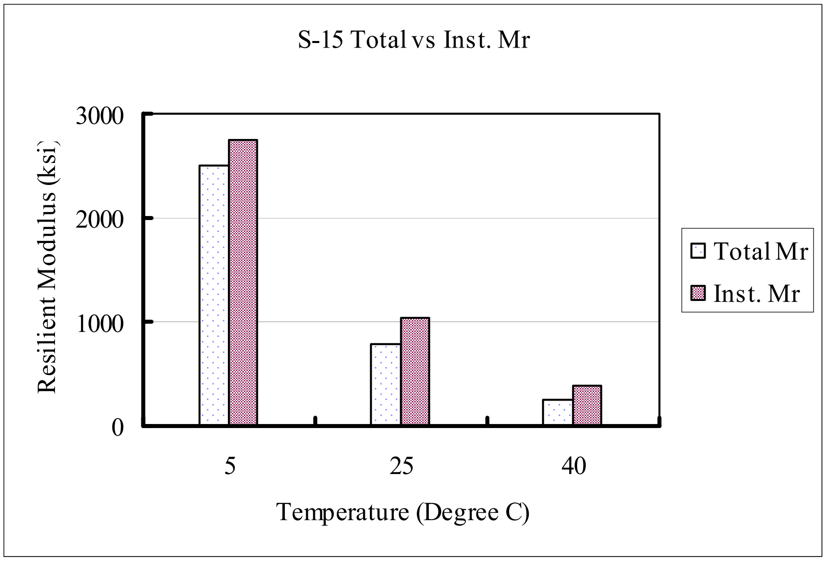


Figure 5-31. Total vs. Inst. MR for S-15 Mixture (Ga-553)

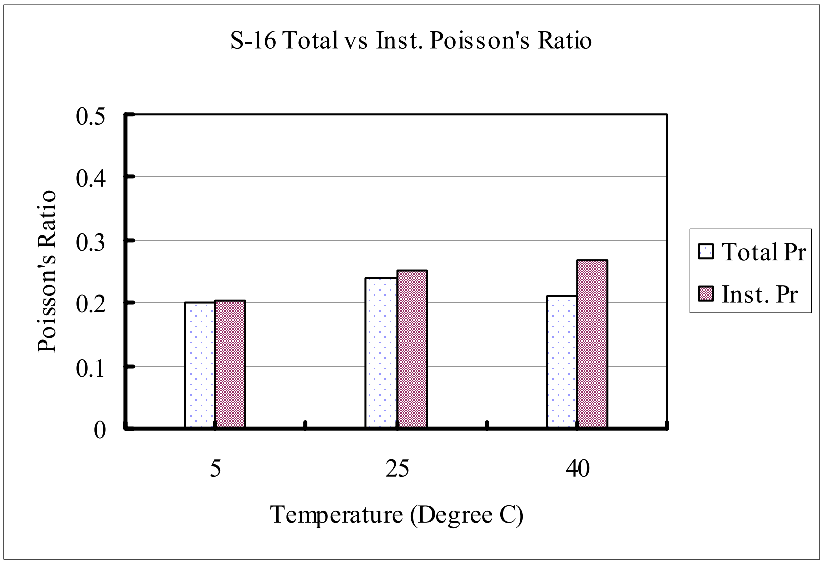


Figure 5-32. Total vs. Inst. Poisson's Ratio for S-16 Mixture (Ga-553)

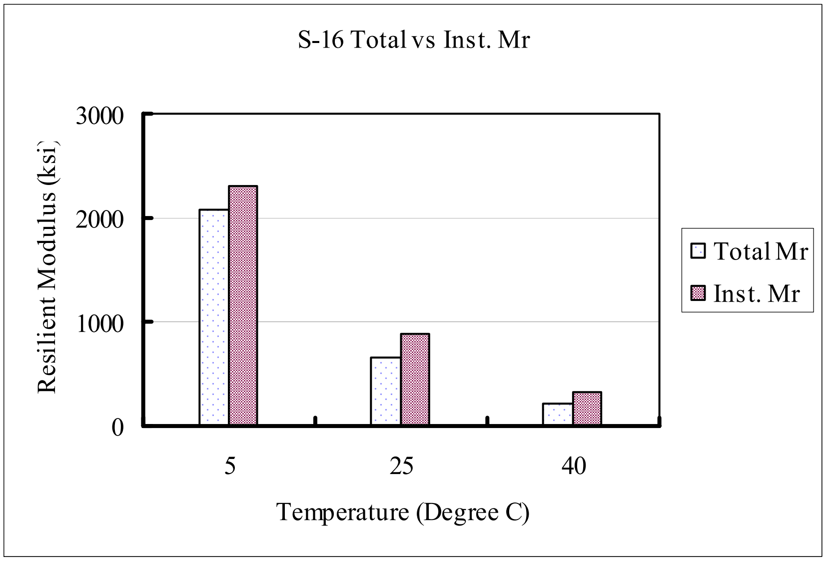


Figure 5-33. Total vs. Inst. MR for S-16 Mixture (Ga-553)

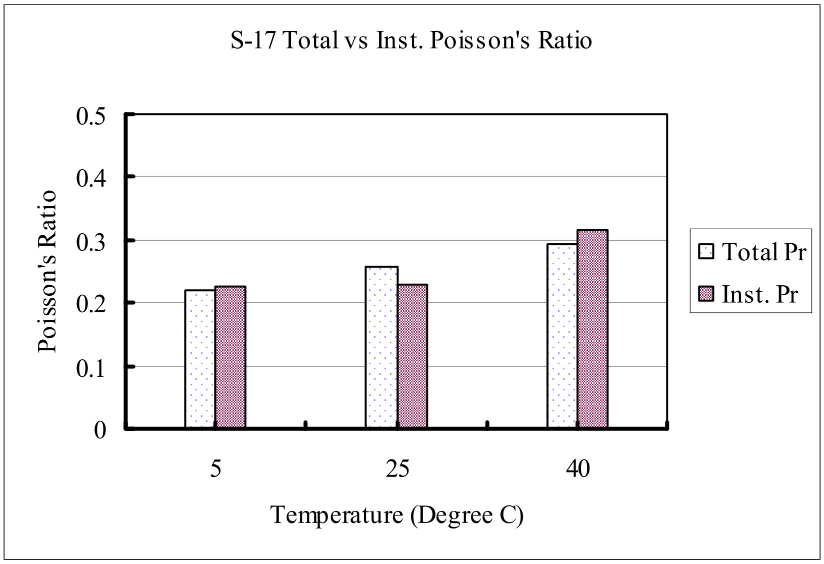


Figure 5-34. Total vs. Inst. Poisson’s Ratio for S-17 Mixture (Ga-553)

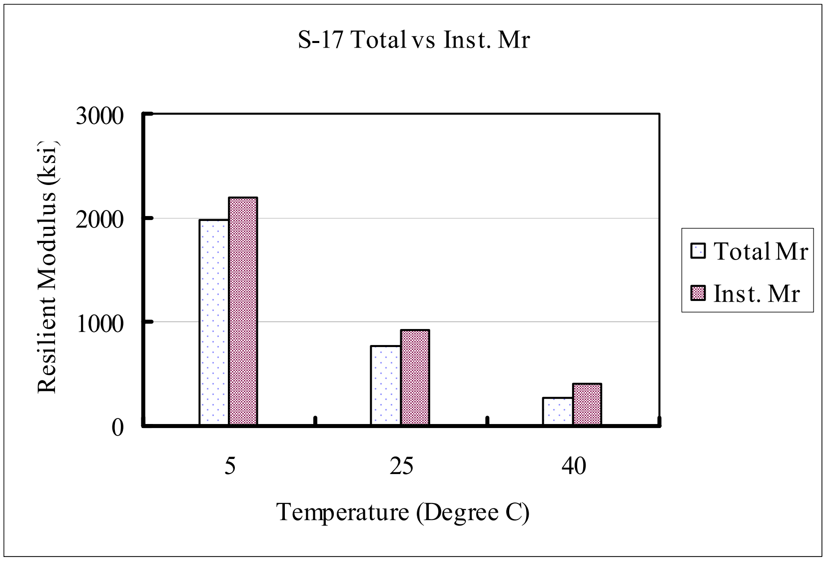


Figure 5-35. Total vs. Inst. MR for S-17 Mixture (Ga-553)

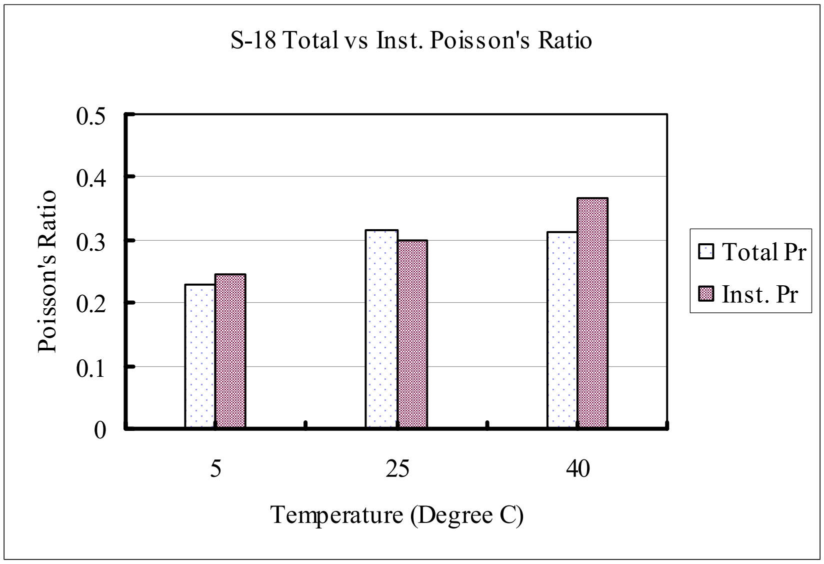


Figure 5-36. Total vs. Inst. Poisson's Ratio for S-18 Mixture (RAP & NFL)

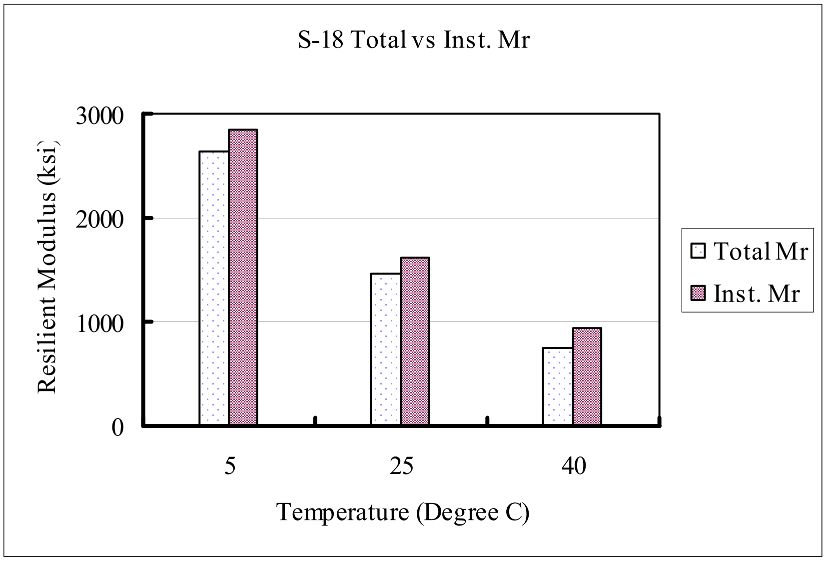


Figure 5-37. Total vs. Inst. MR for S-18 Mixture (RAP & NFL)

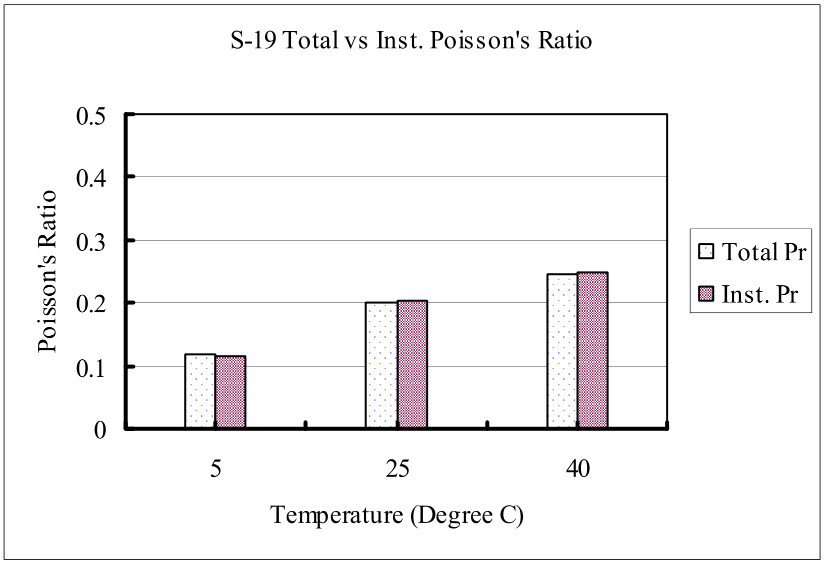


Figure 5-38. Total vs. Inst. Poisson’s Ratio for S-19 Mixture (Ga-553)

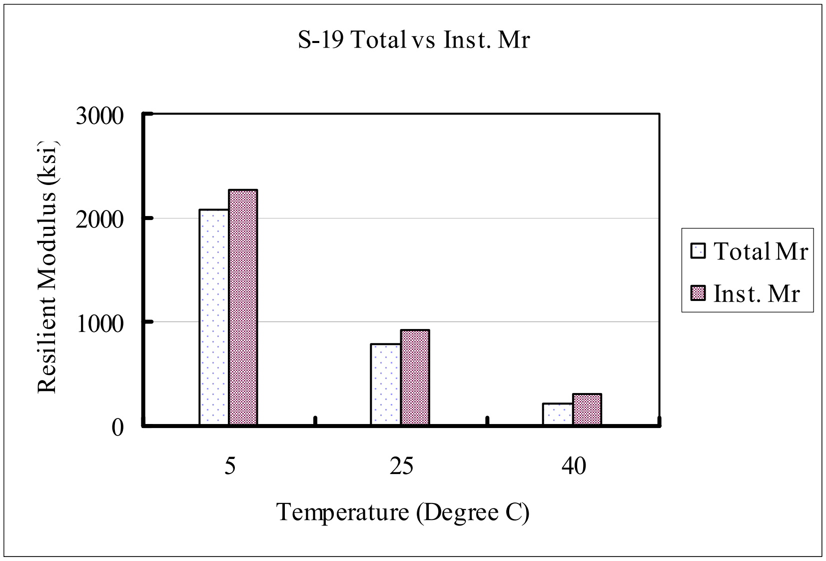


Figure 5-39. Total vs. Inst. MR for S-19 Mixture (Ga-553)

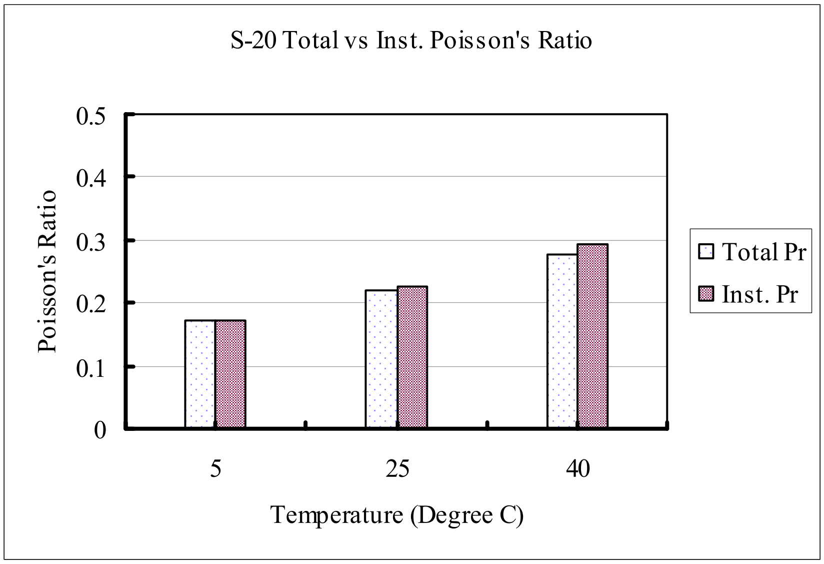


Figure 5-40. Total vs. Inst. Poisson’s Ratio for S-20 Mixture (Ga-553)

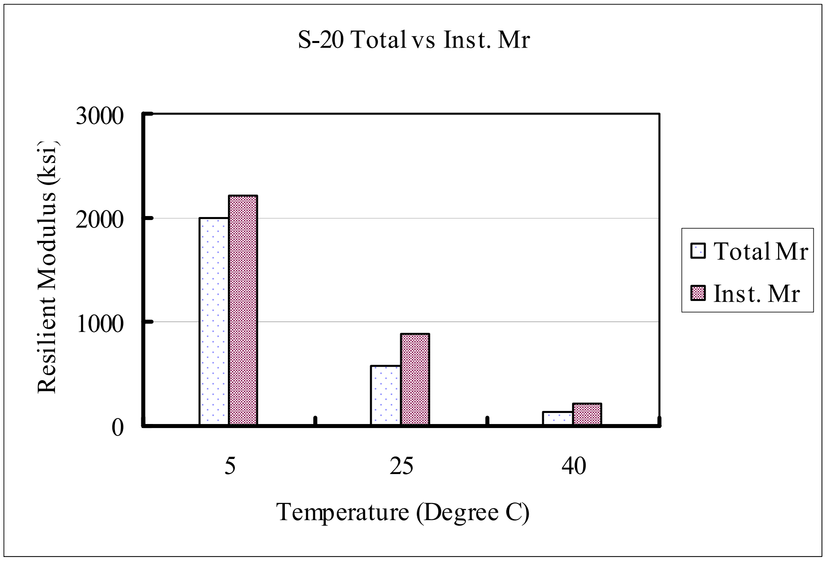


Figure 5-41. Total vs. Inst. MR for S-20 Mixture (Ga-553)

CHAPTER 6

PERSENTATION OF THE DYNAMIC COMPLEX MODULUS TEST RESULTS

6.1 General

The dynamic complex modulus test results are presented in this chapter. All 20 mixtures were tested at three temperature levels: 5, 25, and 40°C (41, 77, and 104°F). For all temperatures tested, the following frequencies were used: 25, 10, 5, 1, and 0.5 Hz. The tests were conducted from the lowest temperature to the highest temperature and from the highest frequency to the lowest frequency, as explained in Chapter 4. All of the dynamic modulus and phase angle test results are summarized in a table and shown in figures. The data processing procedures are described as follows.

6.2 DMT Testing Data Processing

In the National Cooperative Highway Research Program (NCHRP) Project 9-29, “Simple Performance Tester for Superpave Mix Design”, the computations for processing raw data of dynamic modulus testing were described. The related data processing procedures are summarized as follows.

The data produced from the dynamic modulus test at frequency ω_0 will be in the form of several arrays, one for time $[t_i]$, one for each of the $j = 1,\ 2,\ \ldots m$ transducers used $[y_j]$. In the typical arrangement, there will be $m = 3$ transducers: the first transducer will be a load cell, and transducers 2 and 3 will be specimen deformation transducers. However, this approach is general and can be adapted to any number of specimen deformation transducers. The number of $i = 1,\ 2,\ \ldots n$ points in each array will be equal to 500 based on the number of cycles and the acquisition rate. It has been assumed in this procedure that the load will be given in Newtons (N), and the deformations in millimeters (mm). The analysis has been devised to provide complex modulus in units of Pascals (1 Pa = 1 N/m^2) and phase angle in units of degrees. The general approach used here is based upon the least square fit of sinusoid, as described by Chapra and Canale in Numerical Methods for Engineers (McGraw-Hill, 1985, pp. 404-407). However, the approach used is more rigorous, and also includes provisions for estimation drift of the sinusoid over time by including another variable in the regression function. Regression is used, rather than the Fast Fourier Transform (FFT). The regression approach also lends itself to calculating standard errors and other indicators of data quality. This approach should however produce results essentially identical to those produced using FFT analysis.

There was a huge amount of data obtained from the complex modulus test. For each sample at a given temperature and frequency, 10 cycles consisting of 1000 points were analyzed to obtain the dynamic modulus and phase angle. The axial strain was assumed to consist of a linear trend with a sinusoidal wave around the trend.

The calculation proceeded as follows. First, the data for each transducer were centered by subtracting from the measured data the average for that transducer:

$$Y_{ji}^{\prime} = Y_{ji} - \overline{Y}_j \qquad (6\text{-}1)$$

Where:

$Y_{ji}^{\prime}$ = centered data for transducer j at point i in data array

Y_{ji} = raw data for transducer j at point i in data array

$\overline{Y}_j$ = average for transducer j

In the second step in the procedure, the $[X'X]$ matrix was constructed as follows:

$$[X'X] = \begin{bmatrix} N & \sum_{i=1}^{n} t_i & \sum_{i=1}^{n} \cos(\omega_0 \cdot t_i) & \sum_{i=1}^{n} \sin(\omega_0 \cdot t_i) \\ \sum_{i=1}^{n} t_i & \sum_{i=1}^{n} t_i^2 & \sum_{i=1}^{n} t_i \cdot \cos(\omega_0 \cdot t_i) & \sum_{i=1}^{n} t_i \cdot \sin(\omega_0 \cdot t_i) \\ \sum_{i=1}^{n} \cos(\omega_0 \cdot t_i) & \sum_{i=1}^{n} t_i \cdot \cos(\omega_0 \cdot t_i) & \sum_{i=1}^{n} \cos^2(\omega_0 \cdot t_i) & \sum_{i=1}^{n} \sin(\omega_0 \cdot t_i) \cdot \cos(\omega_0 \cdot t_i) \\ \sum_{i=1}^{n} \sin(\omega_0 \cdot t_i) & \sum_{i=1}^{n} t_i \cdot \sin(\omega_0 \cdot t_i) & \sum_{i=1}^{n} \sin(\omega_0 \cdot t_i) \cdot \cos(\omega_0 \cdot t_i) & \sum_{i=1}^{n} \sin^2(\omega_0 \cdot t_i) \end{bmatrix} \quad (6\text{-}2)$$

Where N is the total number of data points, ω_0 is the frequency of the data, t is the time from the start of the data array, and the summation is carried out over all points in the data array.

The inverse of this matrix, $[X'X]^{-1}$, was then calculated. Then for each transducer, the $[X'Y_j]$ array was constructed:

$$[X'Y_j] = \begin{bmatrix} \sum_{i=1}^{n} Y_{ji}^{'} \\ \sum_{i=1}^{n} Y_{ji}^{'} \cdot t \\ \sum_{i=1}^{n} Y_{ji}^{'} \cdot \cos(\omega_0 \cdot t) \\ \sum_{i=1}^{n} Y_{ji}^{'} \cdot \sin(\omega_0 \cdot t) \end{bmatrix} \quad (6\text{-}3)$$

Where Y_j represents the output from one of the three transducers ($j = 1$ for the load cell, $j = 2$ *and* 3 for the two deformation transducers). Again, the summation was carried out for all points in the data arrays.

The array representing the regression coefficients for each transducer was then calculated by multiplying the $[X'X]^{-1}$ matrix by the $[X'Y_j]$ matrix:

$$\begin{bmatrix} A_{j0} \\ A_{j1} \\ A_{j2} \\ B_{j2} \end{bmatrix} = [X'X]^{-1}[X'Y_j] \qquad (6\text{-}4)$$

Where the regression coefficient can be used to calculate predicted values for each of the j transducers using the regression function:

$$\hat{Y}_{ji} = A_{j0} + A_{j1} \cdot t_i + A_{j2} \cdot \cos(\omega_0 \cdot t_i) + B_{j2} \cdot \sin(\omega_0 \cdot t_i) + \varepsilon_{ji} \qquad (6\text{-}5)$$

Where $\hat{Y}_{ji}$ is the predicted value for the i^{th} point of data for the j^{th} transducer, and ε_{ji} represents the error term in the regression function.

From the regression coefficients, several other functions were then calculated as follows:

$$\theta_j = \arctan(-\frac{B_{j2}}{A_{j2}}) \qquad (6\text{-}6)$$

$$| Y_j^* | = \sqrt{A_{j2}^2 + B_{j2}^2} \qquad (6\text{-}7)$$

$$\Delta Y_j = \frac{A_{j1} t_N}{| Y_j^* |} \times 100\% \qquad (6\text{-}8)$$

$$se(Y_j) = \sqrt{\frac{\sum_{i=1}^{n} (\widehat{Y}'_{ji} - Y'_{ji})^2}{n-4}} \cdot \left(\frac{100\%}{| Y_j^* |} \right) \qquad (6\text{-}9)$$

Where:

θ_j = phase angle for transducer j, degrees

$| Y_j^* |$ = amplitude for transducer j, N for load or mm for displacement

ΔY_j = drift for transducer j, as percent of amplitude

t_N = total time covered by data

$\widehat{Y}'_{ji}$ = predicted centered response for transducer j at point i, N or mm

$se(Y_j)$ = standard error for transducer j, %

Y'_{ji} = centered data for transducer j at point i, N or mm

The calculations represented by above equations were carried out for each transducer, typically the load cell, and two deformation transducers. This produced values for the phase angle, and standard errors for each transducer output. The phase angles given by Equation (6-6) represent absolute phase angles, that is, θ_j is an arbitrary value indicating the angle at which the data collection started.

The phase angle of the deformation (response) relative to the load (excitation) is the important mechanical property. To calculate this phase angle, the average phase angle for the deformation was first calculated:

$$\overline{\theta}_D = \frac{\sum_{j=2}^{m} \theta_j}{m-1} \tag{6-10}$$

Where $\overline{\theta}_D$ is the average absolute phase angle for the deformation transducers, and θ_j is the phase angle for each of the $j = 2,\ 3,\ \ldots m$ deformation transducers. For the typical case, there were one load cell and two deformation transducers, so $m = 3$, and Equation (6-10) simply involved summing the phase angle for the two deformation transducers and dividing by two.

The relative phase angle at frequency ω between the deformation and the load, $\theta(\omega)$, was then calculated as follows:

$$\theta(\omega) = \overline{\theta}_D - \theta_P \tag{6-11}$$

Where θ_P is the absolute phase angle calculated for the load.

A similar set of calculations was needed to calculate the overall modulus for the material. First, the average amplitude for the deformation was calculated:

$$|\overline{Y}_D^*| = \frac{\sum_{j=2}^{m} |Y_j^*|}{m-1} \tag{6-12}$$

Where $|\overline{Y}_D^*|$ represents the average amplitude of the deformations (mm). Then, the dynamic modulus $|E^*|$ at frequency ω was calculated using the following equation:

$$|E^*(\omega)| = \frac{|Y_P^*| \cdot L_g}{|\overline{Y}_D^*| \cdot A} \tag{6-13}$$

Where $|E^*(\omega)|$ is in Pa, L_g is the average gage length for the deformation transducers (mm), and A is the loaded cross-sectional area, m^2.

The final part of the analysis involved calculation of several factors indicative of data quality, including the average drift for the deformations, the average standard error for the deformations, and uniformity coefficients for deformation amplitude and phase:

$$\Delta\overline{Y}_D = \frac{\sum_{j=2}^{m} A_{j1} t_N}{\sum_{j=2}^{m} |Y_j^*|} \times 100\% \tag{6-14}$$

$$se(Y_D) = \frac{\sum_{j=2}^{m} se(Y_j)}{m-1} \tag{6-15}$$

$$U_A = \sqrt{\frac{\sum_{j=2}^{m} (|Y_j^*| - |\overline{Y}_D^*|)^2}{m-1}} \cdot \left(\frac{100\%}{|\overline{Y}_D^*|}\right) \tag{6-16}$$

$$U_\theta = \sqrt{\frac{\sum_{j=2}^{m} (\theta_j - \overline{\theta}_D)^2}{m-1}} \qquad (6\text{-}17)$$

Where:

$\Delta \overline{Y}_D$ = average deformation drift, as percent of average deformation amplitude

$se(Y_D)$ = average standard error for all deformation transducers, %

U_A = uniformity coefficient for deformation amplitude, %

U_θ = uniformity coefficient for deformation phase, degrees

6.3 Data Variables

The test variables obtained from the data acquisition system included the time, axial force, and axial displacement from the LVDTs. The variable time is the time period from the beginning of the test to the data recording time. The axial force is the vertical axial load on the specimen. Three pairs of LVDTs were used for each test, and the average displacements from the LVDTs were calculated. Generally three specimens were tested for each mixture design series, depending on the availability of well prepared specimens with acceptable volumetric properties. All specimens were prepared aiming at four percent air voids plus or minus 0.5 percent. At least two replicate specimens for each mix design were produced meeting the air voids criterion. Under certain test conditions, the axial force was divided by the cross sectional area of the specimen to obtain the actual stress load. Similarly, the LVDT displacements were divided by the axial gauge length to arrive at the axial strain for the test under the same test conditions. For any given test temperature, five data files were acquired for each specimen, with testing frequencies of 25 Hz, 10 Hz, 5 Hz, 1 Hz, and 0.5 Hz, respectively. Table 6-1 shows the specimens tested for the dynamic modulus.

The complex dynamic modulus and phase angle of the HMA change with the temperature and frequency of loading. The dynamic modulus of the asphalt mixtures usually increases as the testing temperature decreases. So it is easier to control the applied axial force to achieve small displacement at low temperatures when the modulus of HMA is high.

6.4 Summary of DMT Data

One test file was obtained for each load frequency and testing temperature. In this file, the dynamic modulus in psi and the phase angle in degrees were obtained for the given test temperature and frequency. There were two or three replicate specimens tested for each asphalt mixture. After all the dynamic modulus and phase angle values were calculated for each specimen under the same test conditions, the average value for both parameters was calculated. Table 6-2 shows the average dynamic modulus values of replicate specimens for each asphalt mixture design series.

The plots of dynamic modulus and phase angle results for all 20 mixture designs are shown in Figures 6-1 through 6-40 at the three different testing temperatures. The phase angles were grouped together and are shown in Figure 6-41 for granite, limestone and RAP materials, respectively, at each testing temperature.

As displayed in the plots, the results clearly show the expected trends of the dynamic modulus and phase angle for asphalt mixtures. In summary, the two variables showed the following trends:

1. The dynamic modulus increased as the test frequency increased under a certain testing temperature.

2. The dynamic modulus increased with a decrease in test temperature under a certain loading frequency.
3. The phase angle increased as the test temperature increased.
4. The phase angle has a decreasing trend with increasing load frequency under a certain temperature. A more complex behavior of the phase angle as a function of the loading frequency was observed at higher temperatures.

These trends are in agreement with the research results reported by others.

Table 6-1. Summary of DMT Specimens

Mixture Series	Specimen #	Air Voids	G_{mb}
S-1	S-1-8	5.2	2.419
	S-1-9	4.5	2.439
	S-1-10	5.0	2.426
S-2	S-2-8	4.3	2.184
	S-2-9	4.1	2.188
	S-2-10	4.5	2.180
S-3	S-3-3	4.2	2.157
	S-3-4	4.3	2.155
S-4	S-4-3	3.9	2.451
	S-4-4	4.6	2.432
	S-4-5	4.4	2.439
S-5	S-5-10	3.7	2.451
	S-5-11	4.3	2.436
S-6	S-6-7	4.2	2.487
	S-6-8	3.5	2.507
S-7	S-7-7	4.4	2.461
	S-7-8	4.4	2.456
	S-7-9	4.4	2.461
S-8	S-8-7	3.3	2.404
	S-8-8	3.5	2.400
	S-8-9	3.5	2.389
S-9	S-9-6	3.4	2.218
	S-9-7	3.4	2.219
	S-9-8	3.9	2.208
S-10	S-10-7	3.8	2.456
	S-10-8	3.9	2.453
	S-10-9	3.9	2.454

Table 6-1. Summary of DMT Specimens (Cont.)

Mixture Series	Specimen #	Air Voids	G_{mb}
S-11	S-11-7	4.0	2.337
	S-11-8	3.5	2.349
	S-11-9	3.5	2.350
S-12	S-12-6	4.6	2.426
	S-12-7	3.8	2.446
	S-12-8	3.5	2.453
S-13	S-13-6	4.0	2.460
	S-13-7	4.0	2.461
	S-13-8	3.6	2.471
S-14	S-14-6	4.4	2.455
	S-14-7	4.7	2.446
	S-14-8	4.3	2.457
S-15	S-15-6	4.0	2.458
	S-15-7	3.9	2.461
S-16	S-16-6	4.1	2.436
	S-16-7	4.6	2.423
	S-16-8	4.4	2.428
S-17	S-17-6	4.4	2.410
	S-17-7	4.6	2.404
	S-17-8	4.3	2.412
S-18	S-18-6	3.5	2.349
	S-18-7	3.8	2.343
	S-18-8	3.7	2.345
S-19	S-19-6	4.1	2.452
	S-19-7	3.8	2.458
	S-19-8	4.2	2.448
S-20	S-20-6	4.3	2.438
	S-20-7	4.0	2.446
	S-20-8	3.7	2.453

Table 6-2. Summary of dynamic modulus testing results

Mixture	Temperature (°C)	Dynamic Modulus (psi) at Frequency (Hz)				
		25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz
S1	5	2718556	2505315	2334144	1940728	1763329
	25	1363593	1177199	1010382	667755	533823
	40	514862	448082	347376	189291	146889
S2	5	2195185	2043910	1928686	1643632	1513252
	25	837880	684018	598500	413070	368702
	40	370582	349512	275622	156980	130454
S3	5	1665338	1523653	1383432	1041750	926707
	25	1015881	840265	708900	471784	393277
	40	479986	363429	289464	170541	139570
S4	5	1688377	1515004	1375835	1058085	923347
	25	758494	618952	519722	328501	274068
	40	321230	239316	189747	124783	102381
S5	5	1940695	1813721	1700122	1423737	1298946
	25	1046943	899545	784929	548407	459125
	40	437124	332714	265866	155747	128673
S6	5	3219817	2887077	2676451	2166454	1936833
	25	1402727	1165921	966038	593581	459123
	40	475793	369106	277443	144513	126079
S7	5	2657447	2445081	2254771	1791554	1498947
	25	1137414	959075	793326	472220	358789
	40	424137	301779	227473	133711	104263
S8	5	2106279	1898941	1711824	1276268	1093710
	25	797849	655478	520685	298806	246089
	40	276775	198701	158492	95001	73974
S9	5	2279604	2125885	1963997	1563898	1391163
	25	1131702	936634	795165	505711	397558
	40	431144	327847	254922	159677	129964
S10	5	2771753	2490818	2286261	1808405	1601989
	25	1116202	908742	747045	442313	338010
	40	390597	273649	203734	121979	95205

Table 6-2. Summary of dynamic modulus testing results (Cont.)

Mixture	Temperature (°C)	Dynamic Modulus (psi) at Frequency (Hz)				
		25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz
S11	5	2460067	2216427	2012981	1560490	1367085
	25	1012301	824140	672212	392622	306538
	40	322355	228212	177715	105194	83242
S12	5	2351471	2090847	1889063	1427932	1233845
	25	927331	737812	588777	324985	263962
	40	278916	184464	152604	84398	67535
S13	5	3011584	2818300	2624445	2136791	1924084
	25	1328278	1125221	953667	612433	485643
	40	559182	419748	327764	187856	148362
S14	5	2728458	2499581	2320051	1889681	1703802
	25	1218686	1040795	882519	571472	456110
	40	554386	414528	324182	189306	142947
S15	5	2572339	2395084	2216750	1775124	1584504
	25	1023437	842892	697684	456682	350667
	40	400128	285613	214864	132733	102079
S16	5	2677688	2489353	2278723	1827880	1634091
	25	1115825	944472	787322	485782	378116
	40	385569	281676	220259	131109	101240
S17	5	2526217	2251277	2064508	1640875	1461569
	25	1056637	906080	770487	500564	401294
	40	409877	311574	248031	153194	120265
S18	5	3453820	3194201	3048829	2708039	2554885
	25	1916335	1719572	1566964	1229368	1088818
	40	1029854	860866	740421	509969	423155
S19	5	2513563	2344507	2175441	1749294	1564667
	25	1144054	935766	779194	466181	357925
	40	441512	320771	244152	142058	108477
S20	5	2739617	2560305	2366486	1898011	1689792
	25	1048483	842779	696163	407042	309066
	40	390325	276400	207707	120487	95873

Table 6-3. Summary of phase angle testing results

Mixture	Temperature (°C)	Phase Angle (degree) at Frequency (Hz)				
		25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz
S1	5	6.9	8.2	9.4	11.8	13.2
	25	16.9	19.2	21.6	26.9	30.0
	40	28.5	30.4	32.8	35.2	37.6
S2	5	6.5	7.5	8.5	10.4	11.7
	25	16.5	18.3	20.2	25.0	28.6
	40	29.2	29.1	30.9	32.7	34.7
S3	5	16.1	19.0	20.9	25.2	27.8
	25	22.9	25.4	27.7	31.0	32.2
	40	31.4	32.0	31.3	29.0	28.8
S4	5	9.5	11.3	12.7	16.5	18.5
	25	20.2	22.8	25.2	28.9	31.1
	40	30.3	31.5	31.5	27.8	28.1
S5	5	7.4	8.3	9.3	11.2	12.1
	25	14.4	17.5	19.1	22.1	23.7
	40	22.8	27.9	29.5	30.7	31.2
S6	5	7.2	8.8	10.3	13.3	14.9
	25	19.5	22.1	24.9	30.0	32.8
	40	35.9	35.1	36.7	36.4	36.2
S7	5	9.6	10.2	11.7	14.3	17.4
	25	21.8	24.6	27.2	32.3	35.1
	40	32.0	34.7	36.1	33.9	34.6
S8	5	11.7	13.2	14.8	18.7	20.8
	25	27.0	28.3	31.1	34.7	37.2
	40	35.1	35.2	33.7	29.9	29.4
S9	5	9.0	10.5	11.9	15.0	16.8
	25	19.0	21.0	23.6	28.5	31.2
	40	30.4	31.4	32.7	29.7	30.3
S10	5	9.2	11.0	12.5	15.7	17.6
	25	22.2	24.5	27.1	31.8	34.3
	40	32.7	35.8	36.7	32.2	31.9

Table 6-3. Summary of phase angle testing results (Cont.)

Mixture	Temperature (°C)	Phase Angle (degree) at Frequency (Hz)				
		25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz
S11	5	9.1	11.8	13.3	16.6	18.4
	25	22.2	25.5	28.0	32.6	34.8
	40	34.7	37.0	35.6	30.9	30.2
S12	5	8.7	12.7	14.5	18.4	20.7
	25	23.0	27.6	30.5	35.8	38.6
	40	37.2	38.4	35.2	31.0	29.6
S13	5	7.6	9.3	10.5	13.1	14.6
	25	18.6	20.6	22.8	27.3	30.0
	40	28.7	30.4	32.0	32.7	34.9
S14	5	9.6	9.8	10.9	13.2	14.5
	25	15.4	21.2	23.2	27.2	29.5
	40	27.1	28.7	30.4	32.4	33.3
S15	5	6.6	10.3	11.5	14.0	15.5
	25	22.6	23.2	25.7	30.7	33.3
	40	33.6	34.7	36.1	32.2	32.4
S16	5	4.0	9.7	11.4	14.1	15.5
	25	17.1	23.0	25.2	30.0	32.4
	40	32.6	33.7	34.2	32.7	33.8
S17	5	5.3	10.8	11.9	14.3	15.6
	25	17.9	20.8	22.7	26.4	28.6
	40	28.4	29.2	30.4	30.3	31.9
S18	5	3.5	5.9	6.3	7.3	7.8
	25	11.1	11.9	13.0	15.1	16.3
	40	17.4	19.0	20.4	23.1	24.8
S19	5	8.5	9.6	10.9	13.6	15.2
	25	21.1	23.5	26.1	31.7	34.6
	40	32.7	34.4	36.0	35.4	36.6
S20	5	8.5	10.1	11.3	14.2	15.8
	25	21.2	24.3	26.8	32.3	35.6
	40	34.8	36.2	37.4	35.0	35.1

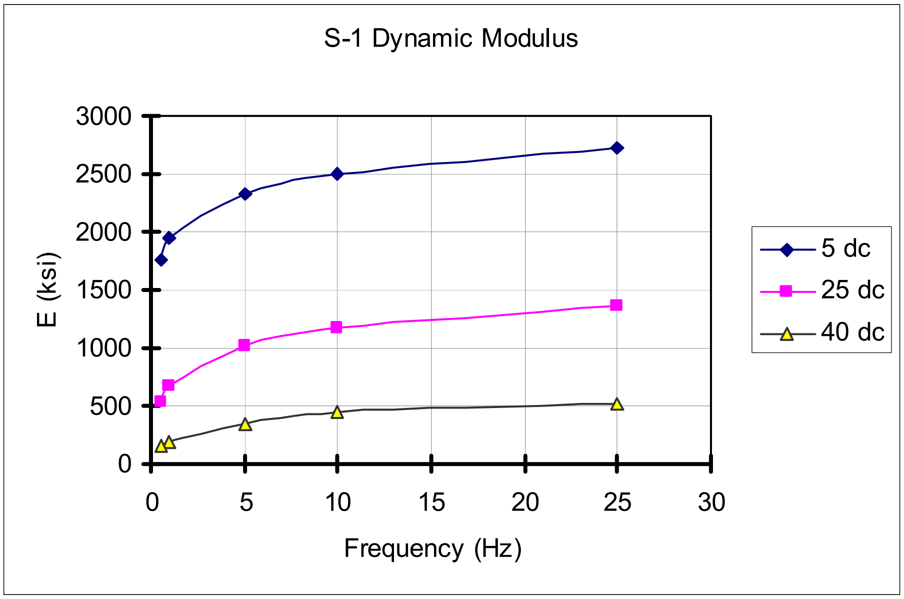


Figure 6-1. Dynamic modulus $|E^*|$ of S-1 (RAP, Ga-553)

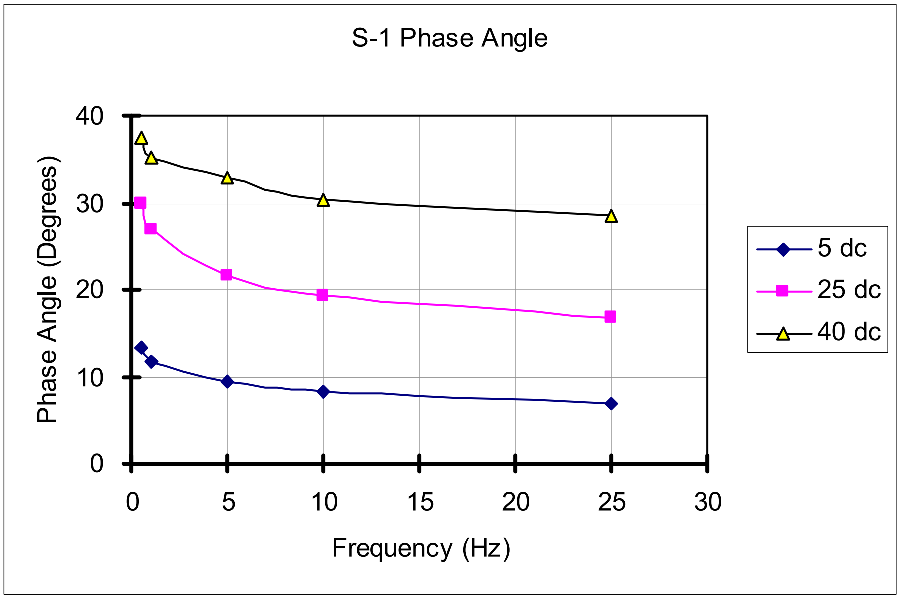


Figure 6-2. Phase angle of S-1

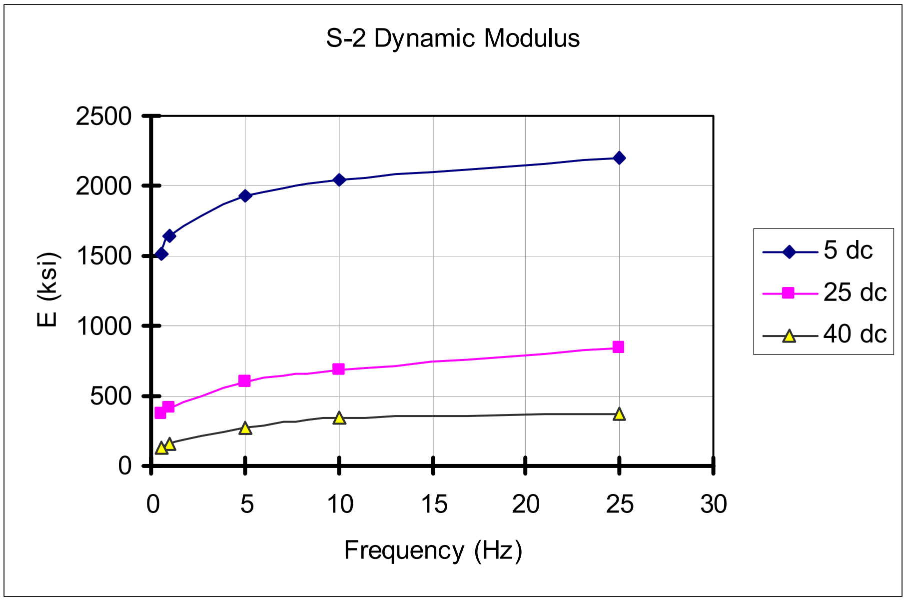


Figure 6-3. Dynamic modulus $|E^*|$ of S-2 (MFL)

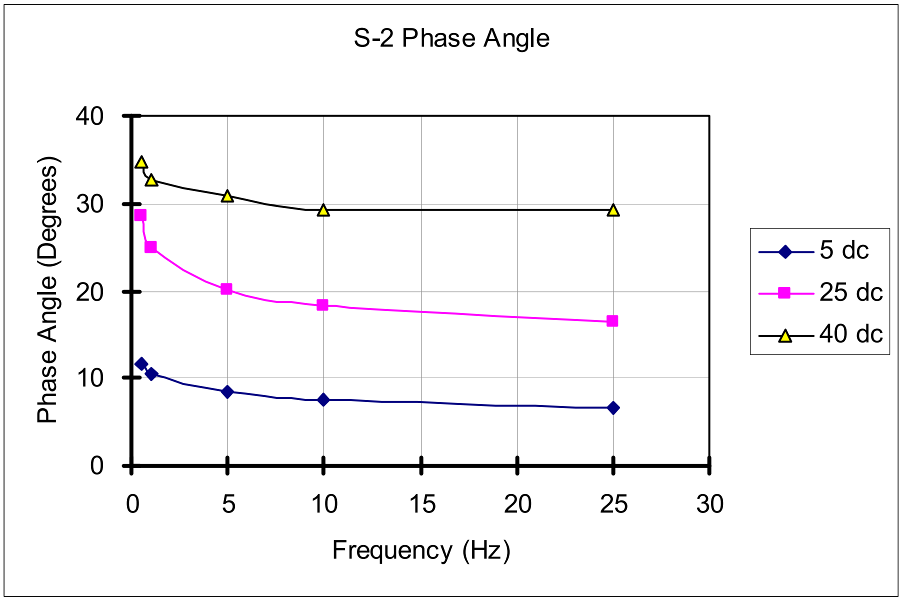


Figure 6-4. Phase angle of S-2

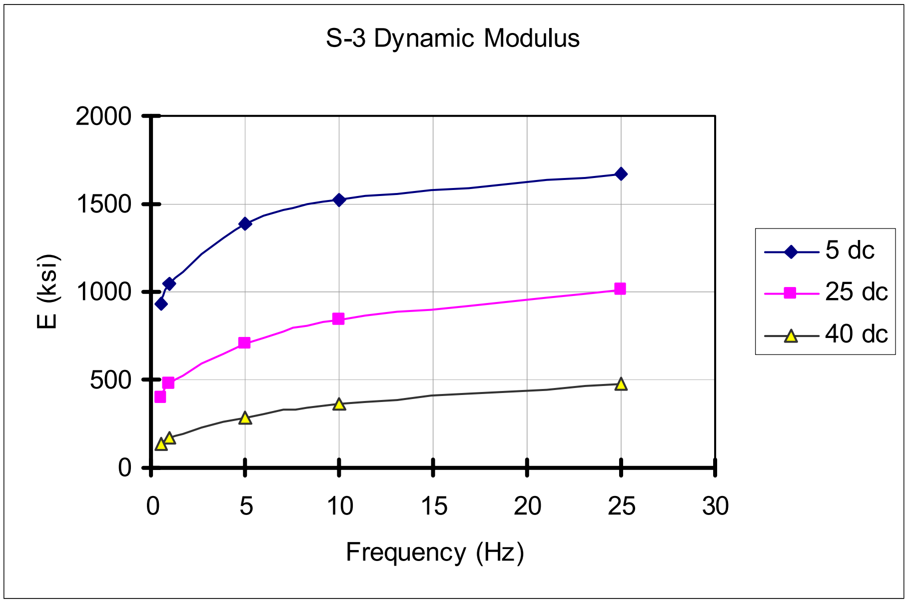


Figure 6-5. Dynamic modulus $|E^*|$ of S-3 (MFL)

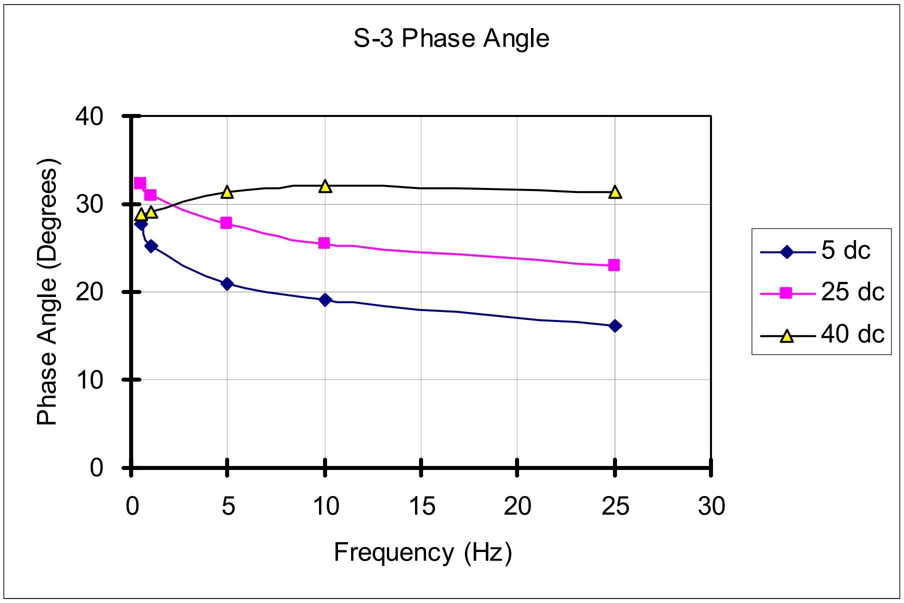


Figure 6-6. Phase angle of S-3

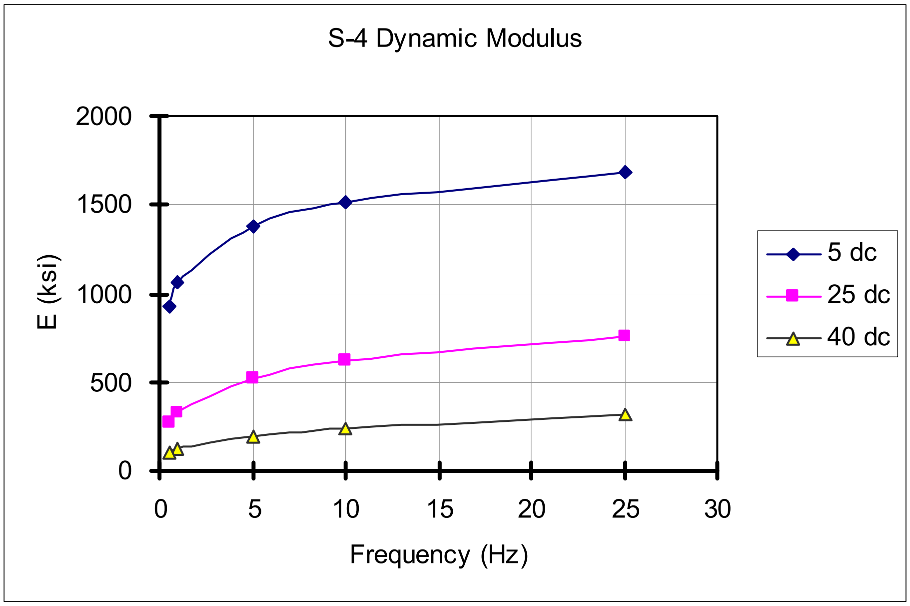


Figure 6-7. Dynamic modulus $|E^*|$ of S-4 (Ga-553)

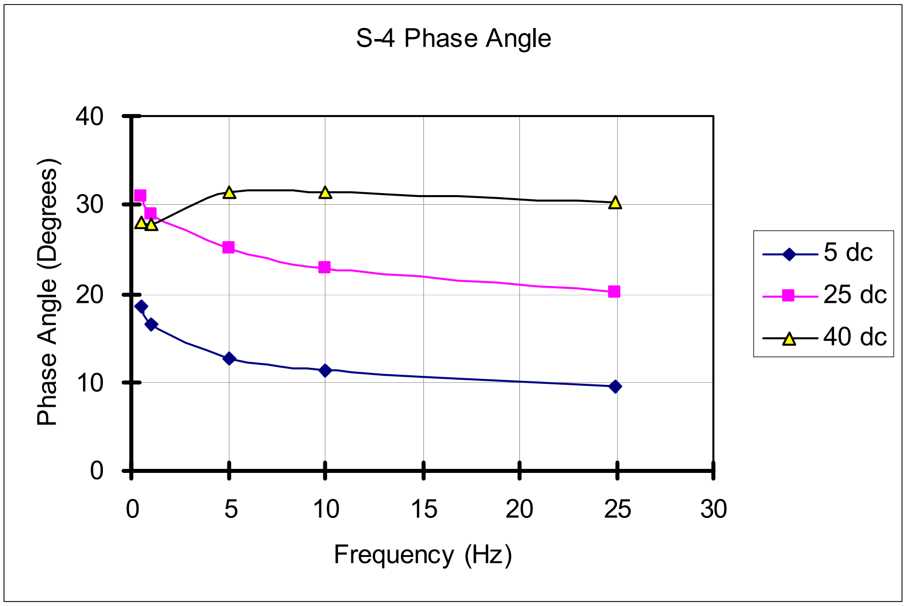


Figure 6-8. Phase angle of S-4

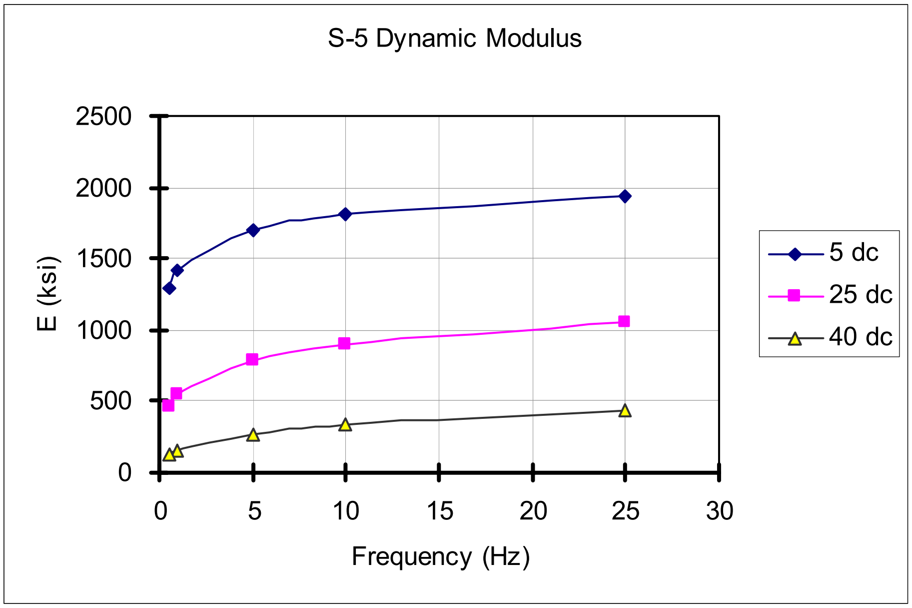


Figure 6-9. Dynamic modulus $|E^*|$ of S-5 (Ga-553)

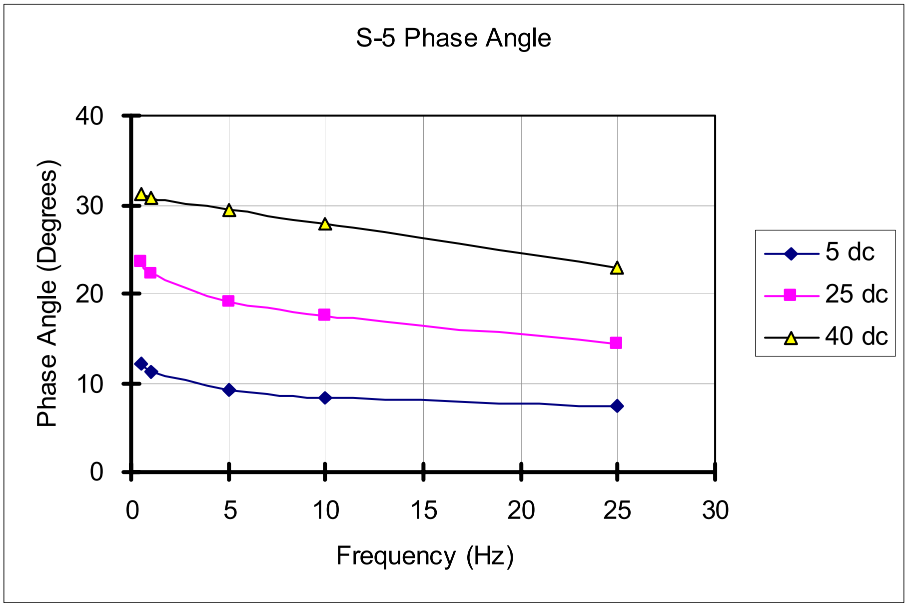


Figure 6-10. Phase angle of S-5

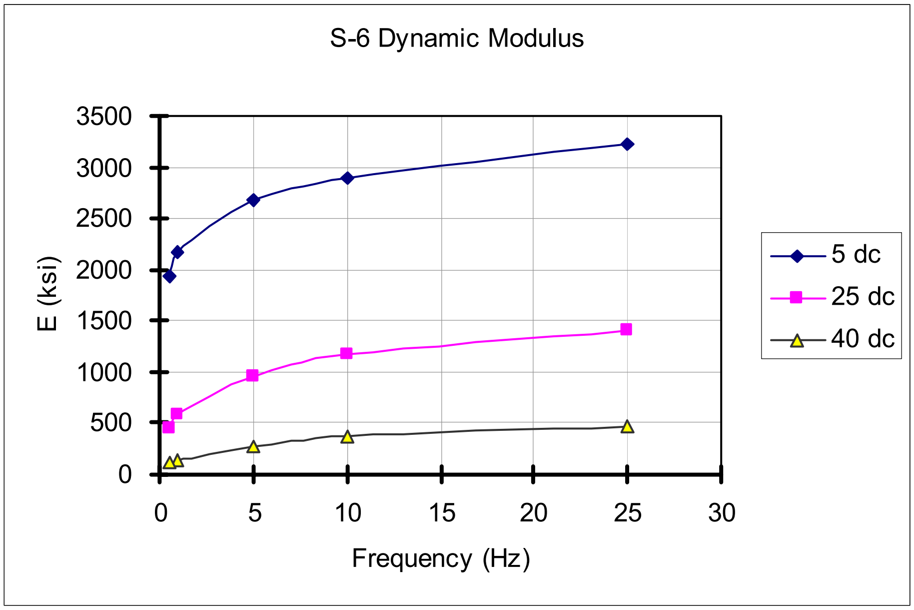


Figure 6-11. Dynamic modulus $|E^*|$ of S-6 (Ga-553)

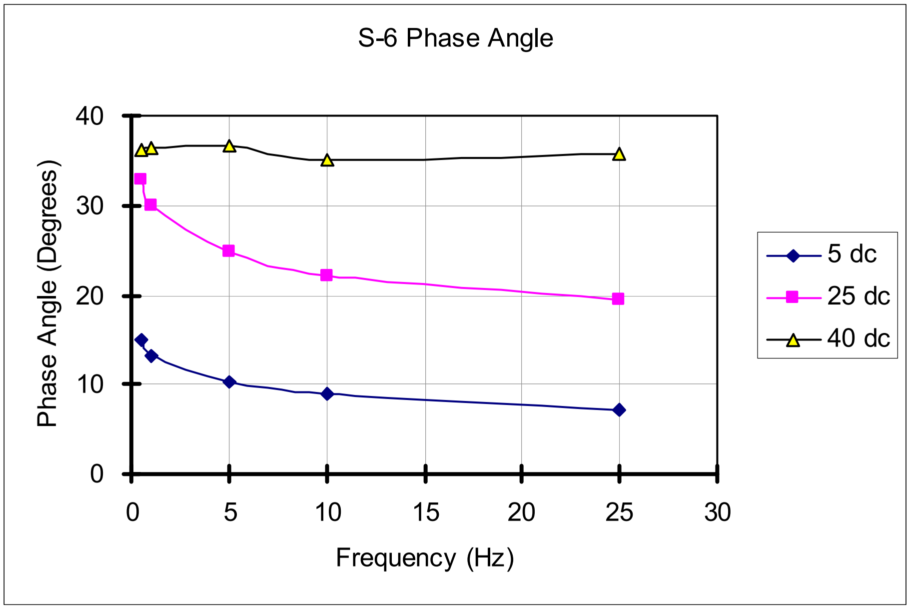


Figure 6-12. Phase angle of S-6

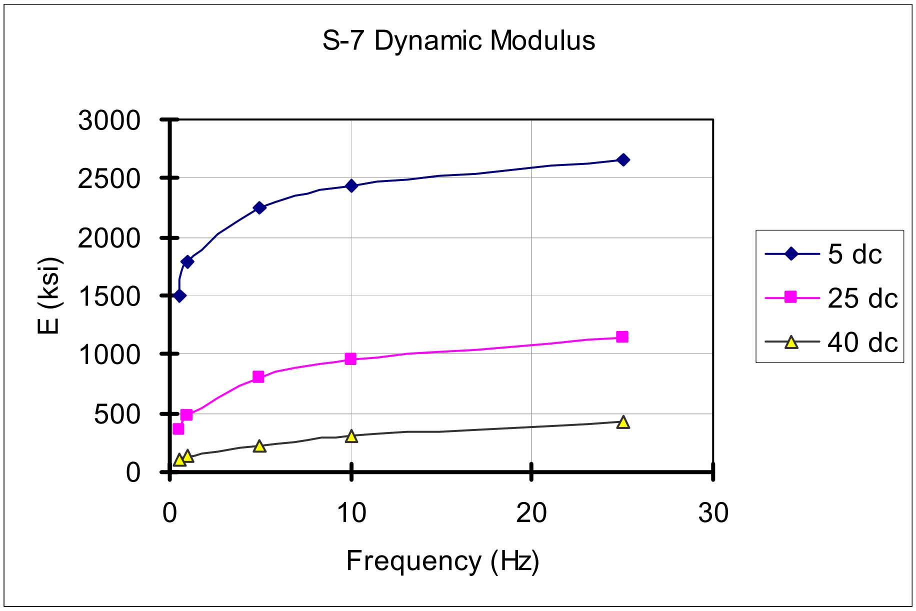


Figure 6-13. Dynamic modulus $|E^*|$ of S-7 (Ga-553)

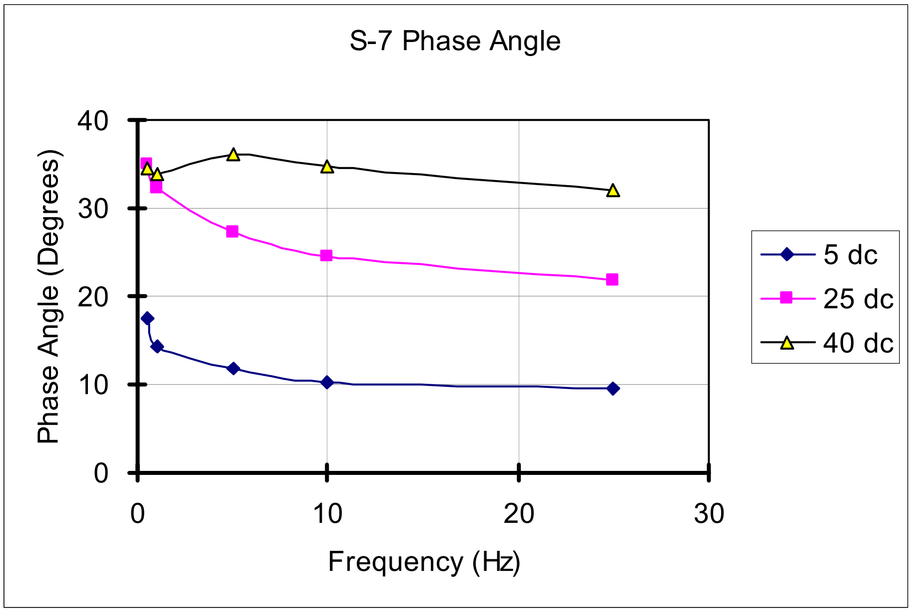


Figure 6-14. Phase angel of S-7

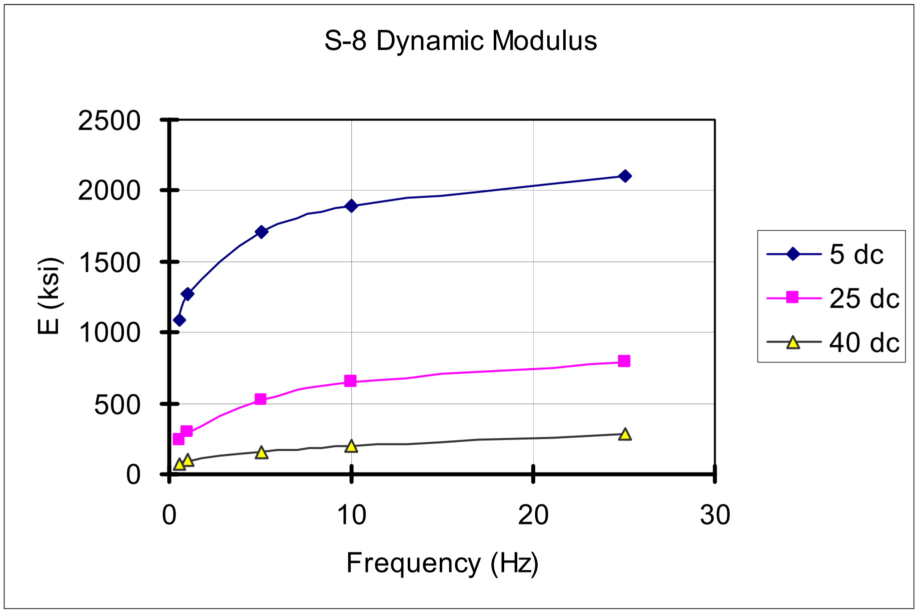


Figure 6-15. Dynamic modulus $|E^*|$ of S-8 (AL)

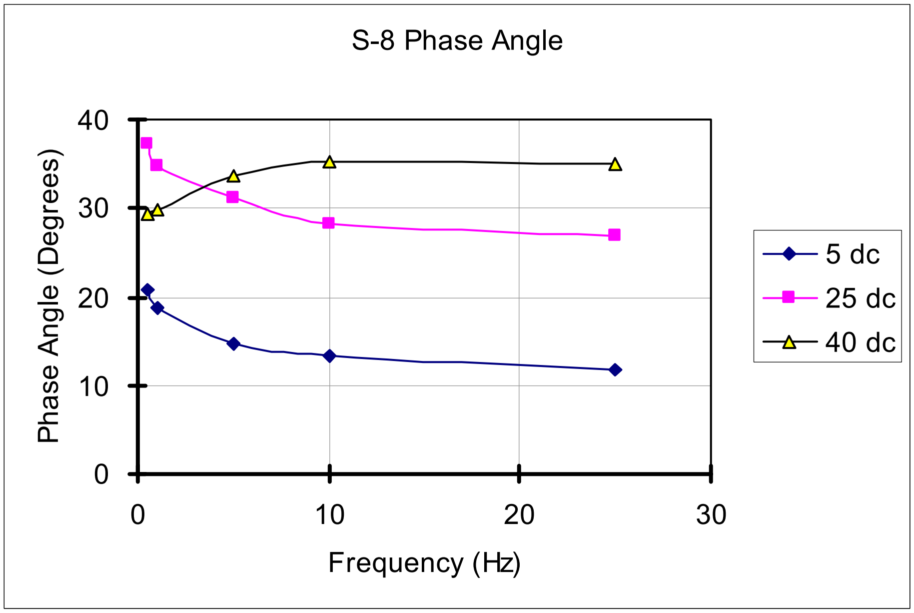


Figure 6-16. Phase angle of S-8

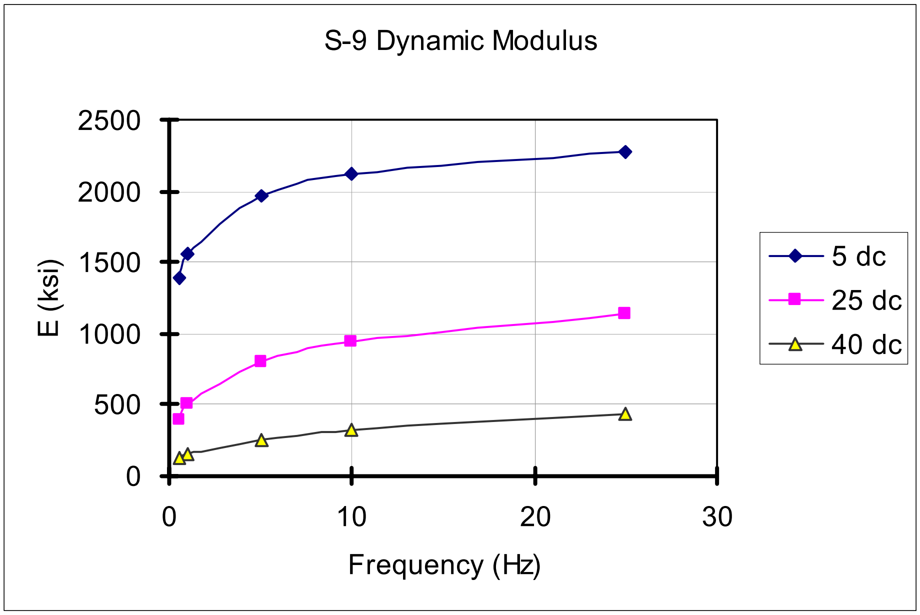


Figure 6-17. Dynamic modulus $|E^*|$ of S-9 (SFL)

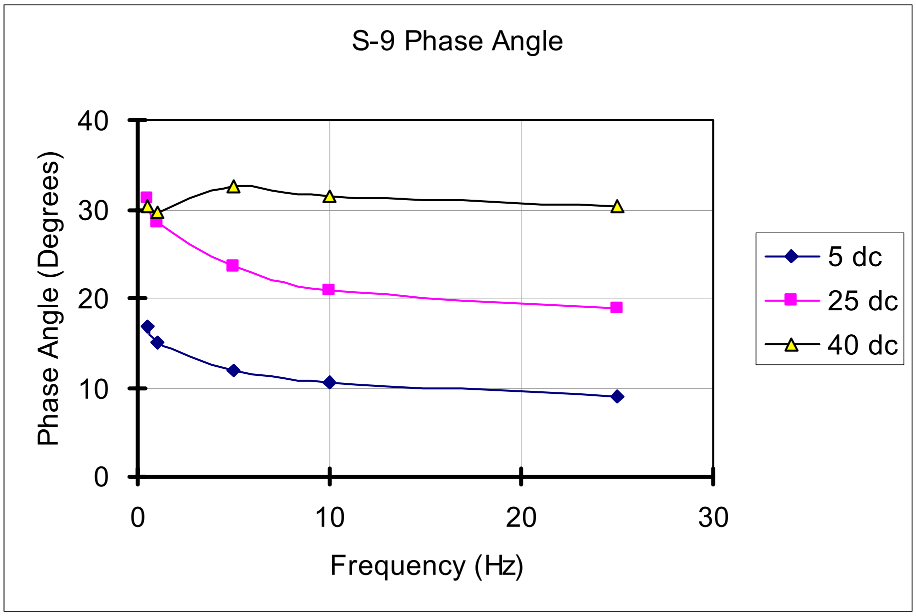


Figure 6-18. Phase angle of S-9

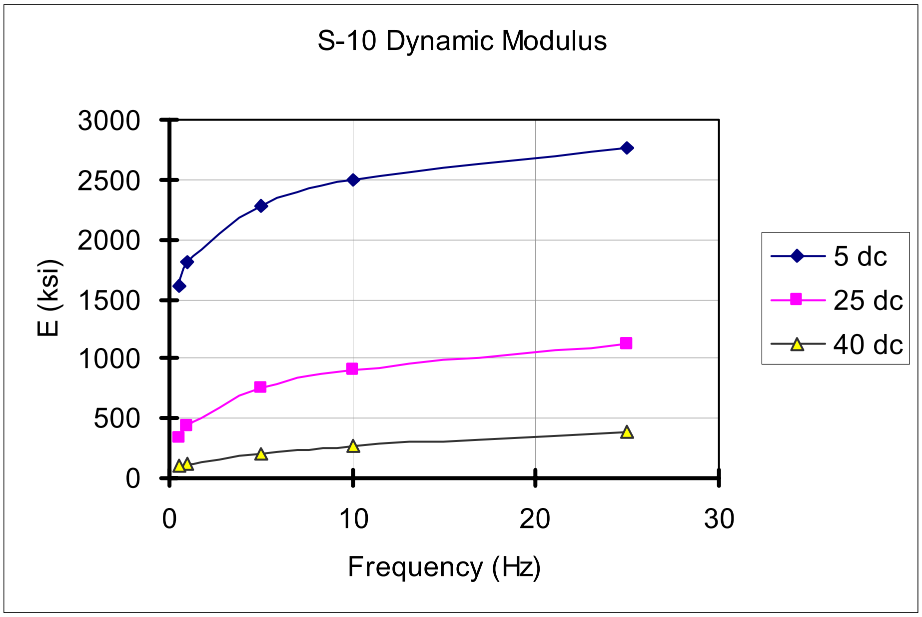


Figure 6-19. Dynamic modulus $|E^*|$ of S-10 (Ga-553 & Ga-206)

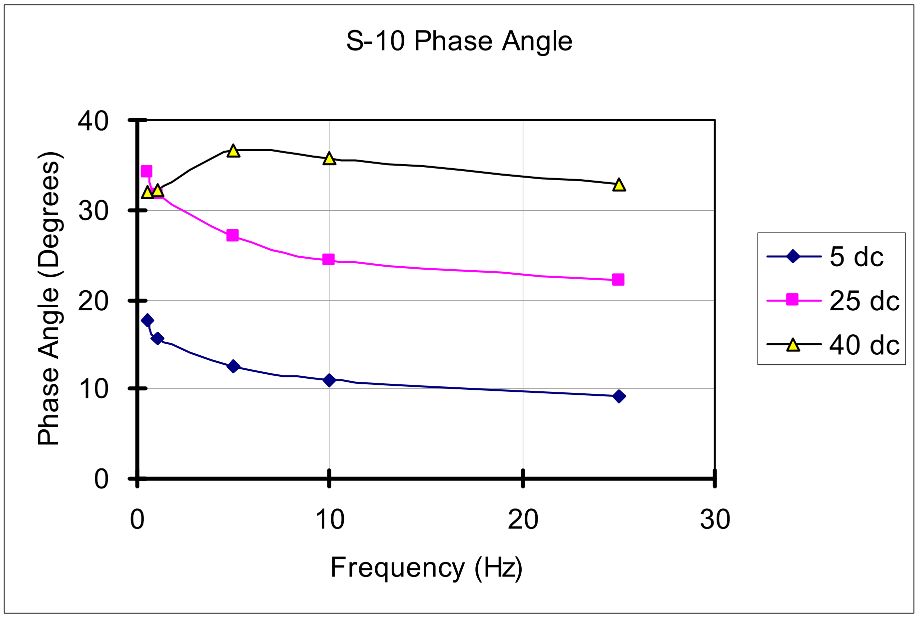


Figure 6-20. Phase angle of S-10

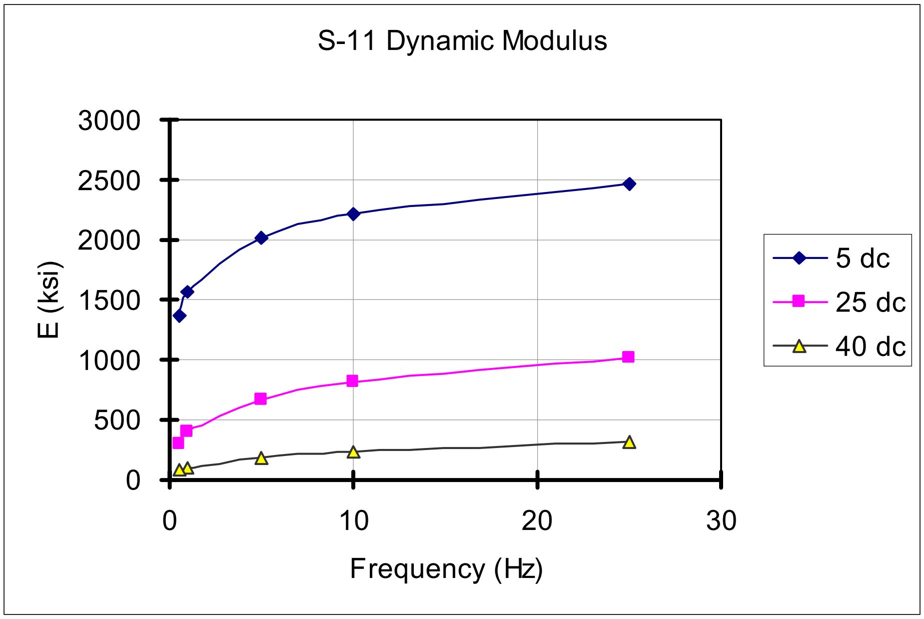


Figure 6-21. Dynamic modulus $|E^*|$ of S-11 (NS)

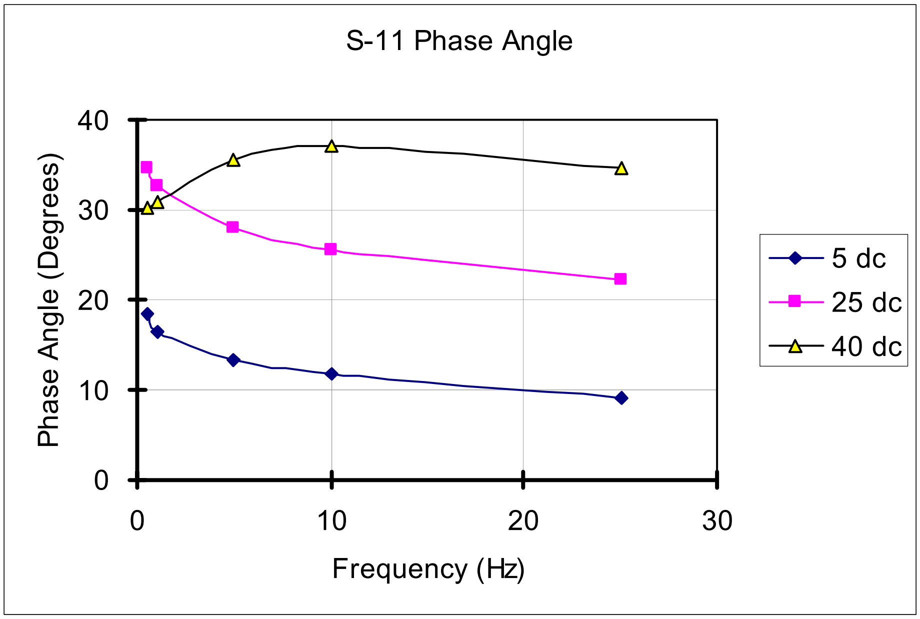


Figure 6-22. Phase angle of S-11

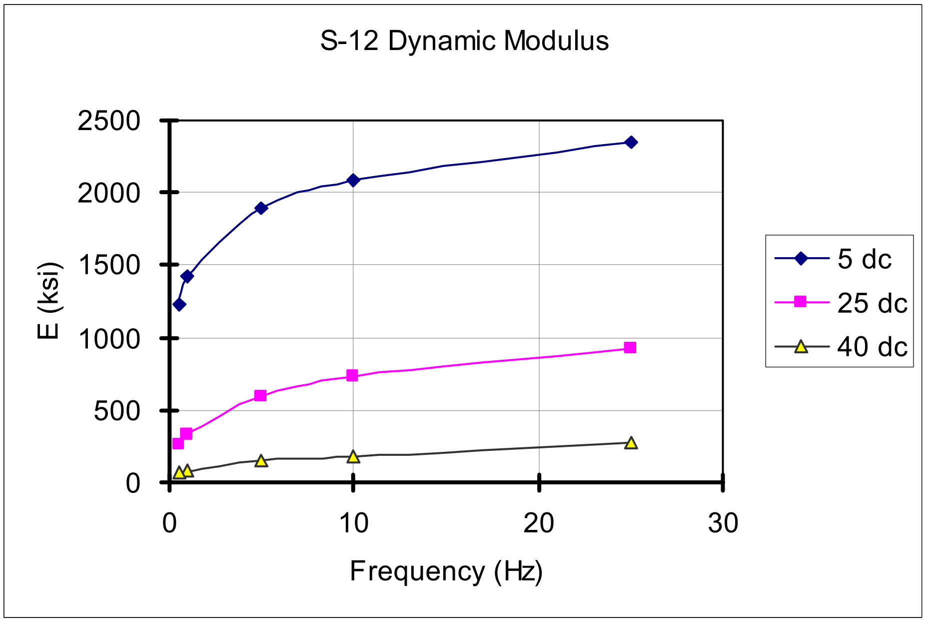


Figure 6-23. Dynamic modulus $|E^*|$ of S-12 (Ga-553)

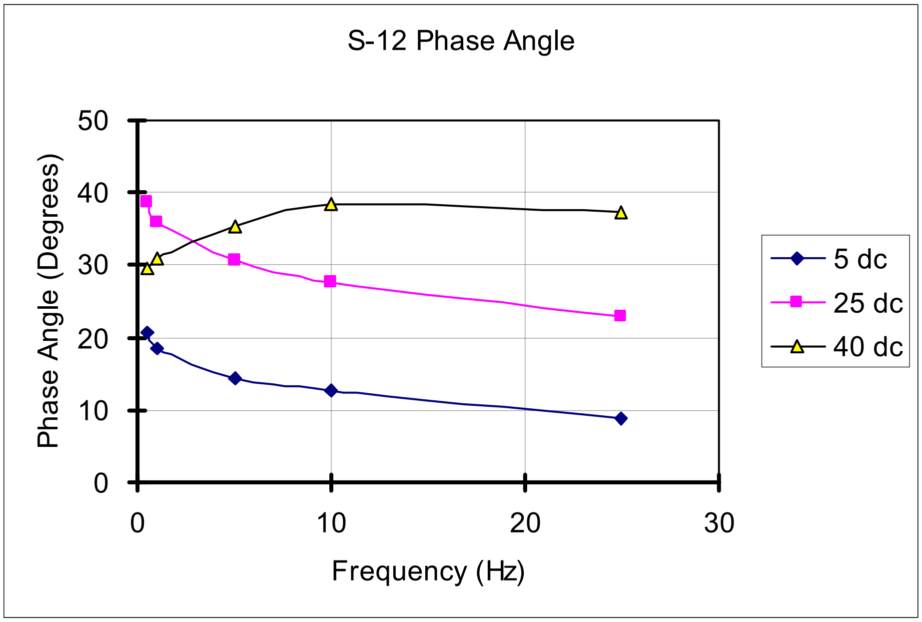


Figure 6-24. Phase angle of S-12

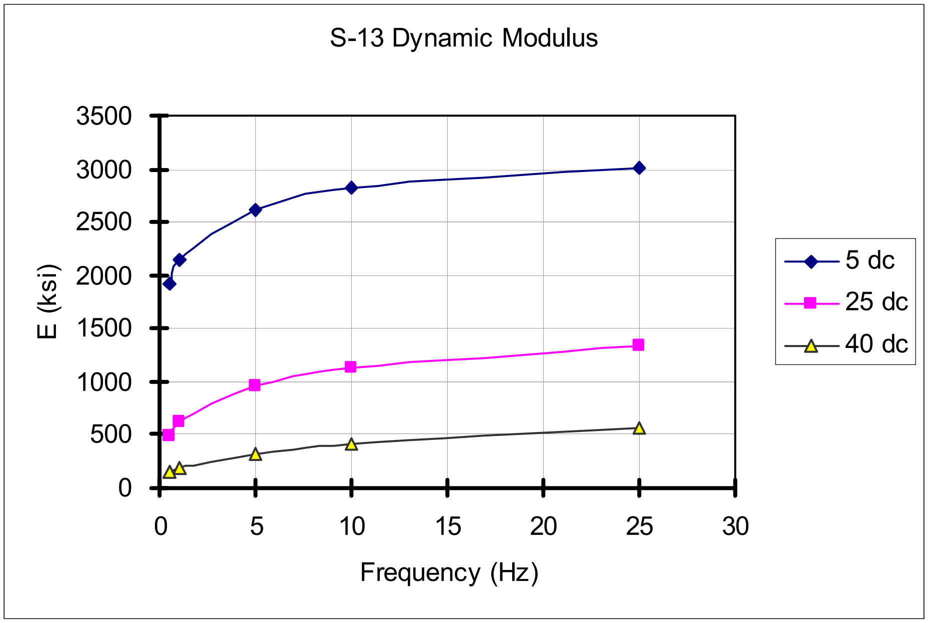


Figure 6-25. Dynamic modulus $|E^*|$ of S-13 (Ga-553)

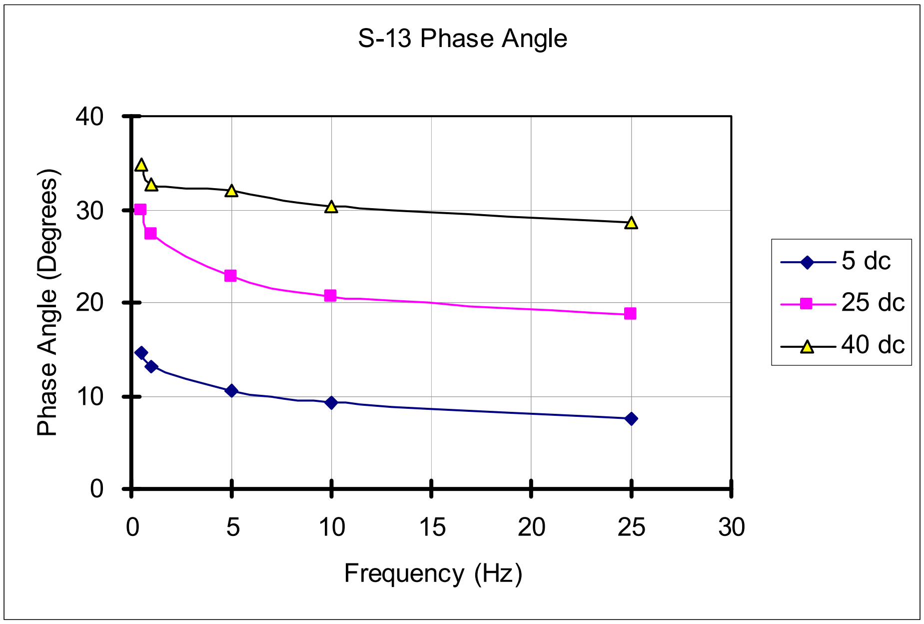


Figure 6-26. Phase angle of S-13

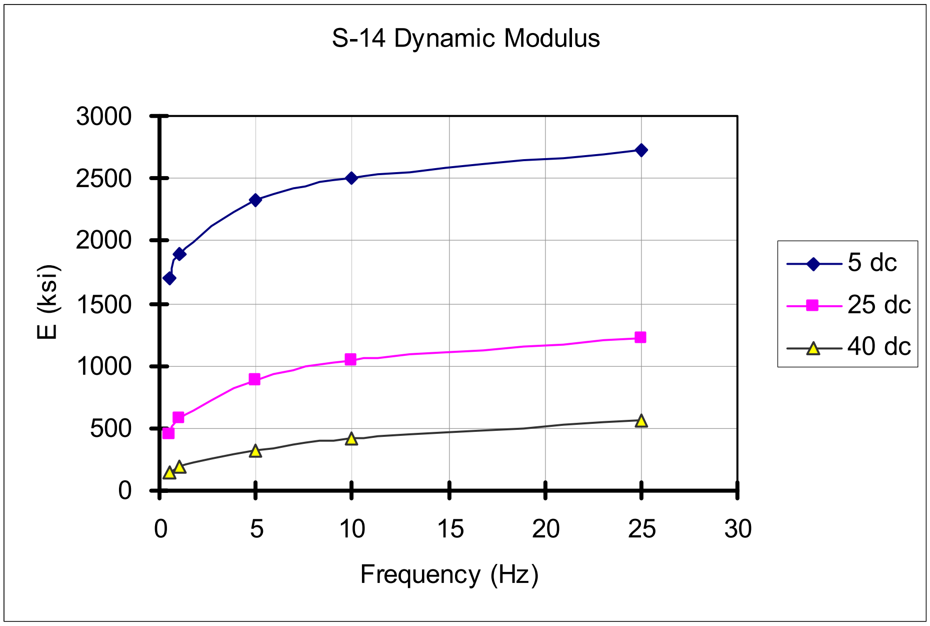


Figure 6-27. Dynamic modulus $|E^*|$ of S-14 (Ga-553)

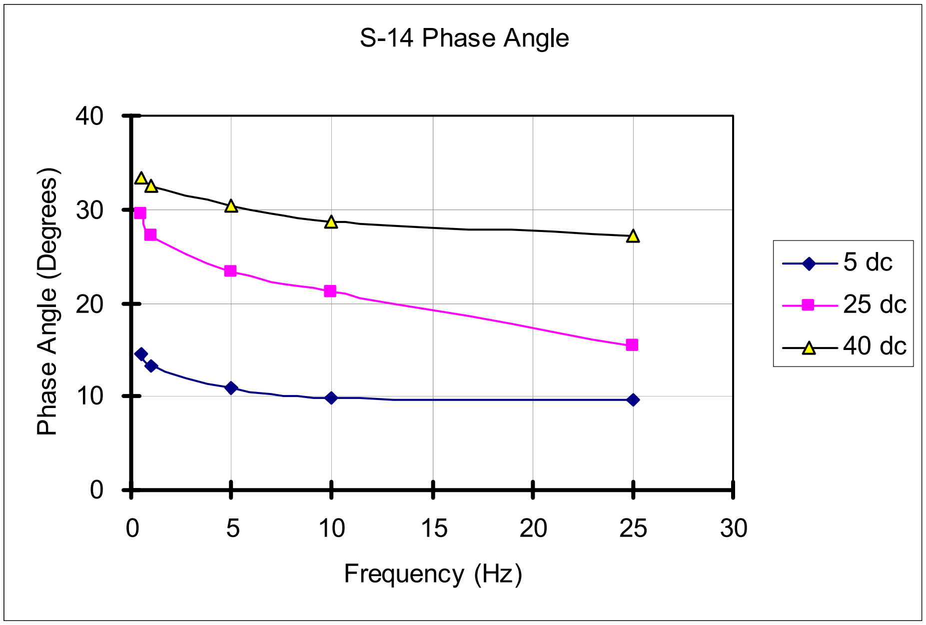


Figure 6-28. Phase angle of S-14

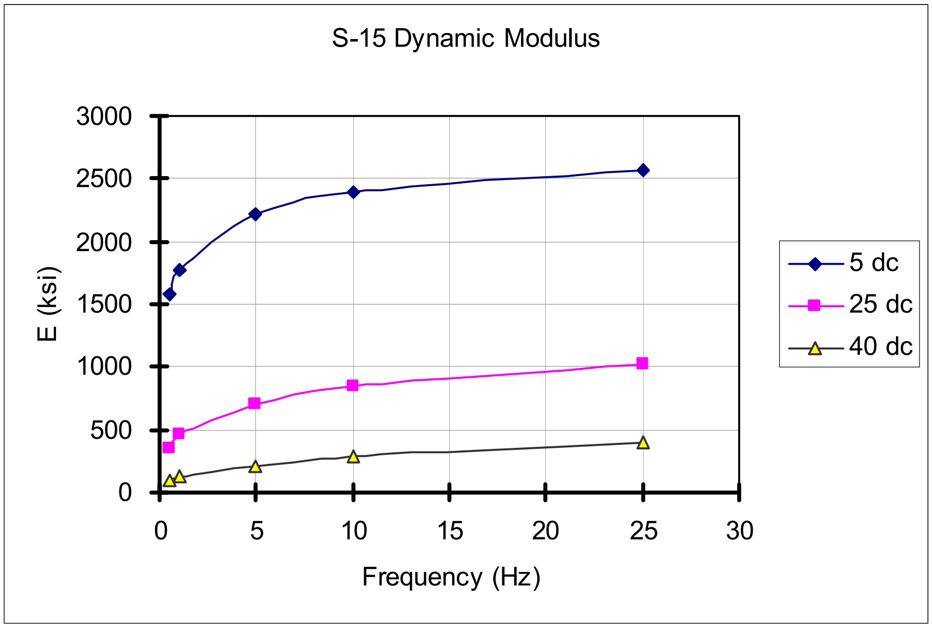


Figure 6-29. Dynamic modulus $|E^*|$ of S-15 (Ga-553)

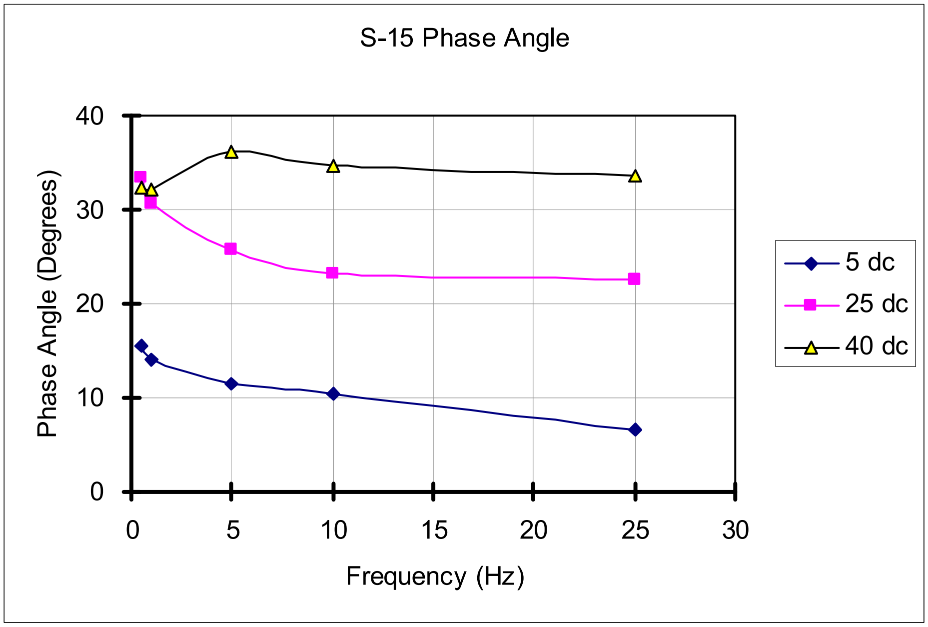


Figure 6-30. Phase angle of S-15

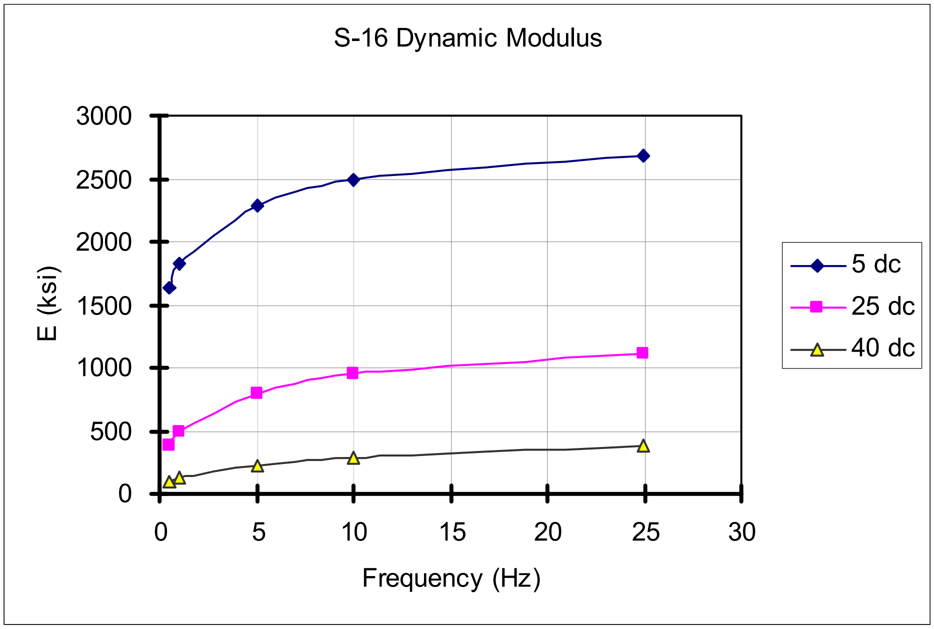


Figure 6-31. Dynamic modulus $|E^*|$ of S-16 (Ga-553)

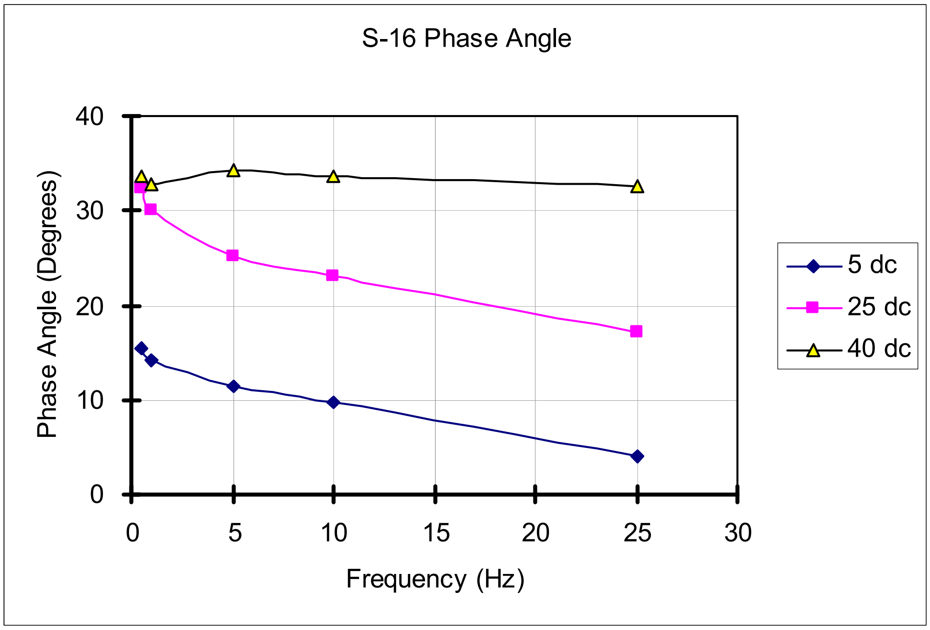


Figure 6-32. Phase angle of S-16

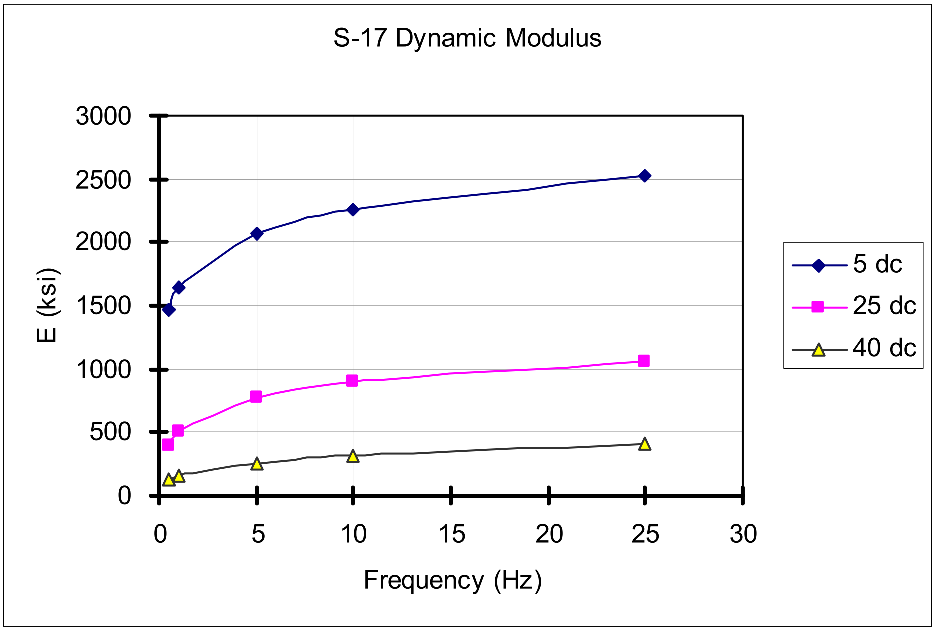


Figure 6-33. Dynamic modulus $|E^*|$ of S-17 (Ga-553)

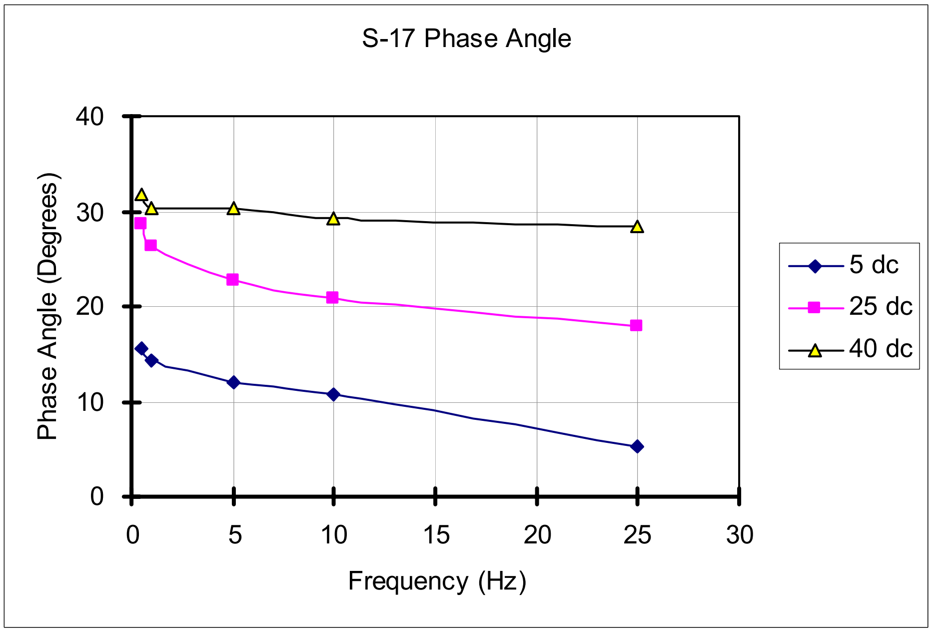


Figure 6-34. Phase angle of S-17

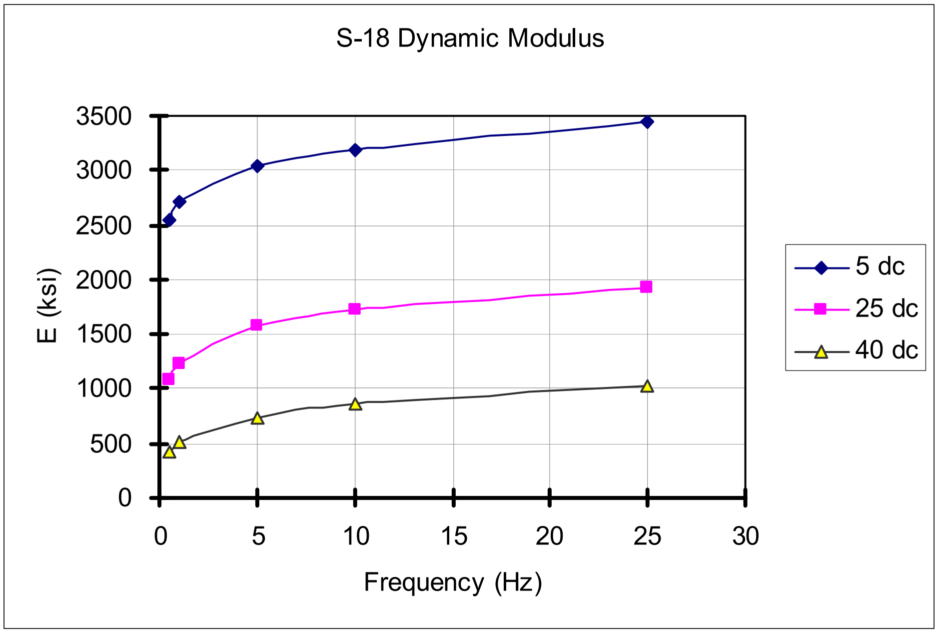


Figure 6-35. Dynamic modulus $|E^*|$ of S-18 (RAP & NFL)

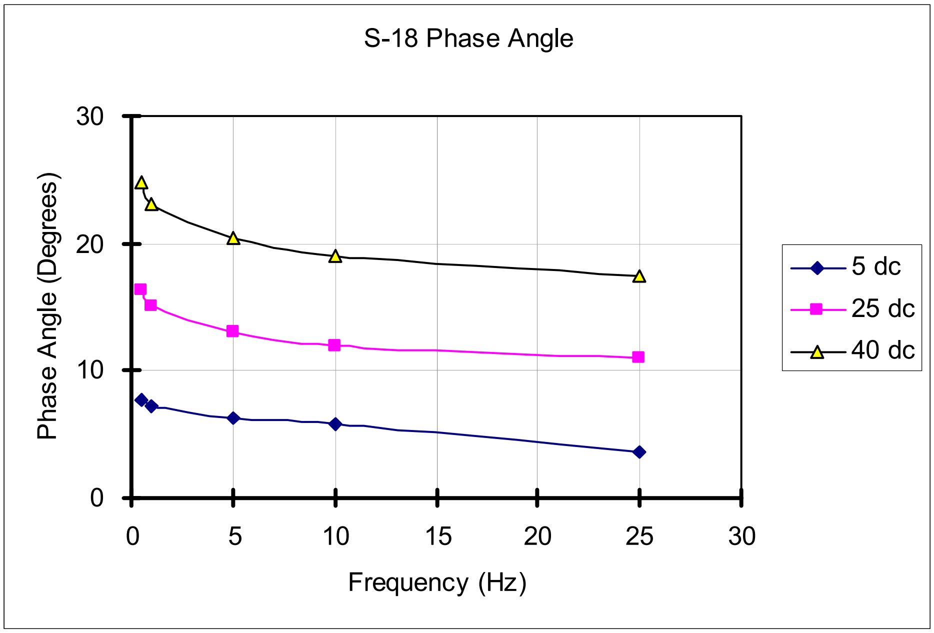


Figure 6-36. Phase angle of S-18

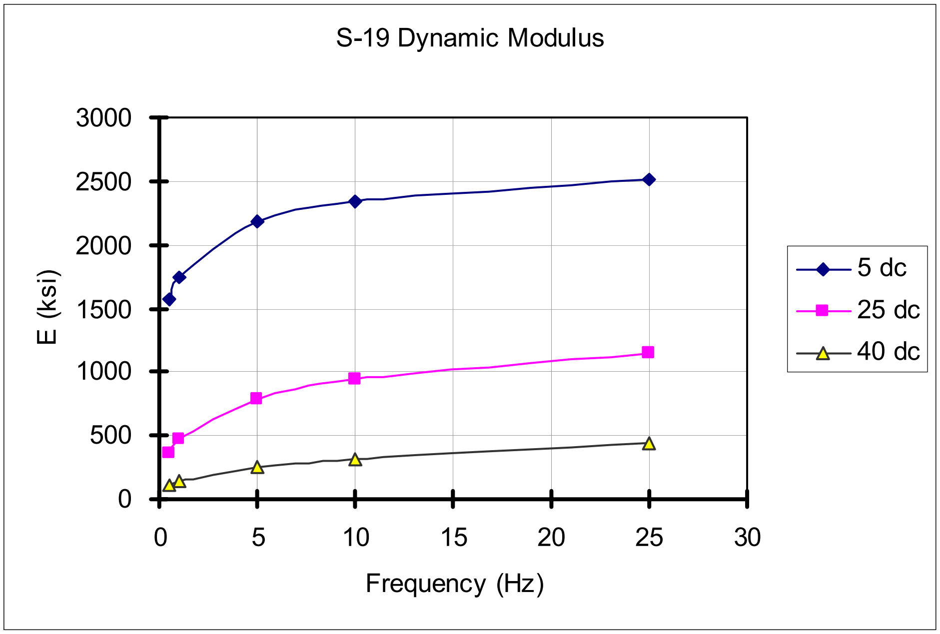


Figure 6-37. Dynamic modulus $|E^*|$ of S-19 (Ga-553)

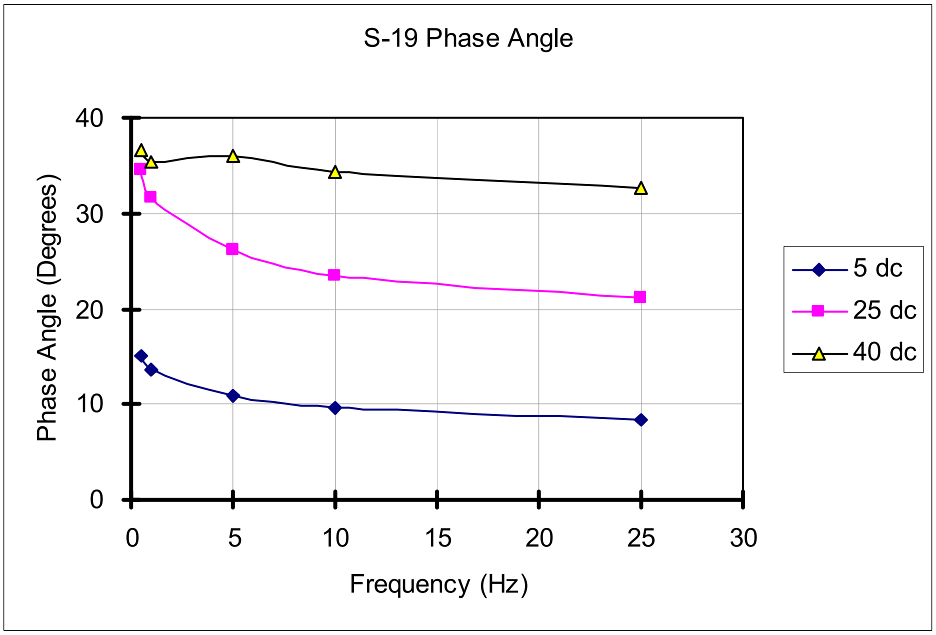


Figure 6-38. Phase angle of S-19

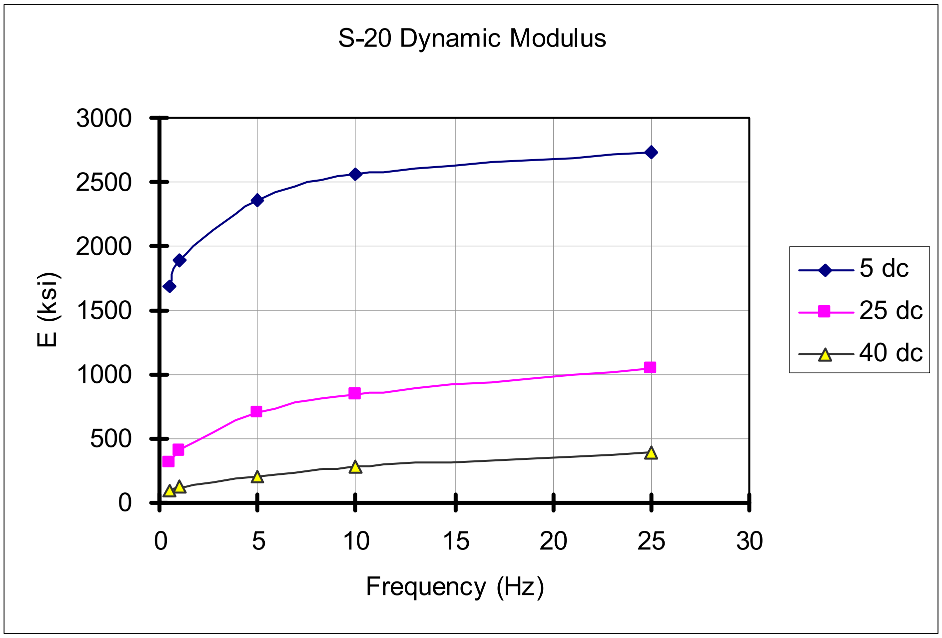


Figure 6-39. Dynamic modulus $|E^*|$ of S-20 (Ga-553)

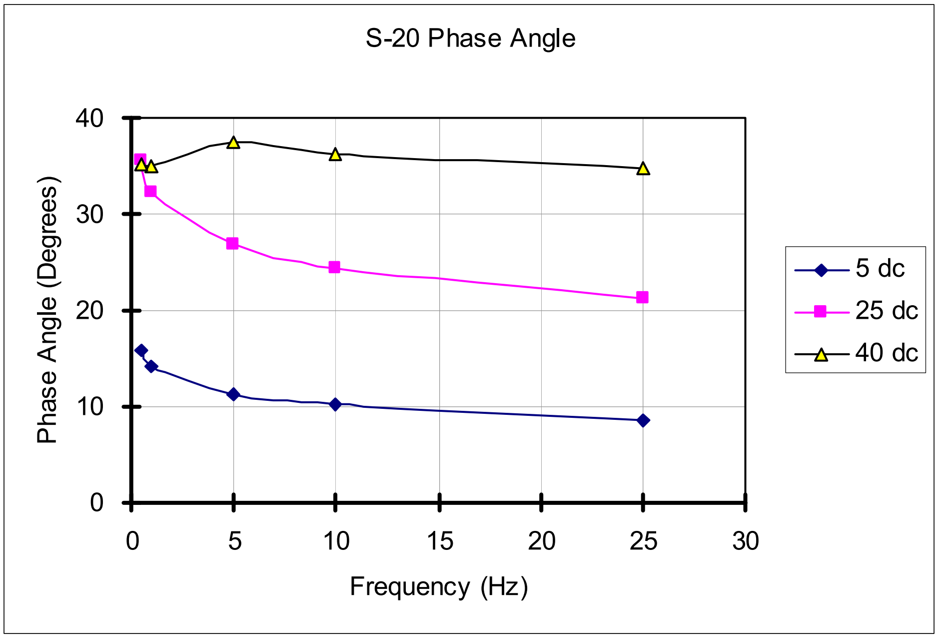


Figure 6-40. Phase angle of S-20

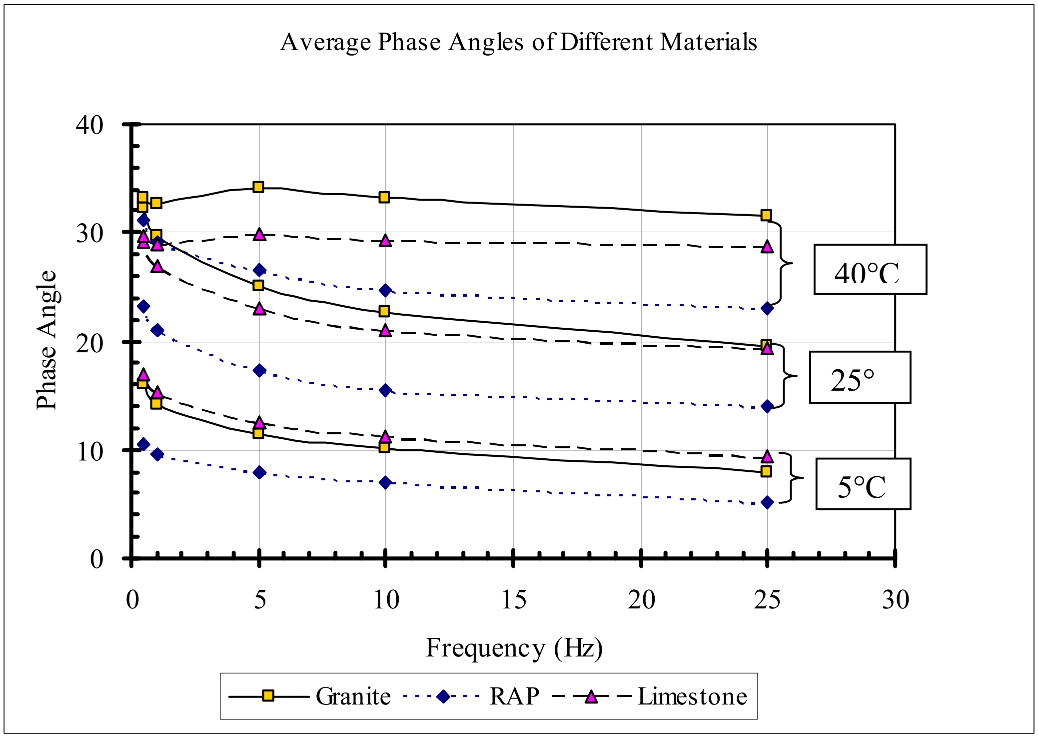


Figure 6-41. Phase Angles for Different Materials

CHAPTER 7

ANALYSES OF THE EXPERIMENTAL RESULTS

7.1 General

The dynamic complex modulus experimental results are further analyzed in this chapter. The master curve was developed and constructed using the time-temperature superposition principle. The resulting master curves for all 20 mixtures were presented. The Witczak prediction model was adopted to perform the comparison between predicted and measured dynamic modulus for all mixture series. A comparative study was also made between the dynamic modulus and resilient modulus test results. The development of the master curve is described as follows.

7.2 HMA Master Curve Development

In the new AASHTO Mechanistic-Empirical (M-E) Pavement Design Guide, the dynamic modulus of HMA, at all levels of temperature and loading frequency, was determined from a master curve constructed at a reference temperature. The dynamic modulus and phase angle of HMA were shifted with respect to frequency axis until the curves merged to form a single smooth characteristic curve, which is referred to as the time-temperature superposition principle. The master curve of the HMA stiffness described the time dependency of the material. The shift factor, $a(T)$, as a function of temperature, defined the required shift at a given temperature to obtain the reduced frequency. It is shown in the following form:

$$a(T) = \frac{f}{f_r} \quad or \quad \log[a(T)] = \log(f) - \log(f_r) \tag{7-1}$$

Where: f = testing frequency at desired temperature

f_r = reduced frequency

T = temperature of interest

Obviously, $a(T) = 1$ at the reference temperature.

Pellinen and Witczak (2002) developed a mathematical model by a sigmoidal fitting function for master curve construction. The shift can be calculated by solving the shift factors simultaneously with the coefficients of the sigmoidal function:

$$\log(|E^*|) = \delta + \frac{\alpha}{1 + e^{\beta + \gamma \log f_r}} \tag{7-2}$$

Where: $\log(|E^*|)$ = log of dynamic modulus

f_r = reduced frequency

δ = minimum modulus value

α = span of modulus value

β, γ = shape parameters

As indicated in the sigmoidal function, the upper limit of the log of dynamic modulus was $\alpha + \delta$, and the minimum value is δ. β *and* γ are shape factors that determine the shape of the master curve. The parameters used in sigmoidal fitting function are demonstrated in Figure 7-1. The characteristics of the sigmoidal function is described as follows. At the reference temperature, the shift factor $a(T) = 1$. The parameter γ influenced the steepness of the function (rate of change between minimum and maximum) and β influenced the horizontal position of the turning point. The upper part of the sigmoidal function approached asymptotically the maximum stiffness of the mix, which was dependent on limiting binder stiffness at cold temperatures. At high temperatures, the compressive loading caused aggregate influence to be more dominant than the viscous binder influence. The modulus started to approach a limiting equilibrium value, which is dependent on the aggregate gradation. Thus, the sigmoidal function captured the physical behavior of the asphalt mixture observed in the mechanical testing using compressive cyclic loading through the entire range of temperatures that are typically of interest.

7.3 Master Curve Construction

The procedure developed by Pellinen and Witczak (2002) was used for obtaining predicted master curves for all mixtures in this project. In all master curve constructions, the reference temperature was taken as 25°C (77°F). The shifting factors were obtained simultaneously with the coefficients of the sigmoidal function through nonlinear regression, without assuming any functional form of $a(T)$ with respect to temperature. The nonlinear regression was performed by using the Solver Function of a Microsoft Excel spreadsheet. For instance, a set of testing values of dynamic modulus for a specific specimen was obtained, at test temperatures of 5, 25 and 40°C and loading frequencies of 25, 10, 5, 1 and 0.5 Hz, respectively. Then the parameters of the sigmoidal function $\alpha, \beta, \delta, \text{ and } \gamma$ were assumed as well as the shift factor $a(T)$ at each corresponding temperature. Equation 7-2 was used to calculate the sigmoidal fitting values of $\log(|E^*|)$. Nonlinear regression was then performed to achieve an optimum fitting between the testing values and the sigmoidal model calculation, which resulted in obtaining the optimized parameters of the sigmoidal function and the shift factors.

7.4 Presentation of the Master Curves

The resulting shift functions and master curves for all 20 mixtures are presented in Figures 7-2 through 7-41. For a few mixtures, the tails of the predicted master curve show a slight concave-down curvature, but not follow an S-shape. In this case, higher and lower temperature results may be required to extrapolate the curve adequately for better prediction. The master curves for granite, RAP and limestone materials are grouped together and shown in Figures 7-42, 7-43, and 7-44, respectively.

7.5 Predictive Regression Equation for the Dynamic Modulus

Efforts were made by asphalt pavement researchers to develop regression equations to estimate the dynamic modulus for a specific hot mix design. One of the most comprehensive mixture dynamic modulus models is the Witczak prediction model described in Chapter 2. It is proposed in the new AASHTO M-E design guide and the calculations were based on the volumetric properties of a given mixture. In this model, the parameter η (bitumen viscosity) for each dynamic modulus test temperature is determined by:

$$\log(\log\eta) = A + VTS \cdot \log T \tag{7-3}$$

Where A is the regression intercept, T is Rankine temperature and VTS is the slope of log-log viscosity vs. temperature relationship. A and VTS parameters are functions of binder type and material characteristics, and they were determined by regression using experiment data of binder viscosity versus temperature T. All HMA in this project used the asphalt binder PG 67-22 (AC-30). In this study, the input binder viscosity was obtained from two sources:

1. Brookfield rotational viscometer results on short-term Rotational Thin Film Oven (RTFO) aged PG 67-22 specimens (Birgisson et al. 2004):

$$A = 10.407 \qquad VTS = -3.4655$$

2. Mix/Laydown conditions for PG 67-22 (AC-30) asphalt binder (Witczak and Fonseca 1996):

$$A = 10.6768 \qquad VTS = -3.56455$$

Witczak's prediction equation was presented in Equation 2-30 and is presented herein for ease of comparison:

$$\begin{aligned}\log\left|E^*\right| &= -1.249937 + 0.029232P_{200} - 0.001767(P_{200})^2 \\ &- 0.002841P_4 - 0.058097V_a - 0.802208\frac{V_{beff}}{(V_{beff} + V_a)} \\ &+ \frac{\left[3.871977 - 0.0021P_4 + 0.003958P_{38} - 0.000017(P_{38})^2 + 0.00547P_{34}\right]}{1 + e^{(-0.603313 - 0.313351\log f - 0.393532\log\eta)}}\end{aligned} \tag{7-4}$$

Where

$|E^*|$ = dynamic modulus, in 10^5 psi

η = bituminous viscosity, in 10^6 poise (at any temperature, degree of aging)

f = load frequency, in Hz

V_a = percent air voids content, by volume

V_{beff} = percent effective bitumen content, by volume

P_{34} = percent retained on 3/4 -in. sieve, by total aggregate weight (cumulative)

P_{38} = percent retained on 3/8 -in. sieve, by total aggregate weight (cumulative)

P_4 = percent retained on No. 4 sieve, by total aggregate weight (cumulative)

P_{200} = percent passing on No. 200 sieve, by total aggregate weight (cumulative)

7.6 Predicted Versus Measured Dynamic Modulus

The predicted dynamic modulus values for all mixture series are summarized in Tables 7-1 and 7-2 under the two binder conditions at all test temperatures and testing frequencies. The comparisons between the predicted and measured dynamic moduli for all mixture series under the two binder conditions are presented in Figures 7-45 and 7-46. The mix design series S-18, which comprises RAP and North Florida Limestone, was excluded from the comparison. Linear regression with zero intercept was performed for the data analysis. R^2 indicated the goodness of fitting, whereas the linear coefficient (slope) was a measure of the quality of fit between prediction and test measurement. Since the comparison was made by using measured dynamic modulus as horizontal x-values, the points above the line of equality indicated a prediction that is not conservative, in which the predicted dynamic modulus was higher than the measured one. The comparison indicated a fair prediction for the mixtures tested in this project.

Since only one type of asphalt binder (PG67-22) was used for all mix designs of this project, the differences of stiffness properties between tested mixtures were primarily due to the different types of aggregates used for each mix design. Therefore, comparisons were made by types of materials used in the mixtures. The comparisons of predicted and measured dynamic modulus for granite, limestone, and RAP materials are shown in Figures 7-47 through 7-52, respectively, under the two binder conditions. As shown in the figures, the prediction model provides conservative estimates for granite and RAP materials, in which the regression slope for granite was closer to unity than that for RAP materials. However, the regression analysis provided a slope that was higher than 1 (1.22 for the mix-laydown condition, 1.20 for the RTFO aged condition) for limestone materials, which meant a prediction that is not conservative. This is likely because the stiffness of granite and RAP materials was much higher than that of limestone in the actual testing. Furthermore, the RAP materials had the lowest regression slope.

The comparison of predicted dynamic modulus values between the tested 4% air voids and that at an assumed air void of 7.0% is shown in Figure 7-53. The higher air void (7.0%) resulted in a lower dynamic modulus, as expected in the prediction model as well as in measured values. For the selected Florida AC mixtures, the dynamic modulus with an assumed air voids of 7.0% was approximately 83.6% of that with the tested air voids, which was about 4.0%.

7.7 Comparison between Resilient Modulus and Dynamic Modulus Test Results

One of the major differences between a resilient modulus test and a dynamic complex modulus test for AC mixtures is that the former has a loading of one cycle per second (1 Hz) with a repeated 0.1 second haversine load followed by a 0.9 second rest period, while the latter applies a sinusoidal or haversine loading with no rest period. The dynamic complex modulus is one of the many methods for describing the stress-strain relationship of viscoelastic material. The dynamic modulus varies with the loading frequency. A frequency that most closely simulates the actual traffic loading should be selected for the test, so the dynamic modulus thus determined would be equivalent to the resilient modulus for pavement design purposes.

In this study, efforts were devoted to preparing the cored dynamic modulus specimens with a targeted air void (approximately 4.0%) as close as possible to the design air voids (4.0%) of the resilient modulus specimens. Thus, neglecting the differences in loading mode (compression versus tension) and loading condition (no rest period versus with rest period) between the two test methods, the dynamic modulus and resilient modulus test results for this study may be compared on the basis of loading frequency.

Comparisons of the test results between dynamic modulus and total resilient modulus are shown in Figures 7-54 through 7-58 for the loading frequencies of 25 Hz, 10 Hz, 5 Hz, 1 Hz, and 0.5 Hz, respectively. The linear regression analysis clearly showed a trend that the total resilient modulus increased with an increase in dynamic modulus at a specific loading frequency. In particular, the dynamic modulus values were very close to the resilient modulus values at the loading frequency of 5 Hz (Figure 7-56).

The linear regression equations are grouped together and presented in Figure 7-59 for the loading frequencies of 25 Hz, 10 Hz, 5 Hz, 1 Hz, and 0.5 Hz. The best interpreted loading frequency would be of approximately 4 Hz for obtaining an equal value of resilient modulus and dynamic modulus. In summary, the dynamic modulus values measured at loading frequency of 4 Hz may be comparable with the resilient modulus values obtained from the indirect diametral test at the same temperature level.

Table 7-1. Summary of Predicted Dynamic Modulus Values

(Brookfield RTFO Aged Condition, Birgisson et al. 2004)

Mixture	Temperature (°C)	Dynamic Modulus (ksi) at Frequency (Hz)				
		25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz
S1	5	2635	2399	2220	1812	1642
	25	979	815	704	486	409
	40	400	315	262	166	136
S2	5	2497	2273	2103	1715	1555
	25	926	770	665	458	386
	40	377	297	247	157	128
S3	5	2320	2113	1957	1599	1450
	25	867	723	624	432	364
	40	356	281	233	149	122
S4	5	2564	2335	2161	1764	1600
	25	955	795	686	474	400
	40	390	308	256	163	133
S5	5	2591	2360	2185	1784	1618
	25	967	805	695	481	405
	40	396	312	259	165	135
S6	5	2236	2039	1889	1546	1404
	25	843	704	609	422	357
	40	349	276	230	147	120
S7	5	2185	1991	1844	1508	1368
	25	819	683	590	409	345
	40	337	266	221	141	116
S8	5	2704	2461	2277	1858	1683
	25	1002	834	719	496	418
	40	408	322	267	169	138
S9	5	2773	2524	2336	1906	1727
	25	1029	857	739	510	430
	40	420	331	275	174	143
S10	5	2328	2120	1963	1604	1455
	25	870	725	626	433	365
	40	357	282	234	149	122

Table 7-1. Summary of Predicted Dynamic Modulus Values (Cont.)

(Brookfield RTFO Aged Condition, Birgisson et al. 2004)

Mixture	Temperature (°C)	Dynamic Modulus (ksi) at Frequency (Hz)				
		25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz
S11	5	2281	2078	1924	1572	1425
	25	852	710	613	424	358
	40	349	276	229	146	119
S12	5	1942	1772	1642	1346	1222
	25	737	616	533	371	313
	40	306	243	202	130	107
S13	5	2349	2140	1982	1620	1469
	25	879	733	633	438	370
	40	361	285	237	151	124
S14	5	2115	1926	1784	1458	1322
	25	791	659	570	394	333
	40	325	257	213	136	111
S15	5	2221	2023	1872	1529	1387
	25	828	690	596	412	347
	40	339	268	222	142	116
S16	5	2633	2397	2219	1812	1643
	25	980	817	705	487	411
	40	401	316	263	167	137
S17	5	2490	2268	2099	1713	1553
	25	927	772	666	460	388
	40	379	299	248	158	129
S18	5	2705	2463	2280	1861	1687
	25	1006	838	723	499	421
	40	411	324	269	171	140
S19	5	2276	2073	1919	1568	1421
	25	849	708	611	422	356
	40	348	275	228	145	119
S20	5	2188	1993	1845	1507	1366
	25	817	680	588	406	343
	40	335	264	219	140	114

Table 7-2. Summary of Predicted Dynamic Modulus Values

(Mix/laydown Condition, Witczak and Fonseca 1996)

Mixture	Temperature (°C)	Dynamic Modulus (ksi) at Frequency (Hz)				
		25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz
S1	5	2681	2446	2267	1857	1686
	25	973	809	698	482	406
	40	386	304	252	160	131
S2	5	2541	2317	2147	1758	1596
	25	920	765	660	455	383
	40	365	287	238	151	123
S3	5	2360	2154	1998	1638	1488
	25	862	718	620	428	361
	40	344	271	225	143	117
S4	5	2609	2380	2206	1808	1642
	25	948	790	681	470	396
	40	378	297	247	157	128
S5	5	2636	2406	2230	1829	1661
	25	960	800	690	477	402
	40	383	302	250	159	130
S6	5	2275	2078	1928	1584	1440
	25	838	699	604	419	354
	40	337	266	221	141	116
S7	5	2223	2029	1882	1545	1404
	25	814	678	586	406	342
	40	326	257	214	136	111
S8	5	2752	2509	2325	1904	1728
	25	996	828	714	492	414
	40	395	310	257	163	133
S9	5	2821	2573	2385	1953	1773
	25	1022	851	734	506	426
	40	406	319	265	168	137
S10	5	2368	2162	2004	1644	1493
	25	864	720	621	430	362
	40	345	272	226	144	117

Table 7-2. Summary of Predicted Dynamic Modulus Values (Cont.)

(Mix/laydown Condition, Witczak and Fonseca 1996)

Mixture	Temperature (°C)	Dynamic Modulus (ksi) at Frequency (Hz)				
		25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz
S11	5	2321	2118	1964	1610	1463
	25	846	705	609	421	354
	40	338	266	221	140	115
S12	5	1976	1806	1676	1379	1254
	25	732	611	529	368	311
	40	296	234	195	125	103
S13	5	2390	2182	2023	1660	1508
	25	873	728	628	435	367
	40	349	275	229	146	119
S14	5	2152	1964	1821	1494	1357
	25	786	655	565	391	330
	40	314	248	206	131	107
S15	5	2260	2062	1912	1567	1423
	25	823	685	591	408	344
	40	328	258	214	136	111
S16	5	2679	2444	2266	1857	1686
	25	974	811	700	483	407
	40	388	305	253	161	131
S17	5	2534	2312	2143	1756	1595
	25	921	766	661	456	385
	40	366	289	239	152	124
S18	5	2753	2511	2327	1907	1732
	25	999	832	718	495	417
	40	397	313	259	165	135
S19	5	2316	2114	1960	1607	1459
	25	844	703	606	419	353
	40	336	265	220	140	114
S20	5	2226	2031	1883	1544	1403
	25	811	676	583	403	340
	40	324	255	212	135	110

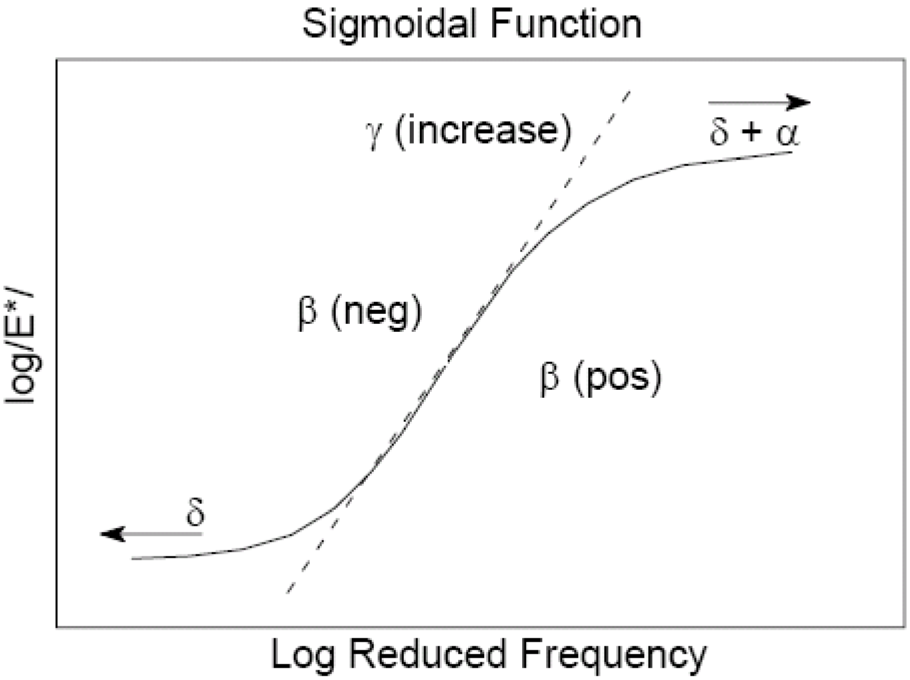


Figure 7-1. Parameters Used in Sigmoidal Fitting Function of Master Curve

(Birgisson et al. 2004)

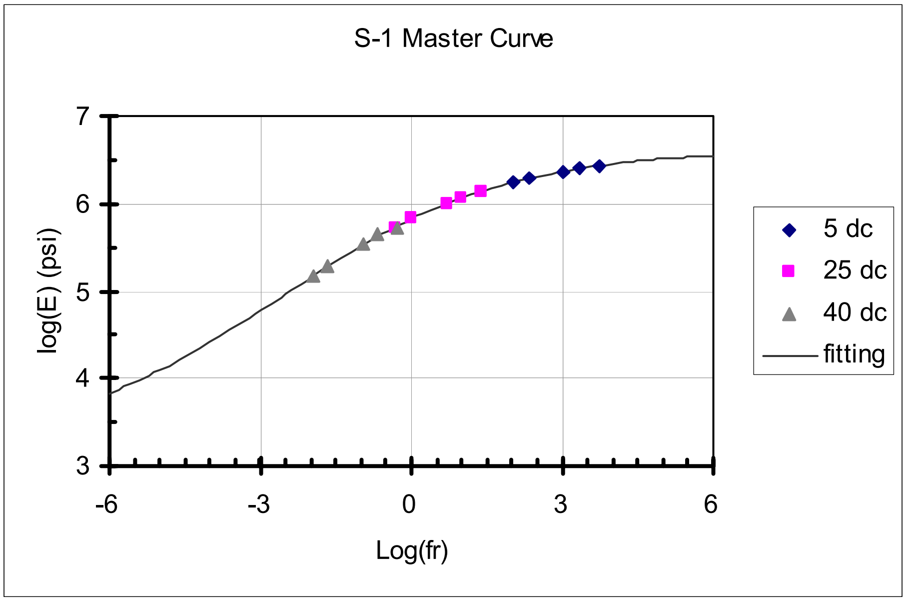


Figure 7-2. Master Curve for S-1 mixture

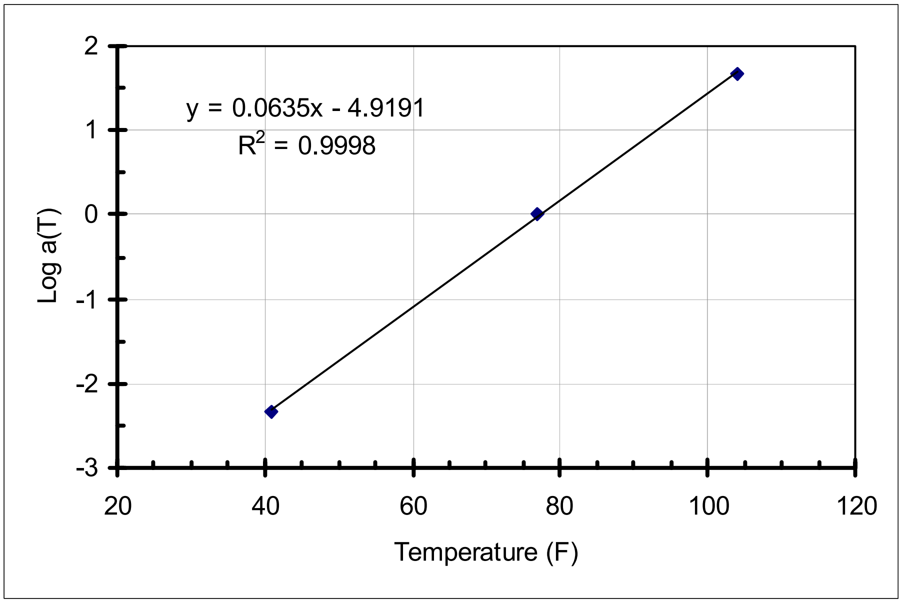


Figure 7-3. Shift function for S-1 mixture

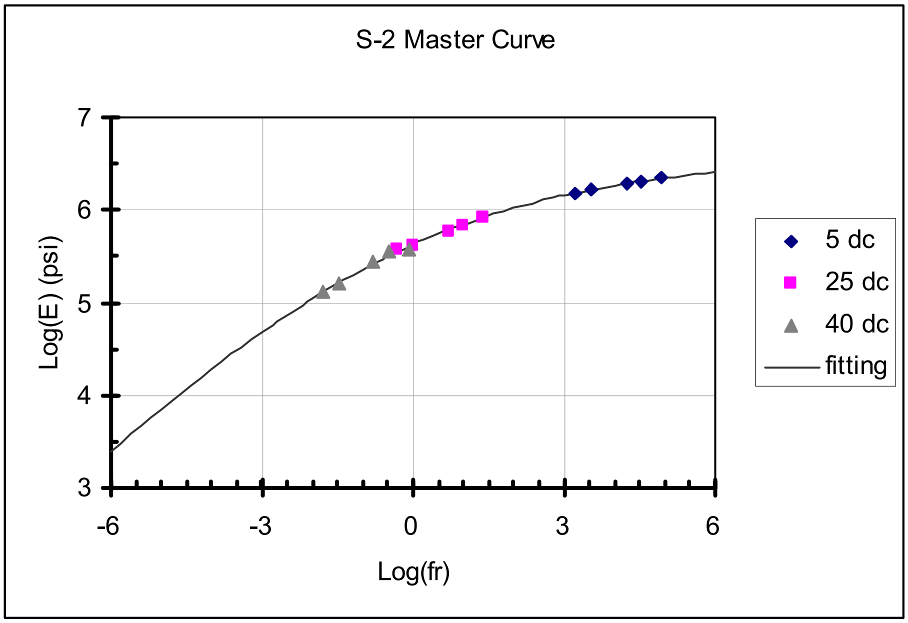


Figure 7-4. Master Curve for S-2 mixture

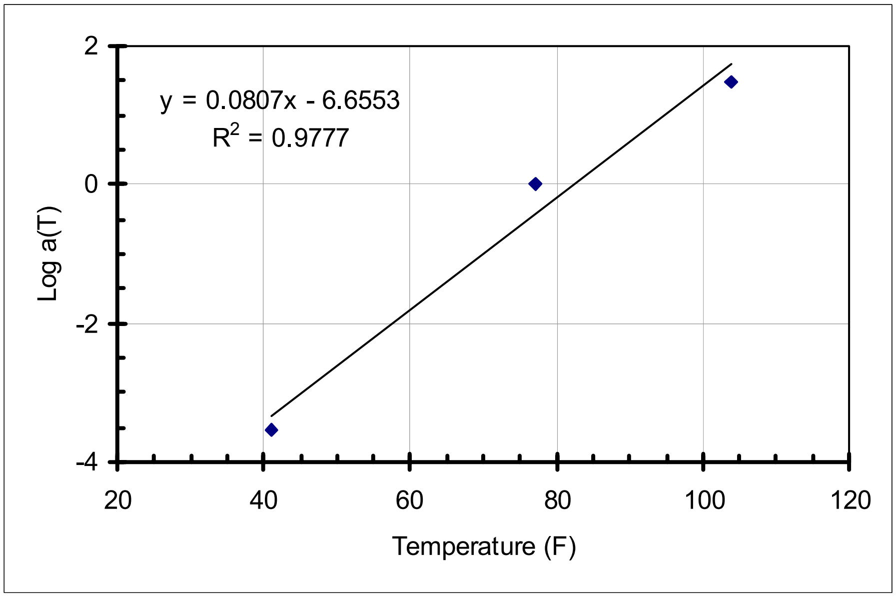


Figure 7-5. Shift function for S-2 mixture

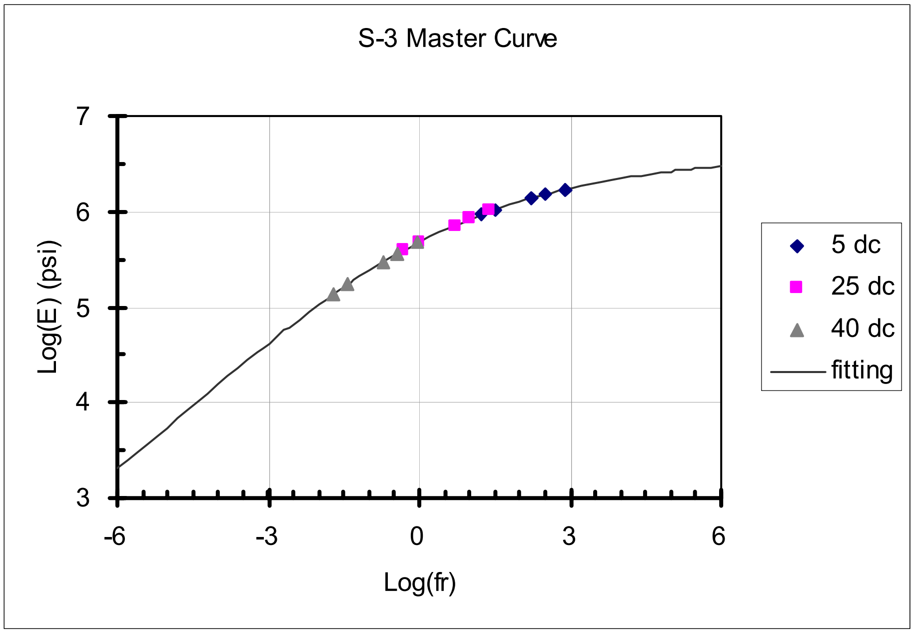


Figure 7-6. Master Curve for S-3 mixture

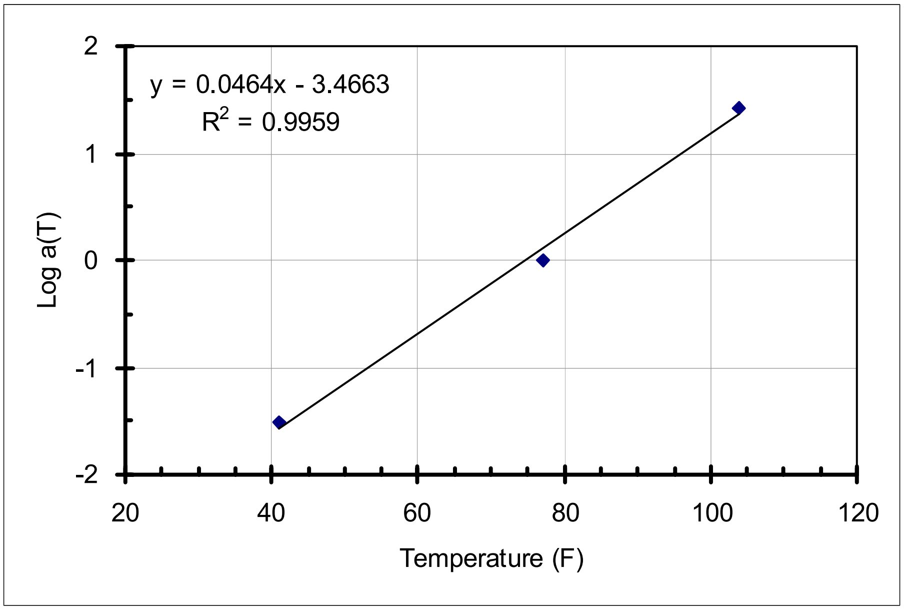


Figure 7-7. Shift function for S-3 mixture

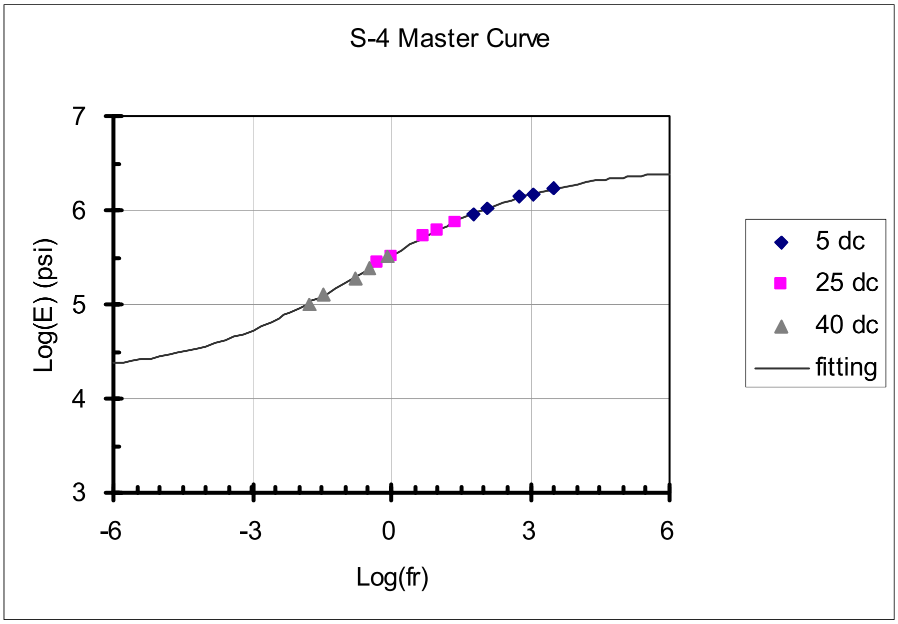


Figure 7-8. Master Curve for S-4 mixture

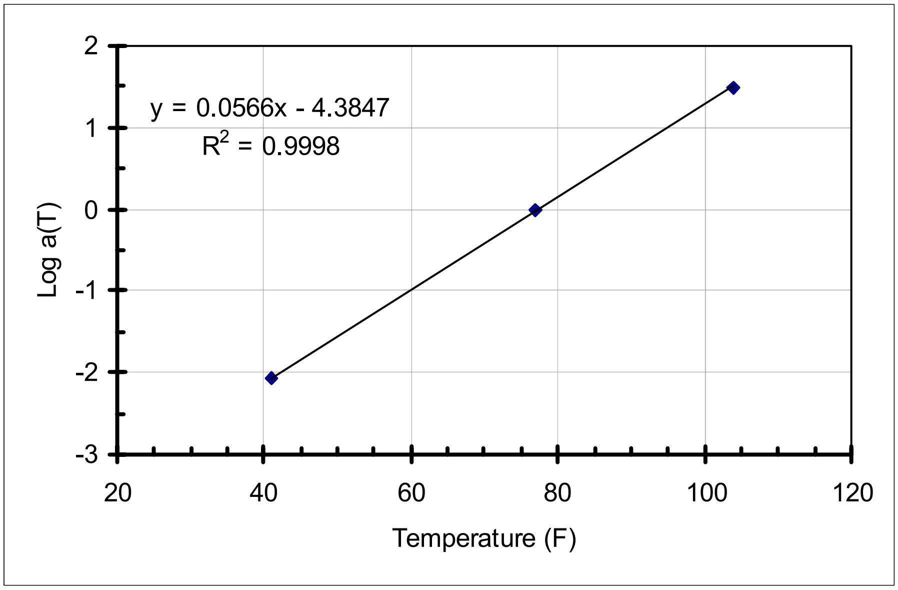


Figure 7-9. Shift function for S-4 mixture

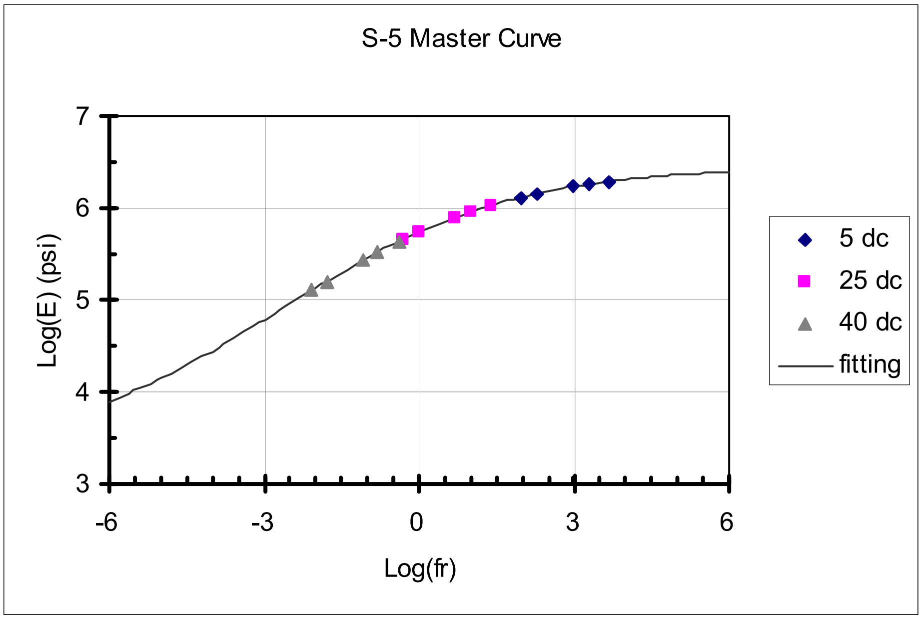


Figure 7-10. Master Curve for S-5 mixture

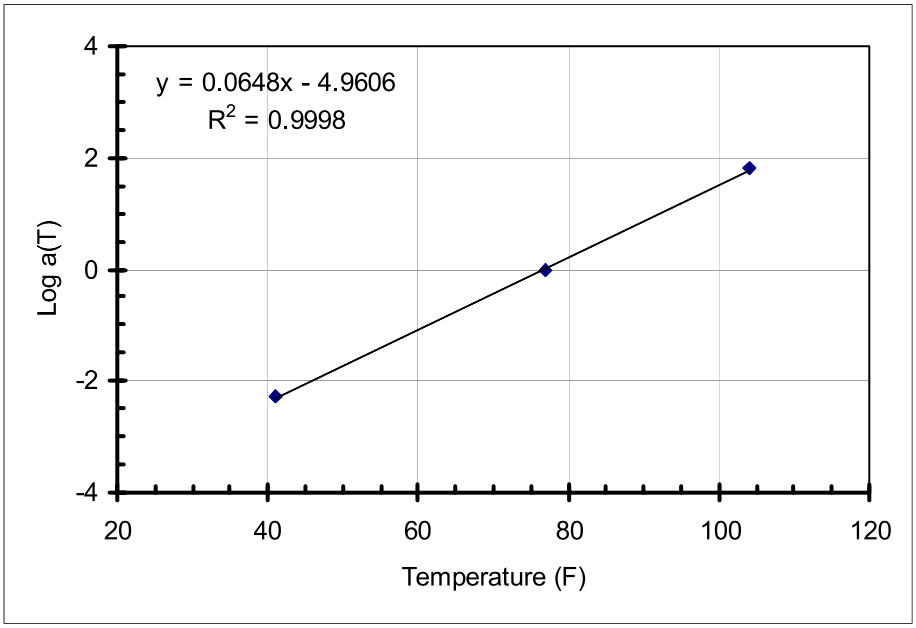


Figure 7-11. Shift function for S-5 mixture

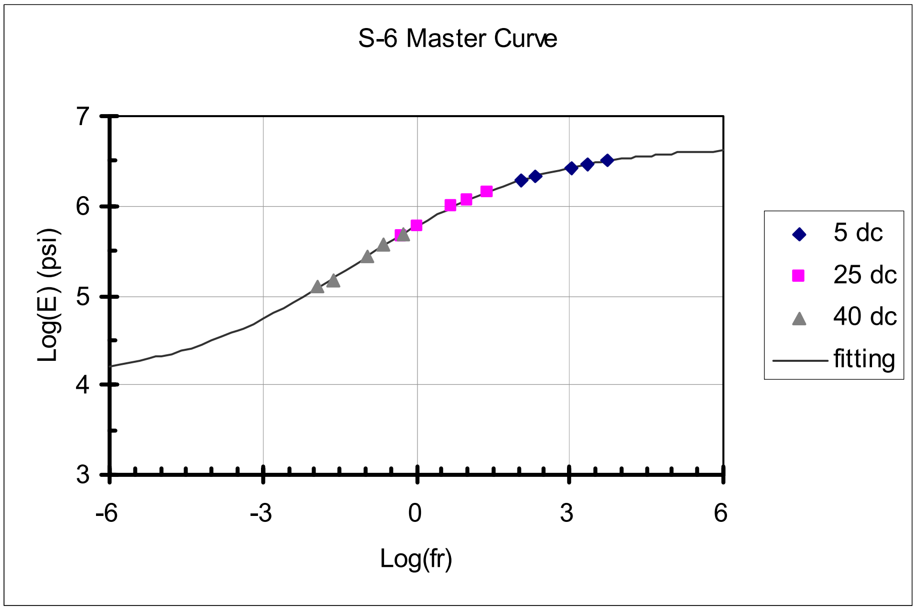


Figure 7-12. Master Curve for S-6 mixture

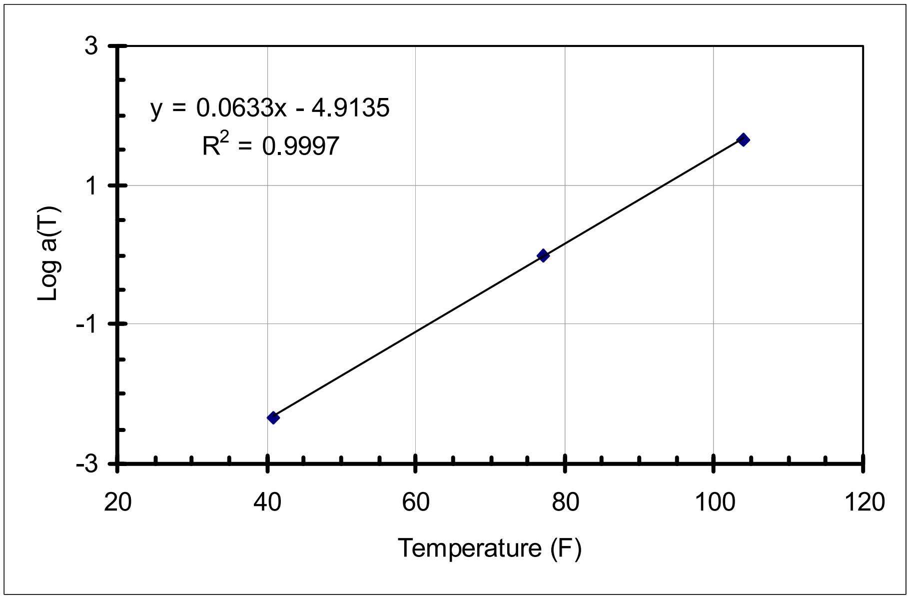


Figure 7-13. Shift function for S-6 mixture

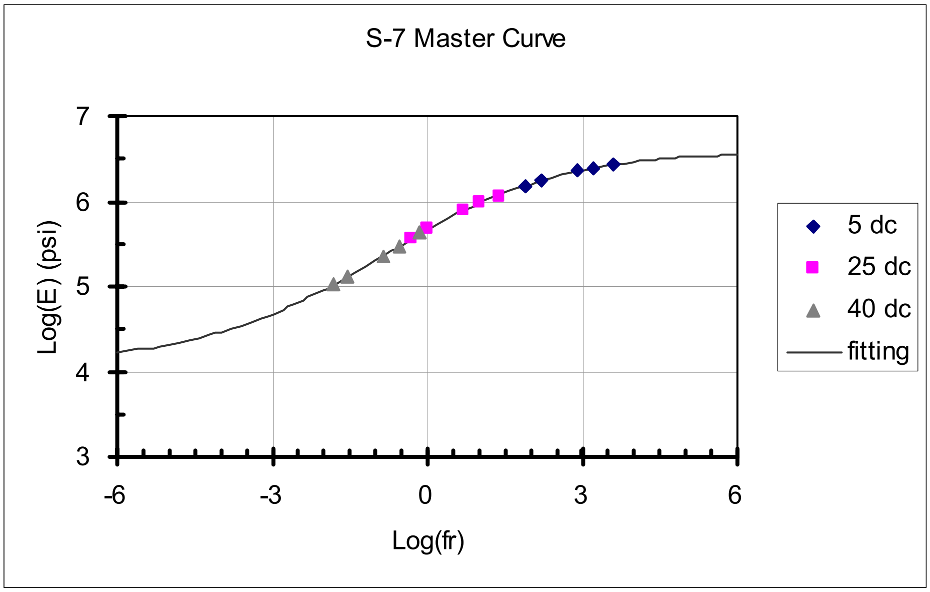


Figure 7-14. Master Curve for S-7 mixture

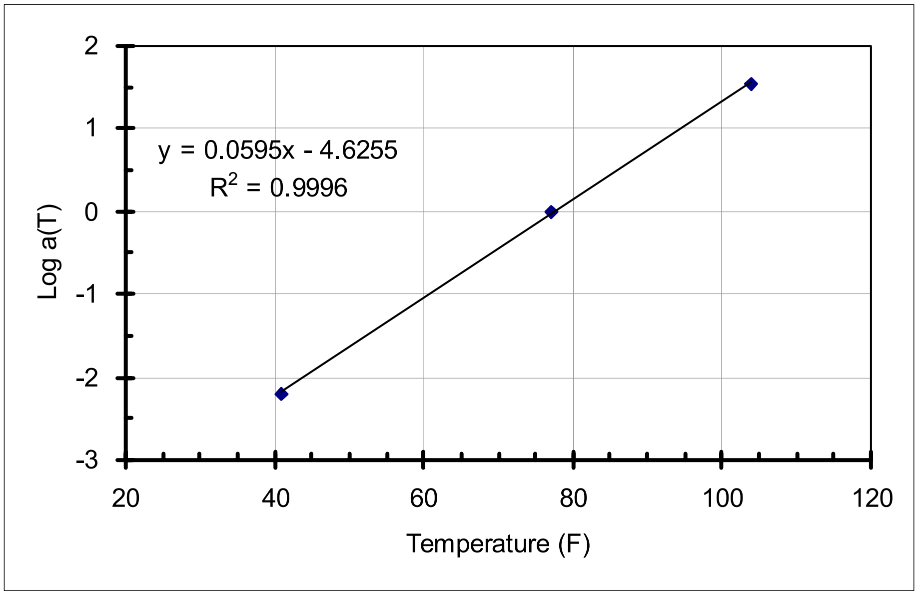


Figure 7-15. Shift function for S-7 mixture

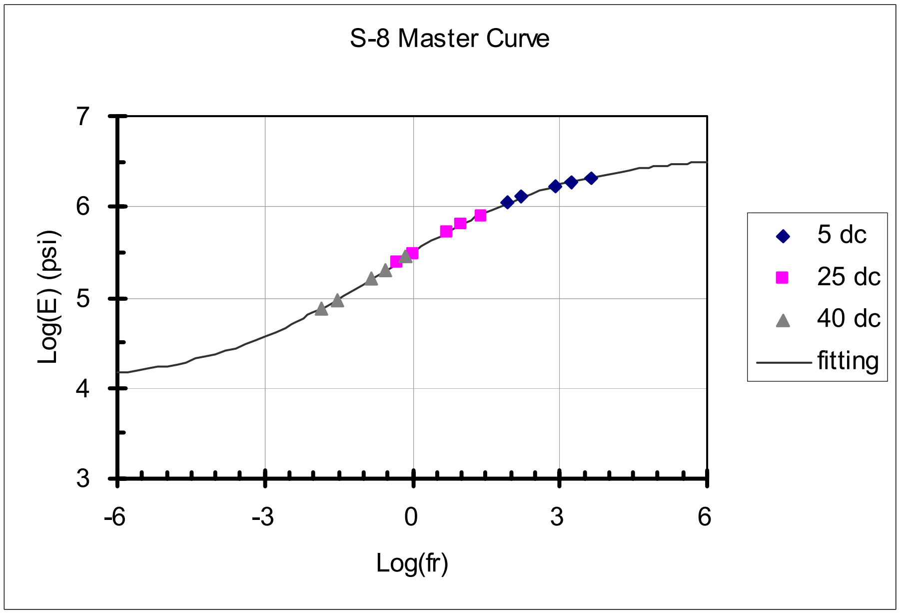


Figure 7-16. Master Curve for S-8 mixture

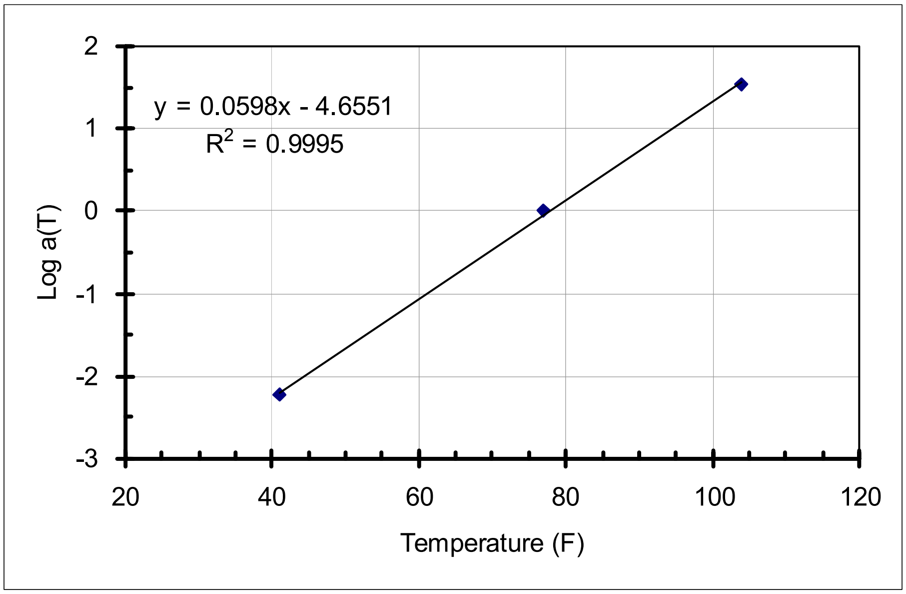


Figure 7-17. Shift function for S-8 mixture

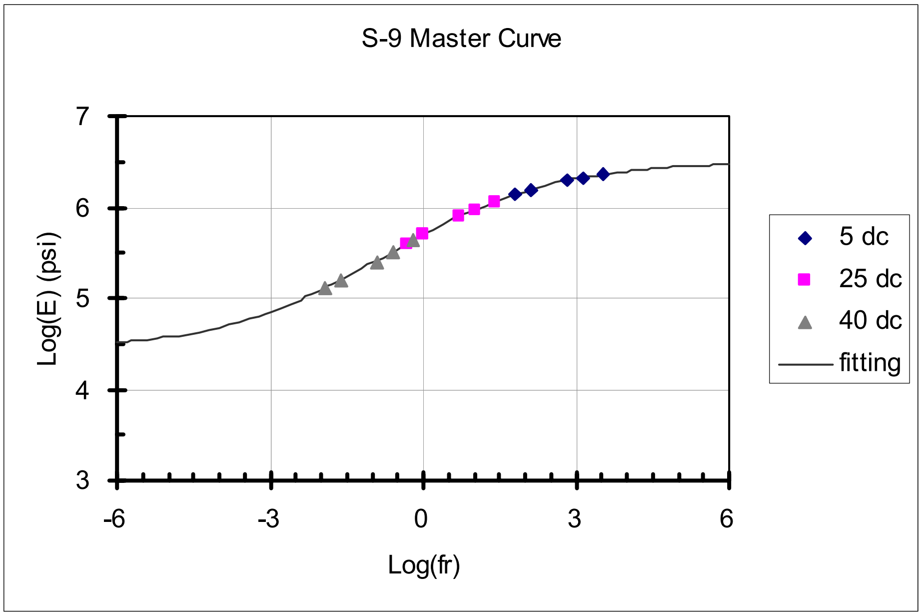


Figure 7-18. Master Curve for S-9 mixture

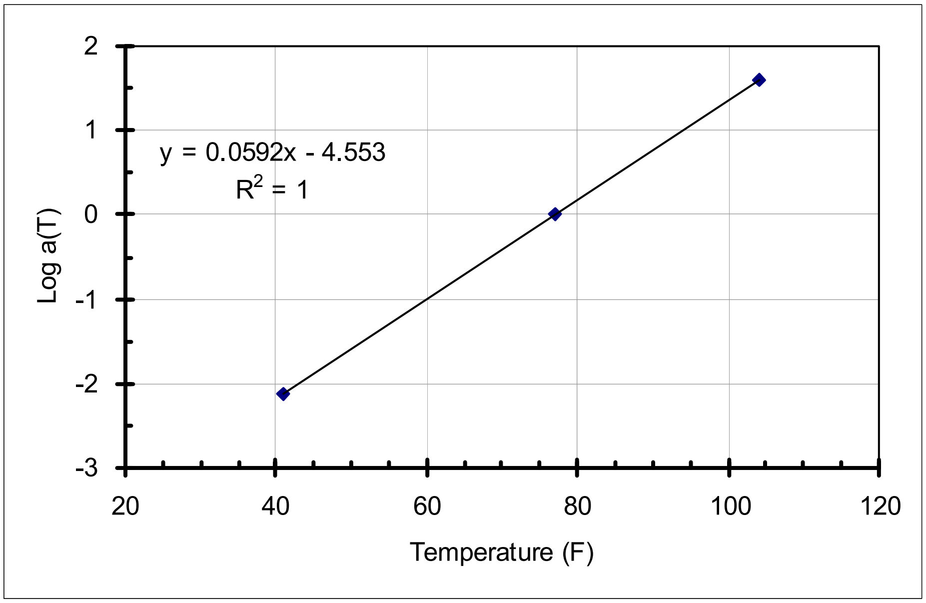


Figure 7-19. Shift function for S-9 mixture

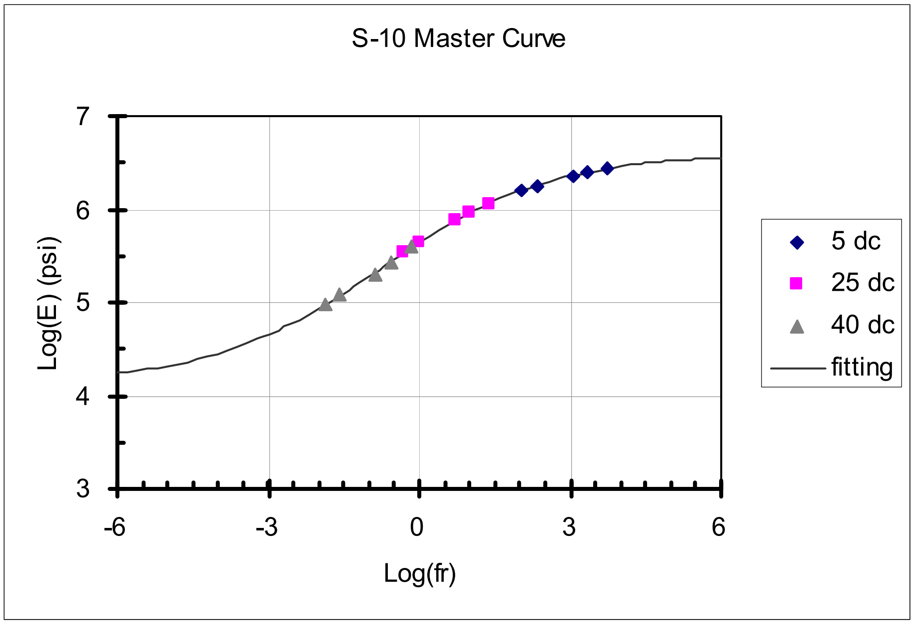


Figure 7-20. Master Curve for S-10 mixture

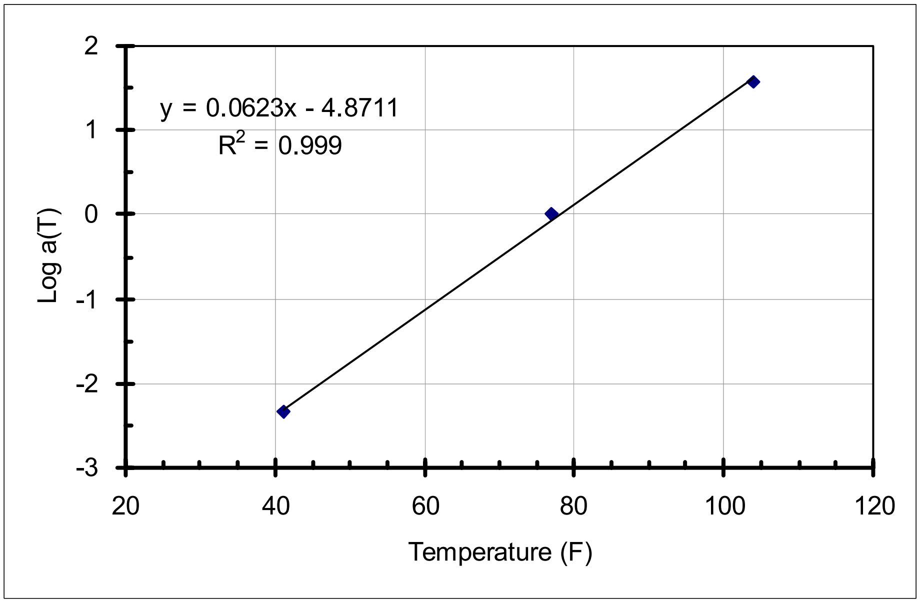


Figure 7-21. Shift function for S-10 mixture

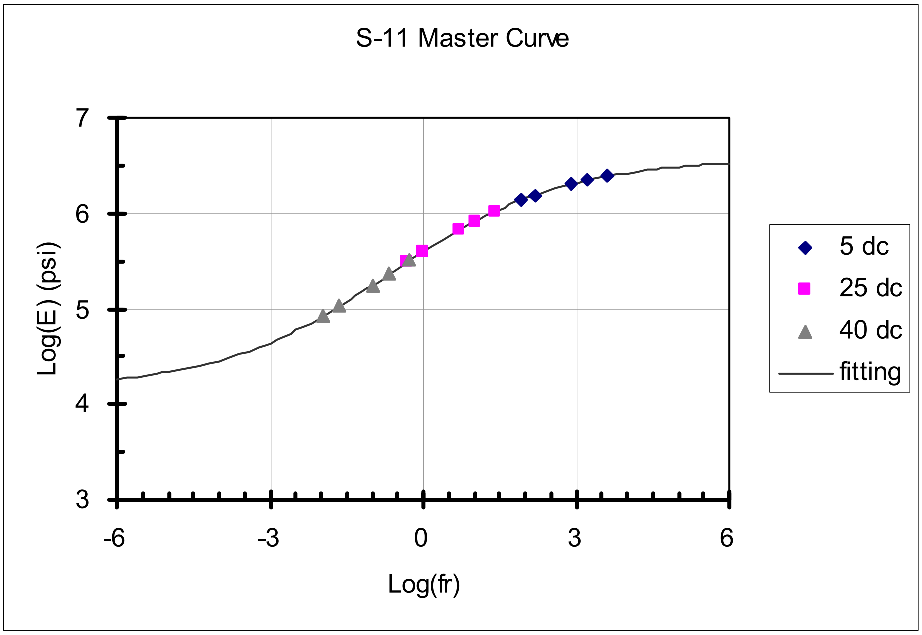


Figure 7-22. Master Curve for S-11 mixture

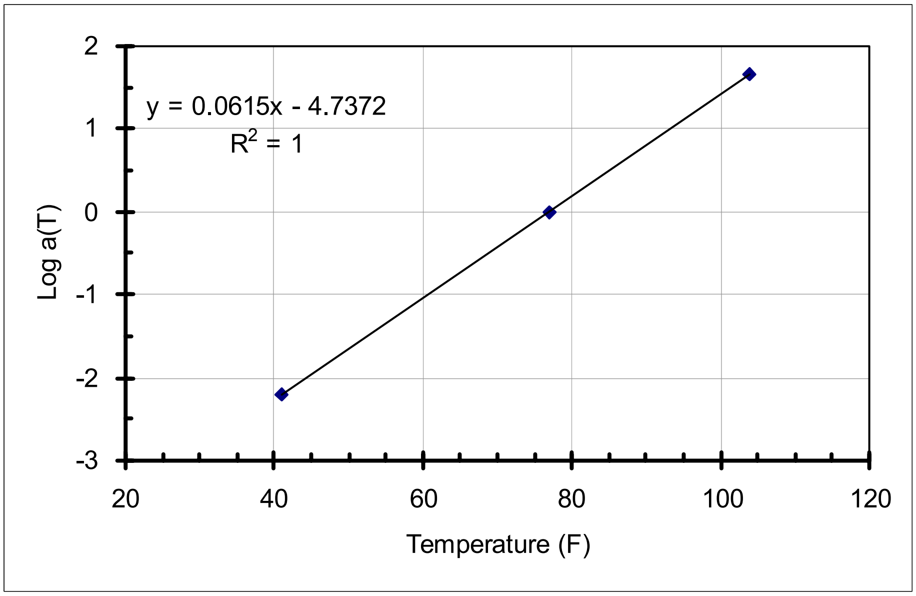


Figure 7-23. Shift function for S-11 mixture

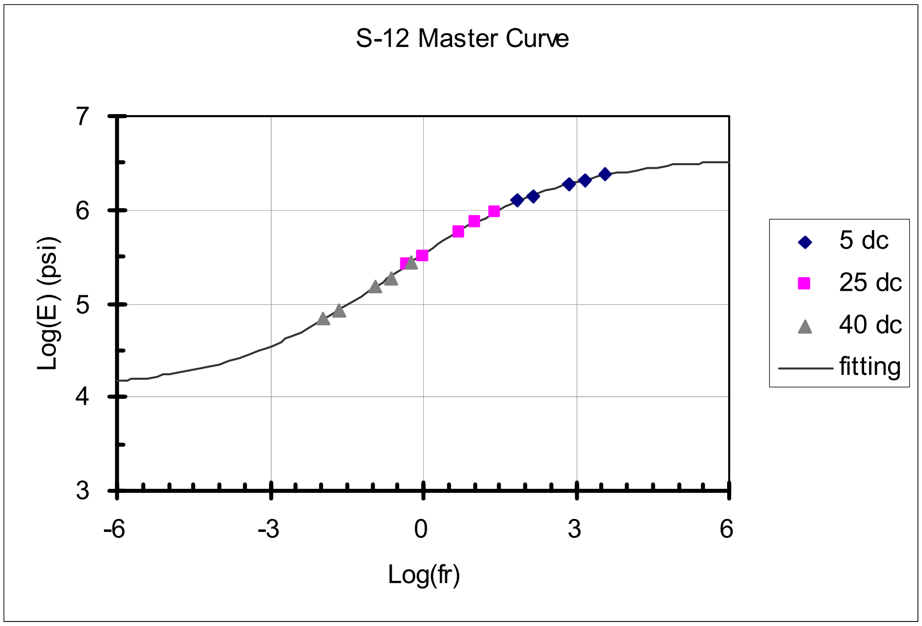


Figure 7-24. Master Curve for S-12 mixture

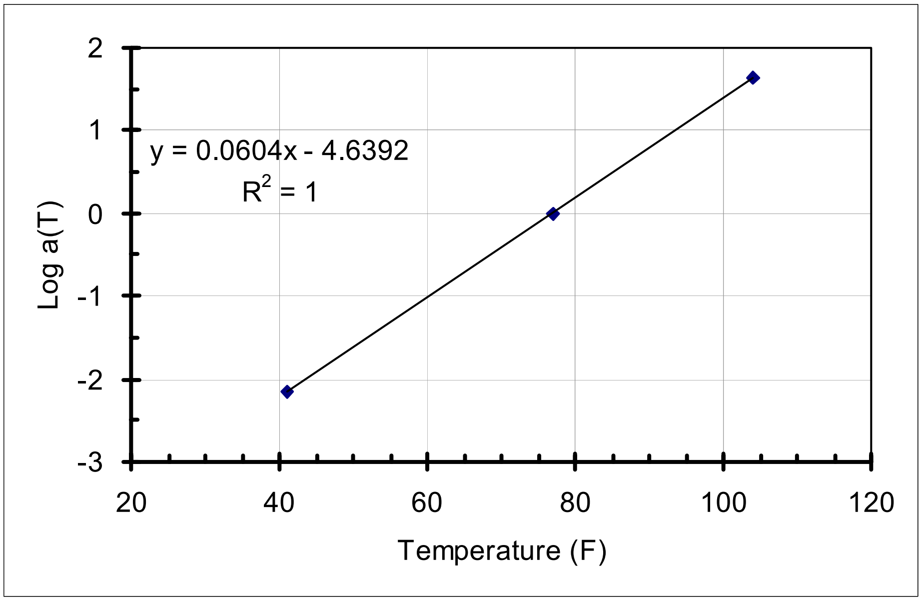


Figure 7-25. Shift function for S-12 mixture

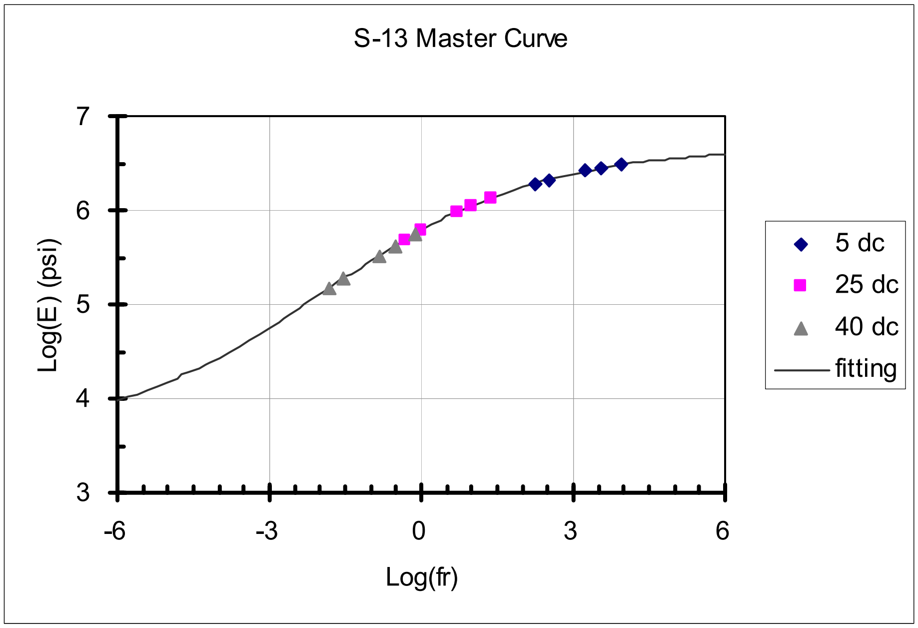


Figure 7-26. Master Curve for S-13 mixture

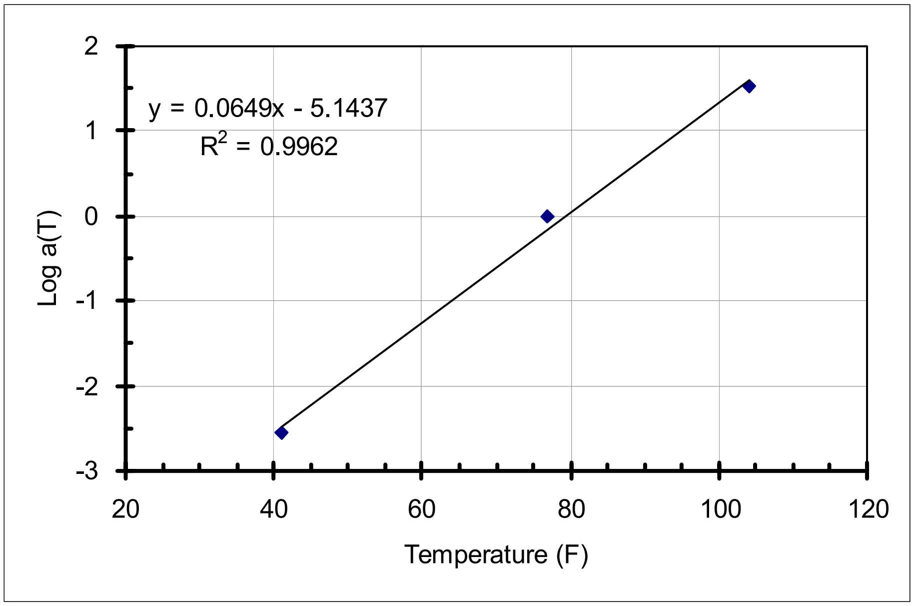


Figure 7-27. Shift function for S-13 mixture

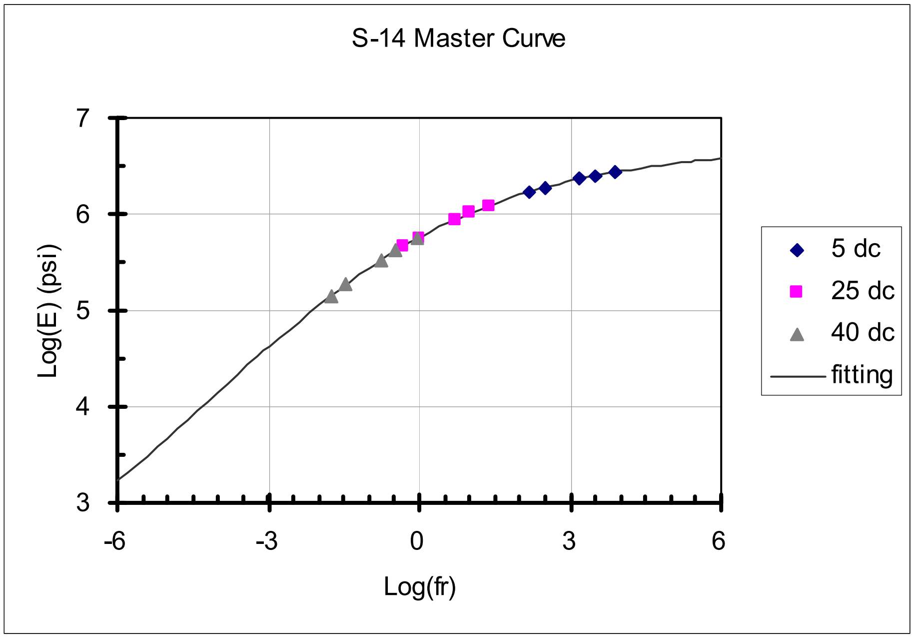


Figure 7-28. Master Curve for S-14 mixture

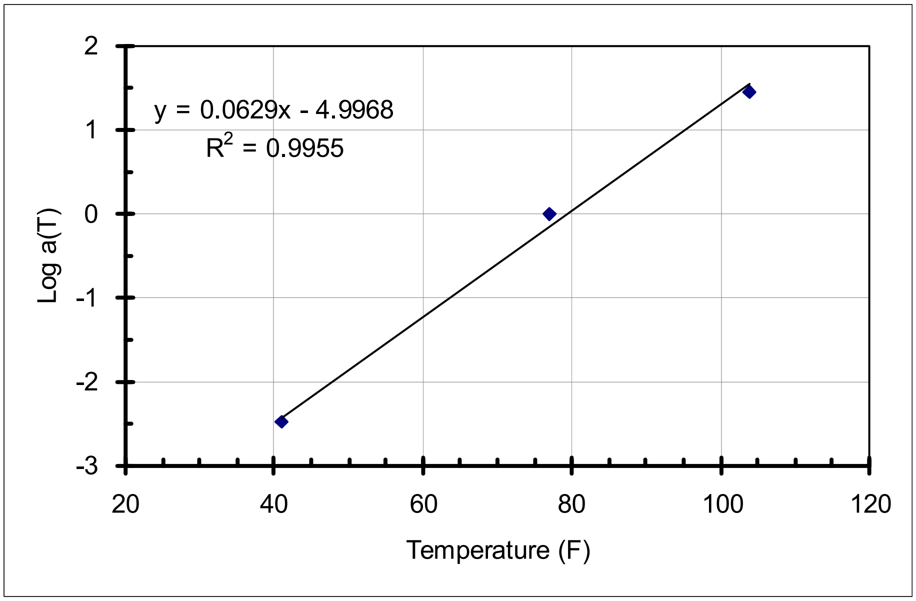


Figure 7-29. Shift function for S-14 mixture

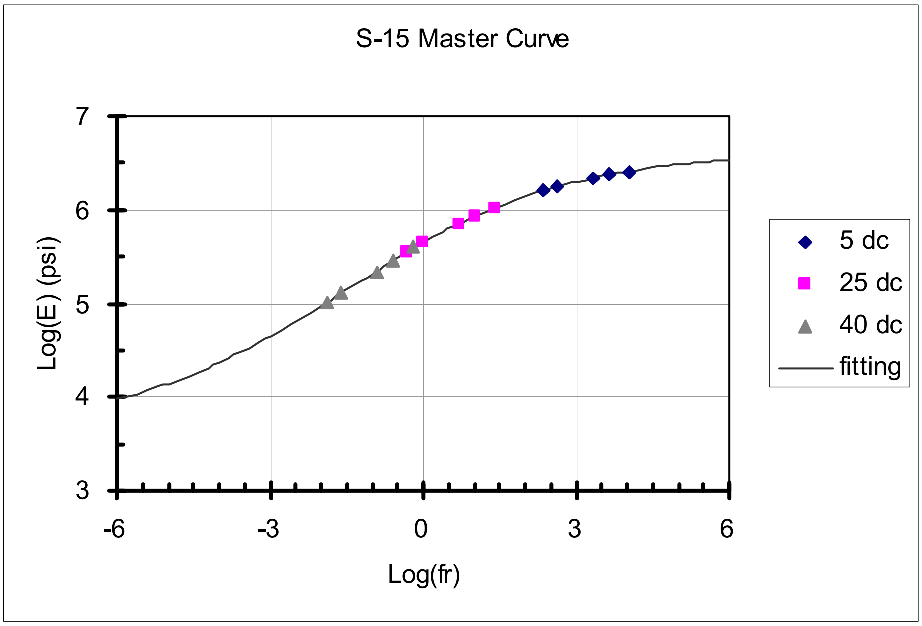


Figure 7-30. Master Curve for S-15 mixture

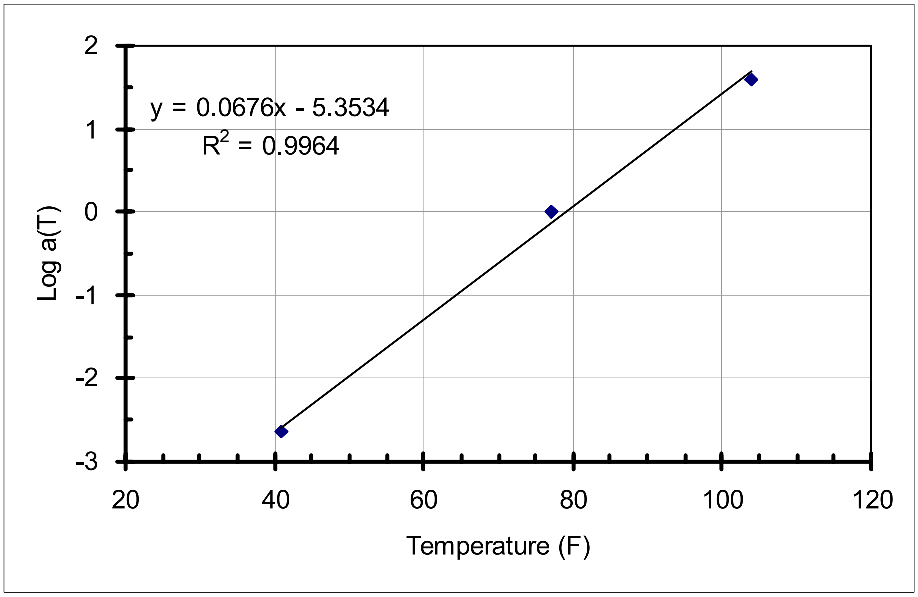


Figure 7-31. Shift function for S-15 mixture

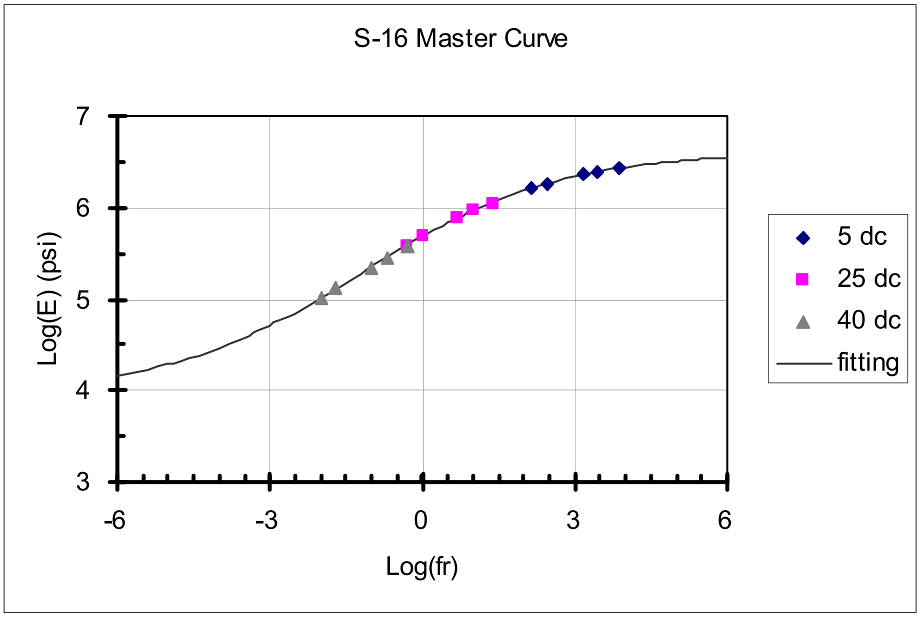


Figure 7-32. Master Curve for S-16 mixture

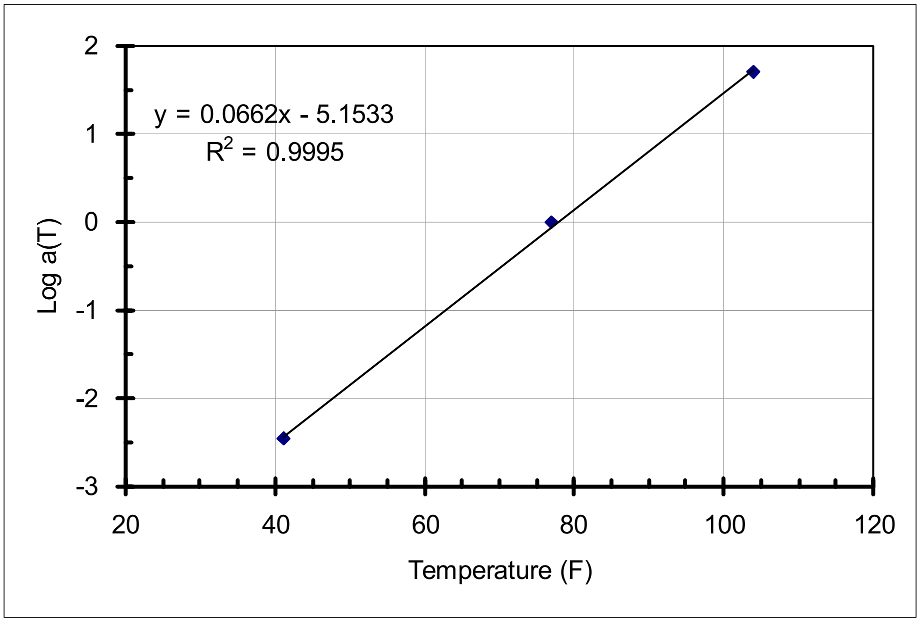


Figure 7-33. Shift function for S-16 mixture

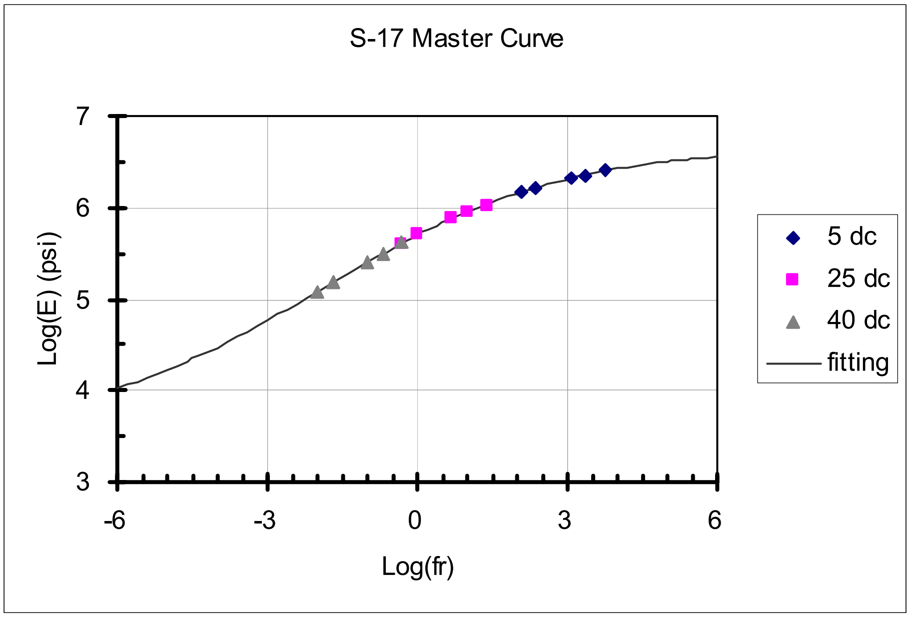


Figure 7-34. Master Curve for S-17 mixture

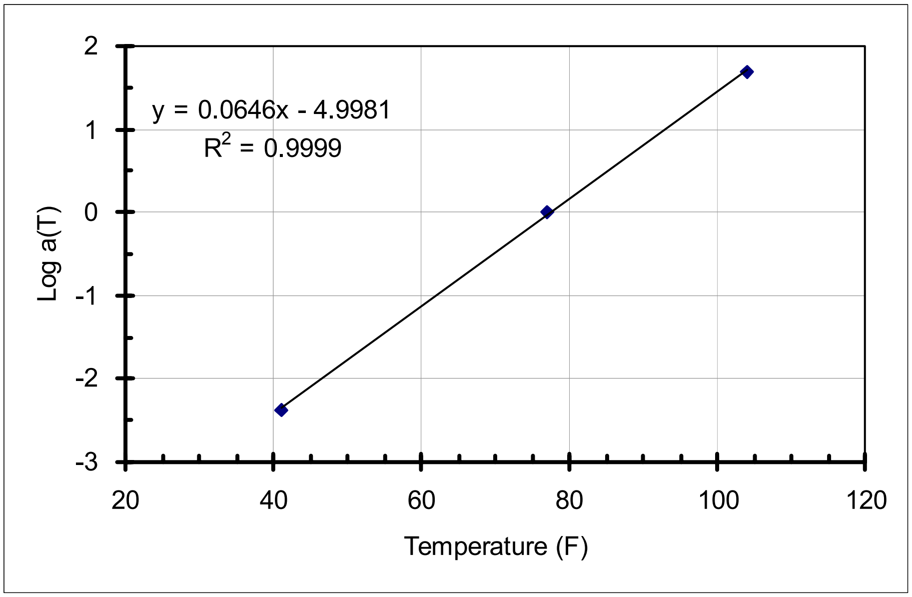


Figure 7-35. Shift function for S-17 mixture

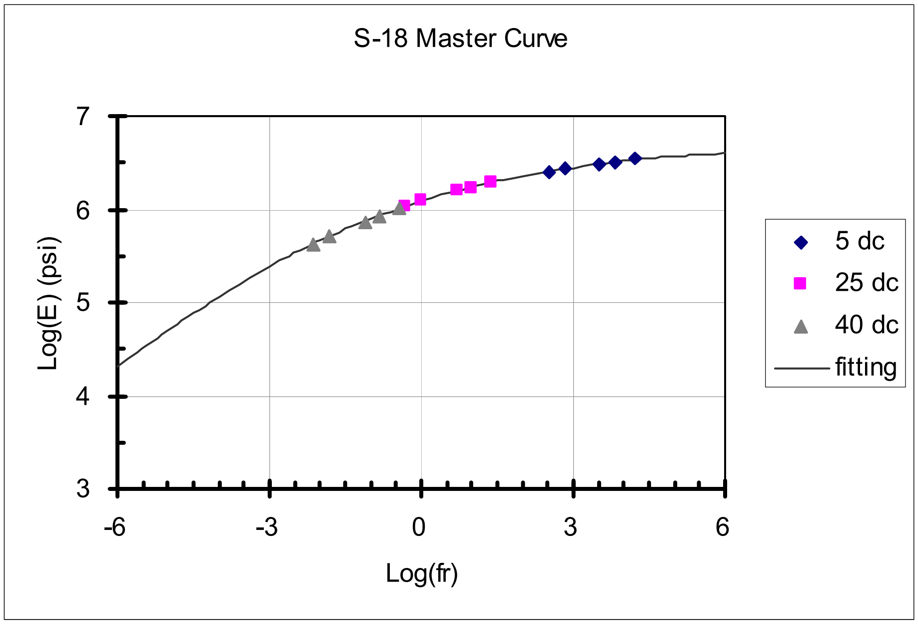


Figure 7-36. Master Curve for S-18 mixture

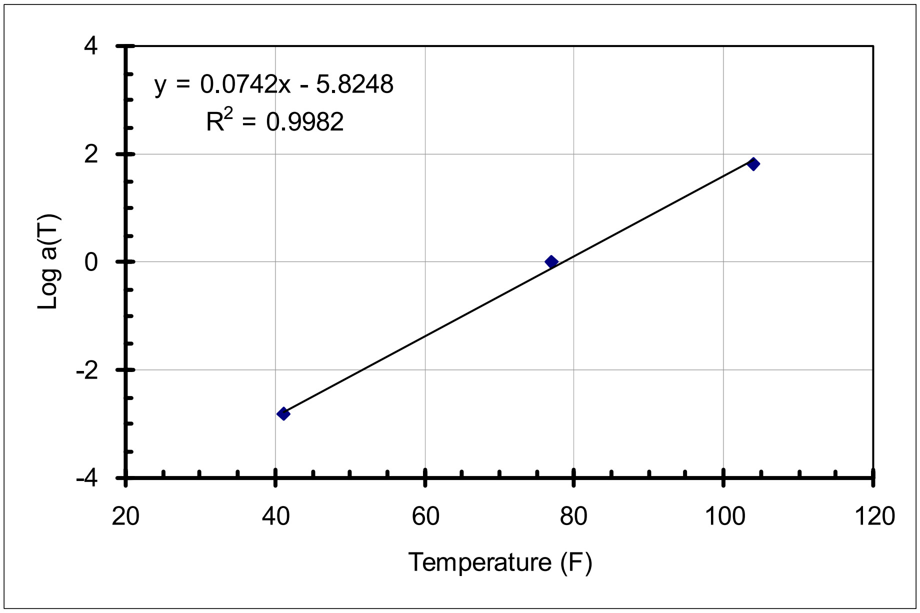


Figure 7-37. Shift function for S-18 mixture

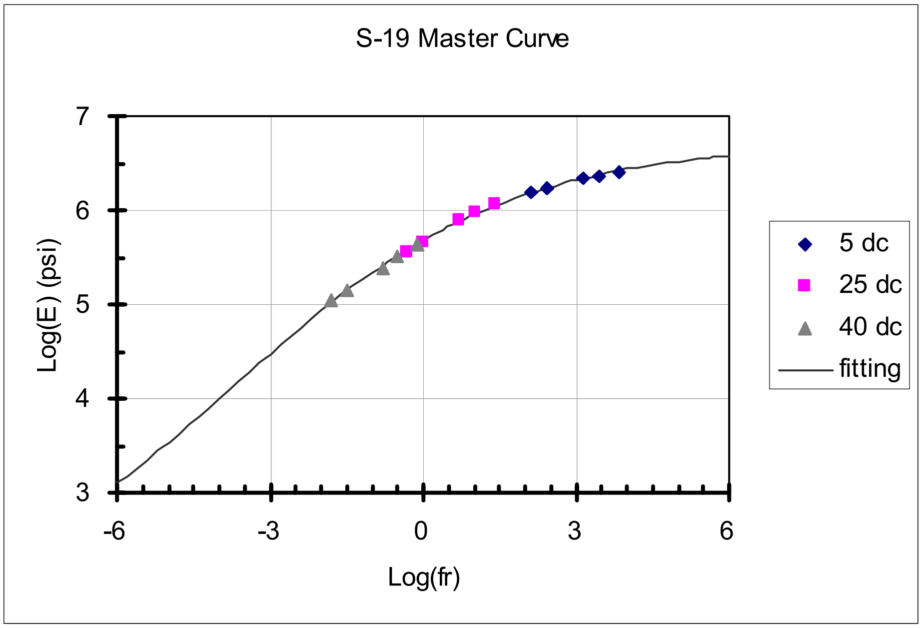


Figure 7-38. Master Curve for S-19 mixture

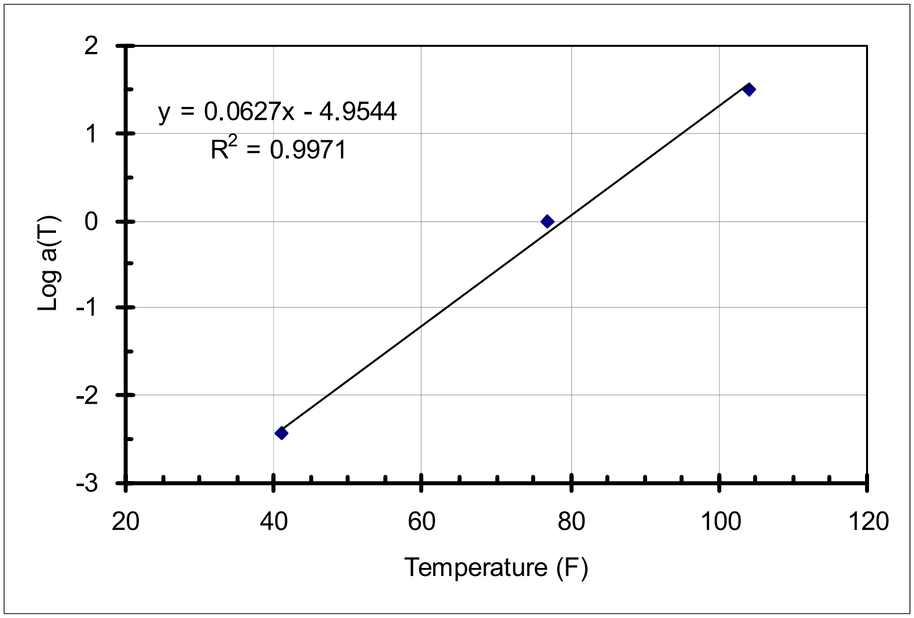


Figure 7-39. Shift function for S-19 mixture

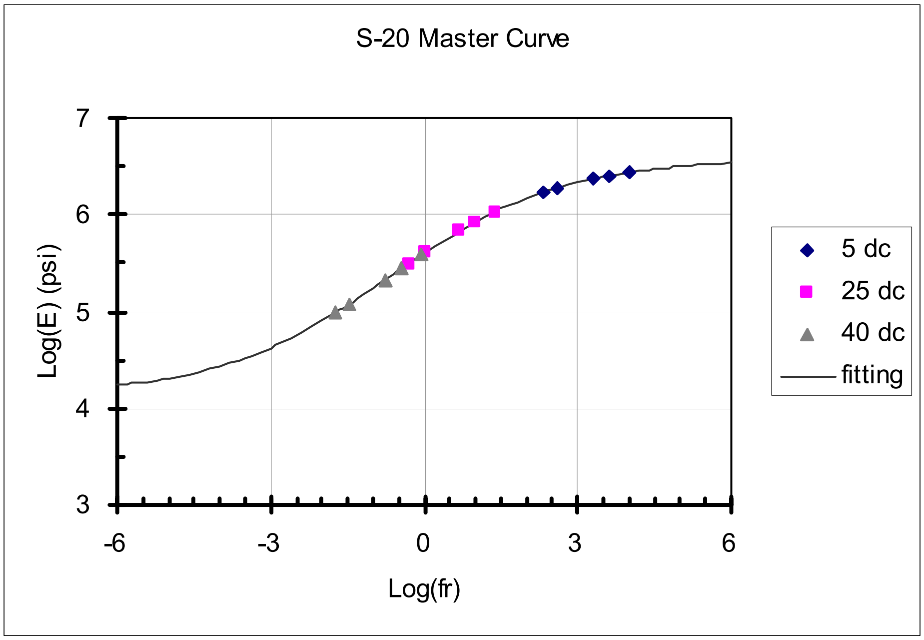


Figure 7-40. Master Curve for S-20 mixture

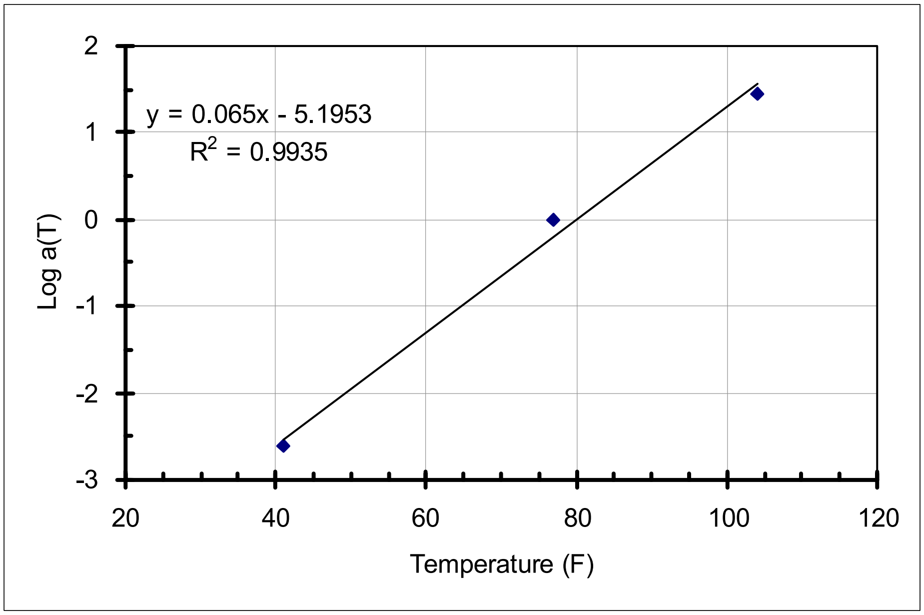


Figure 7-41. Shift function for S-20 mixture

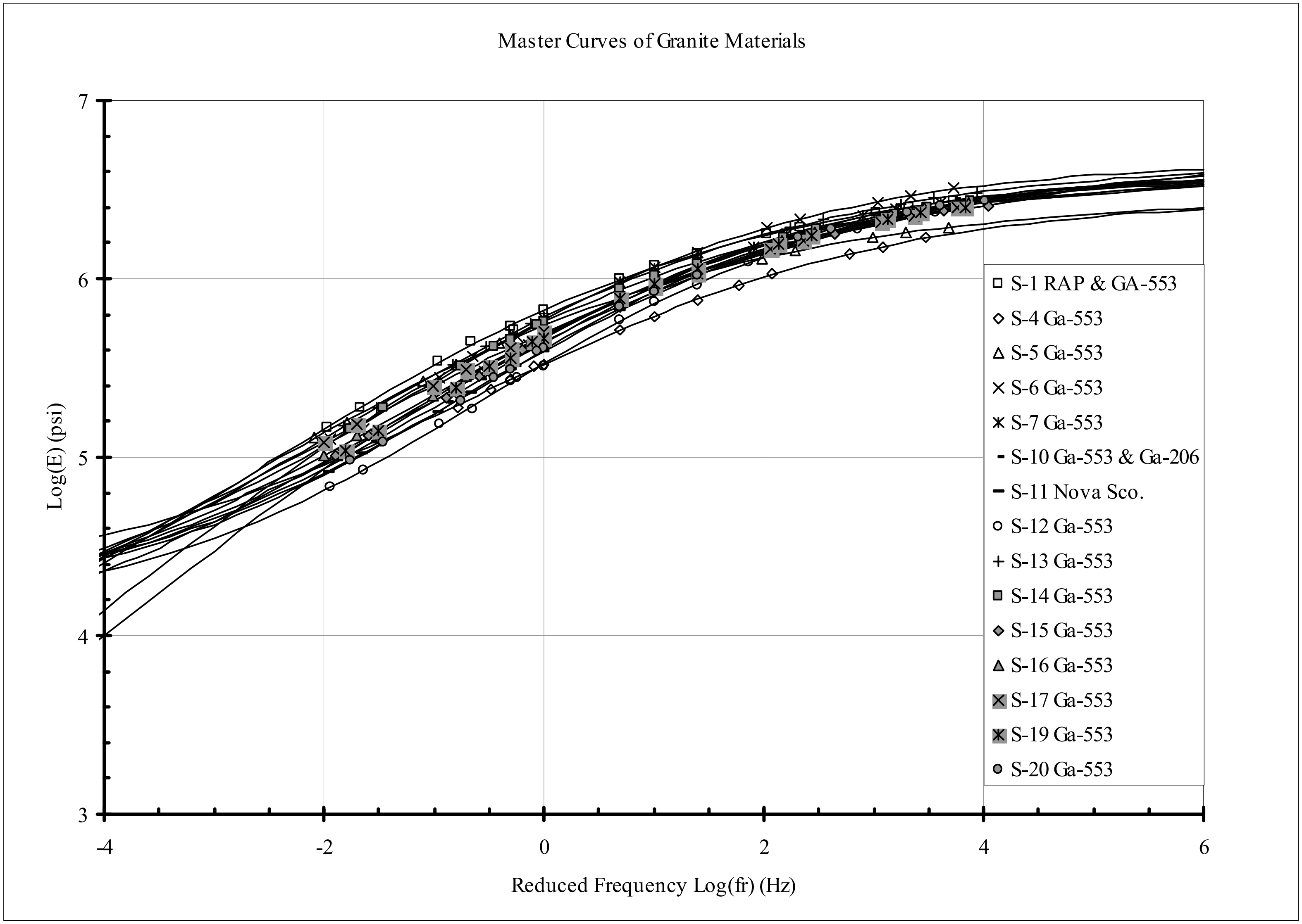


Figure 7-42. Master Curves for Granite Materials

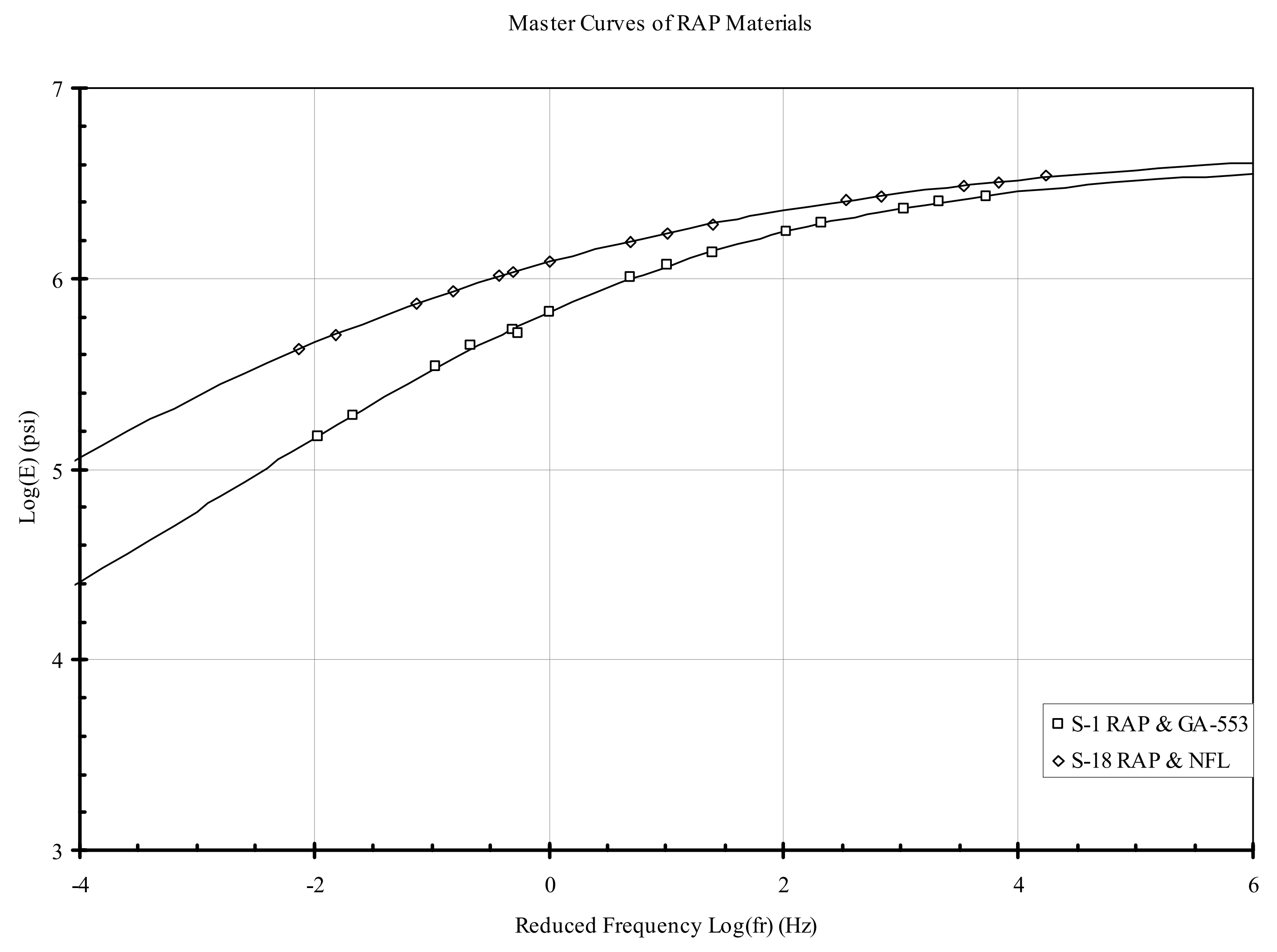


Figure 7-43. Master Curves for RAP materials

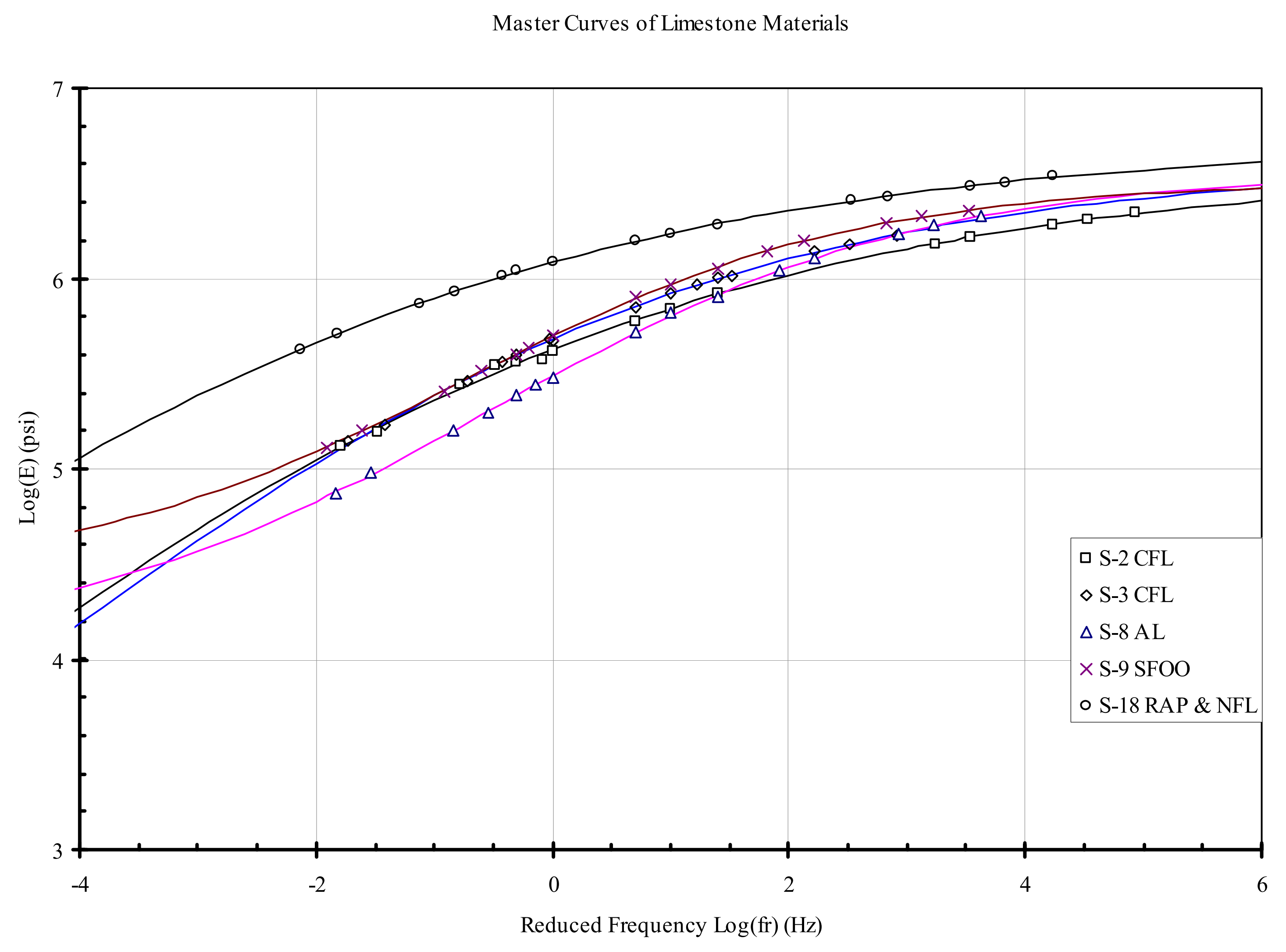


Figure 7-44. Master Curves for Limestone Materials

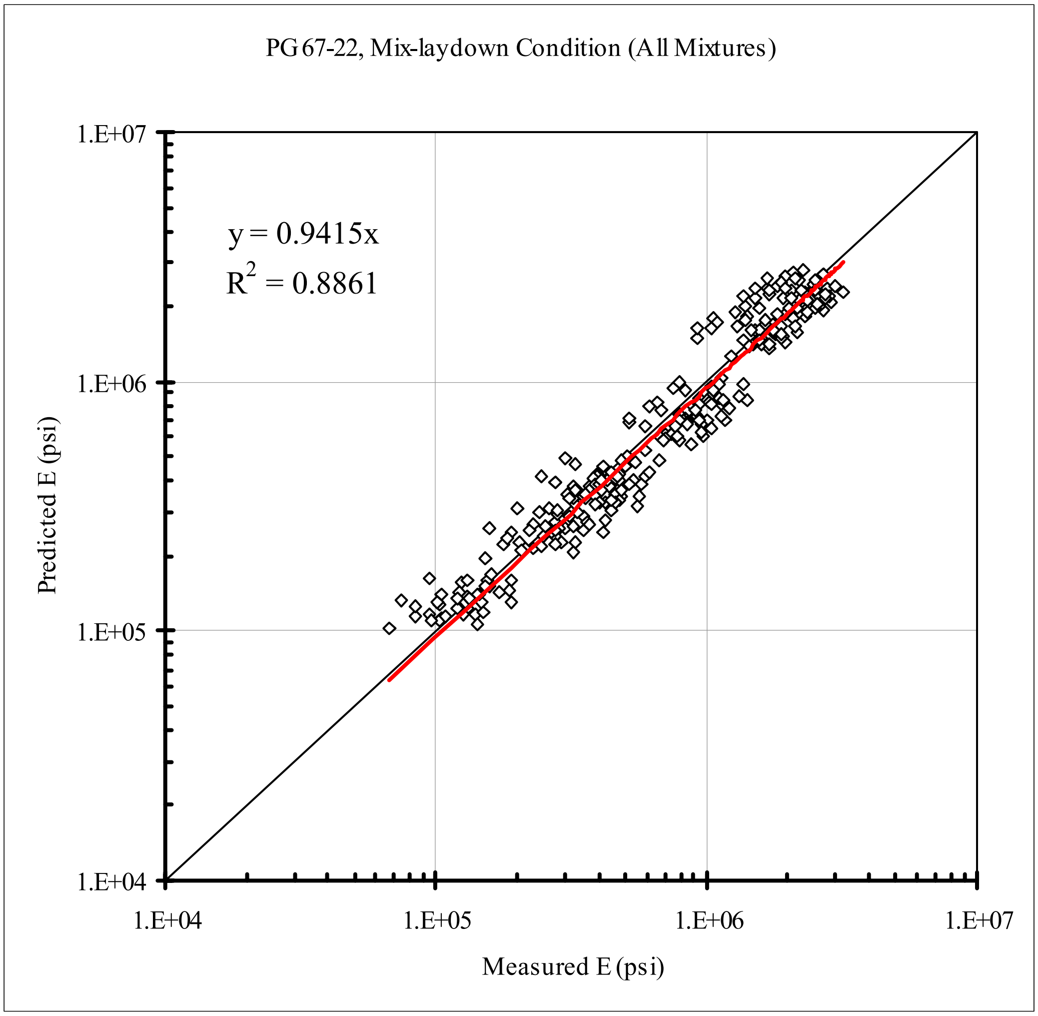


Figure 7-45. Measured values versus predicted values of dynamic modulus

(Asphalt binder PG 67-22, mix-laydown condition)

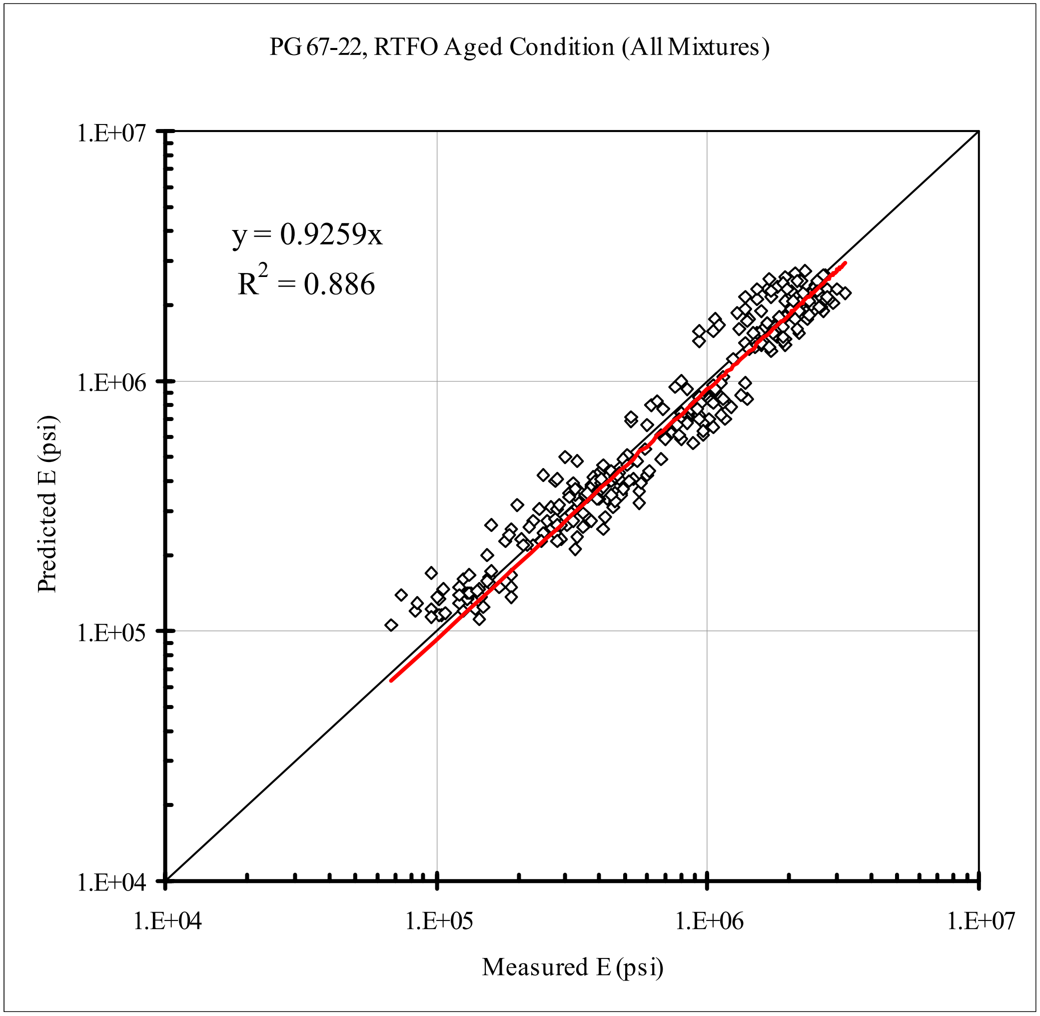


Figure 7-46. Measured values versus predicted values of dynamic modulus

(Asphalt binder PG 67-22, RTFO aged condition)

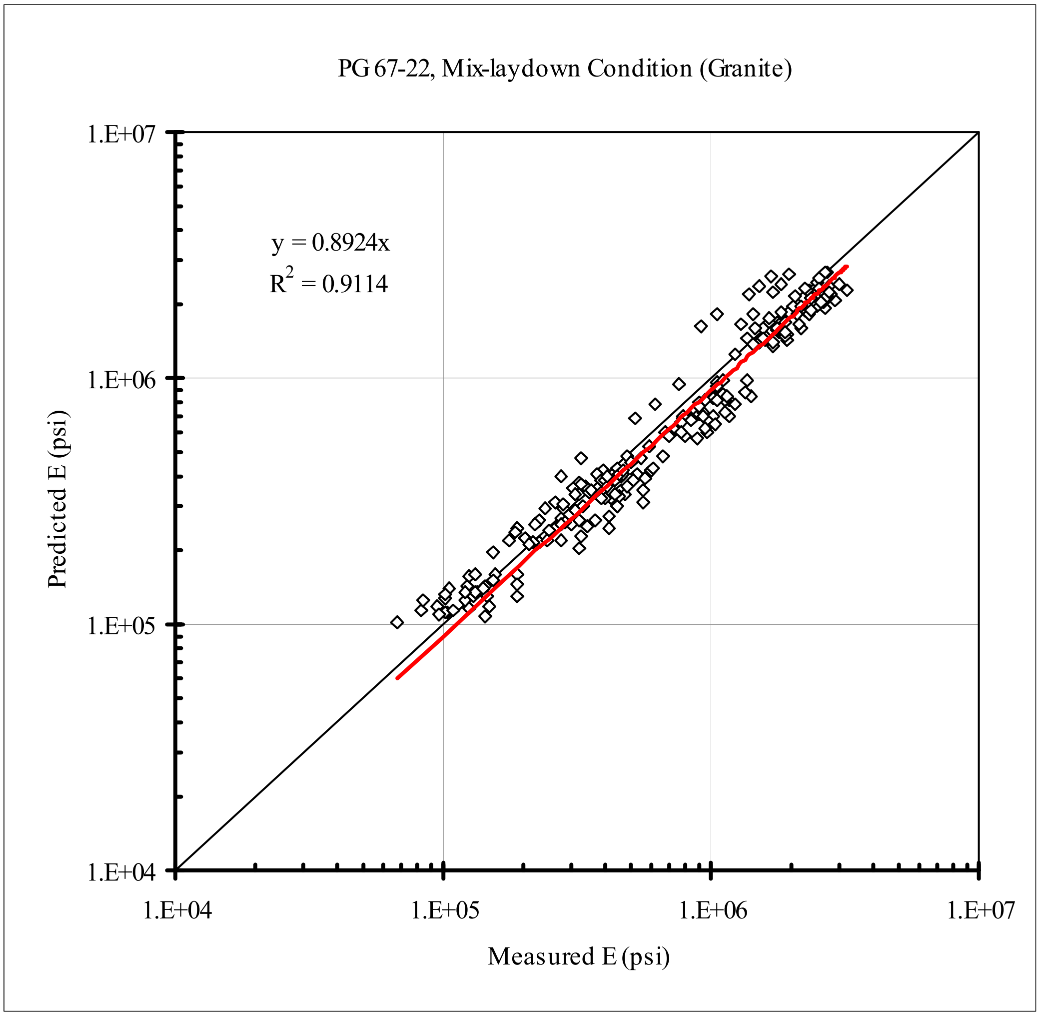


Figure 7-47. Measured values versus predicted values of dynamic modulus for granite materials (Asphalt binder PG 67-22, mix-laydown condition)

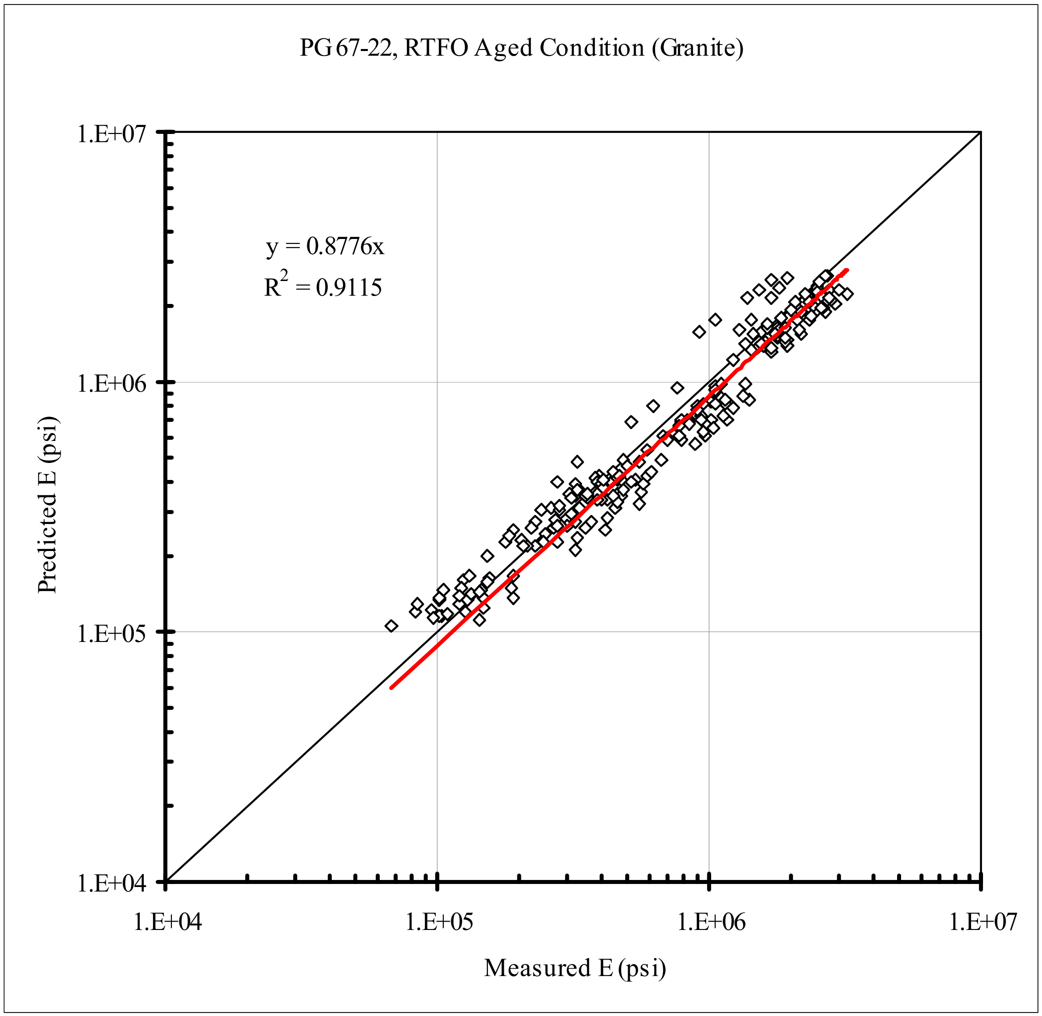


Figure 7-48. Measured values versus predicted values of dynamic modulus for granite materials (Asphalt binder PG 67-22, RTFO aged condition)

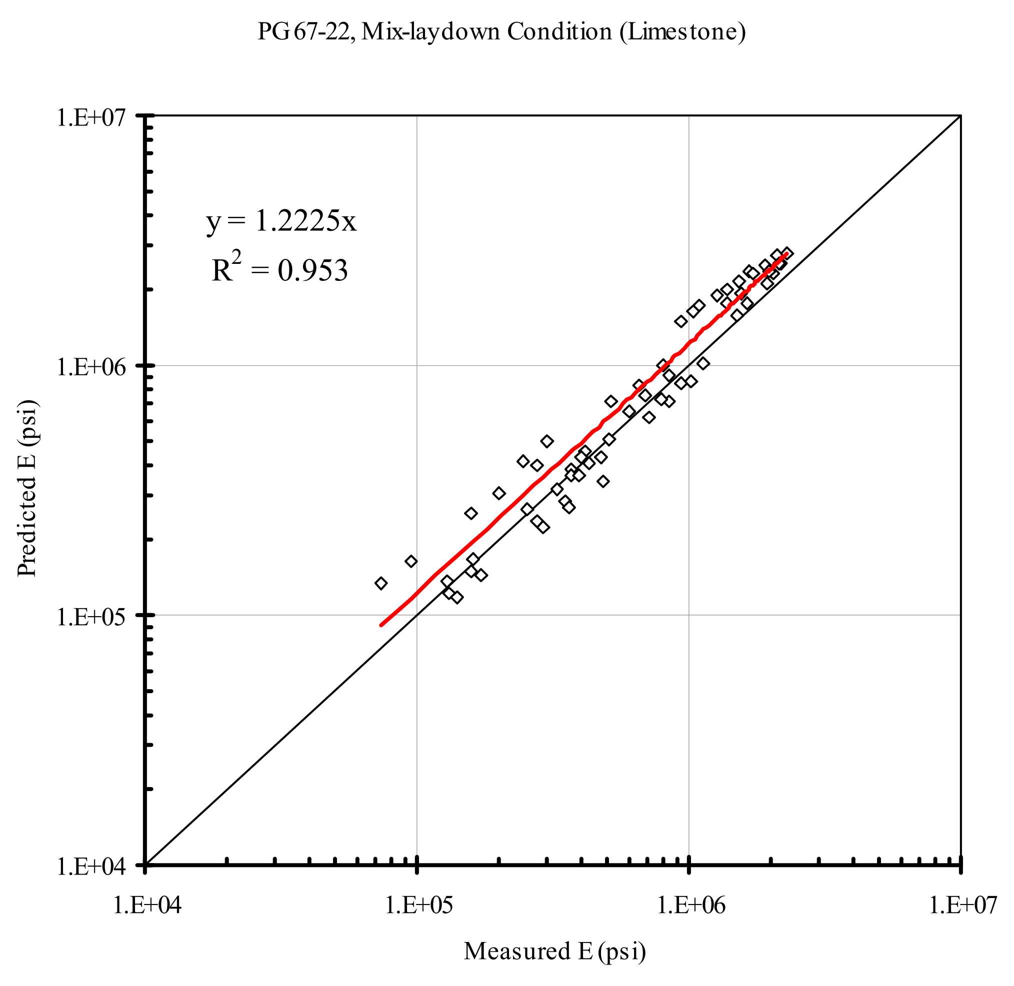


Figure 7-49. Measured values versus predicted values of dynamic modulus for limestone materials (Asphalt binder PG 67-22, mix-laydown condition)

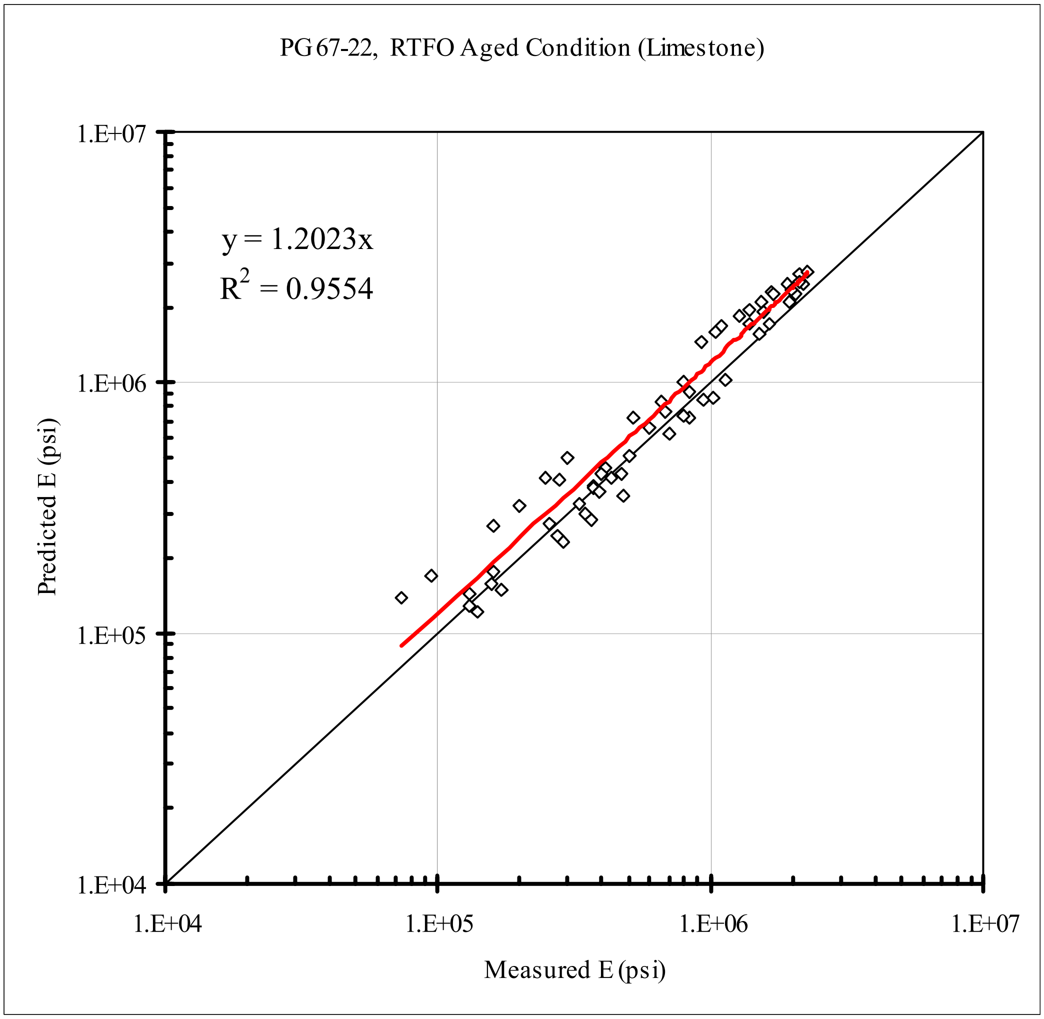


Figure 7-50. Measured values versus predicted values of dynamic modulus for limestone materials (Asphalt binder PG 67-22, RTFO aged condition)

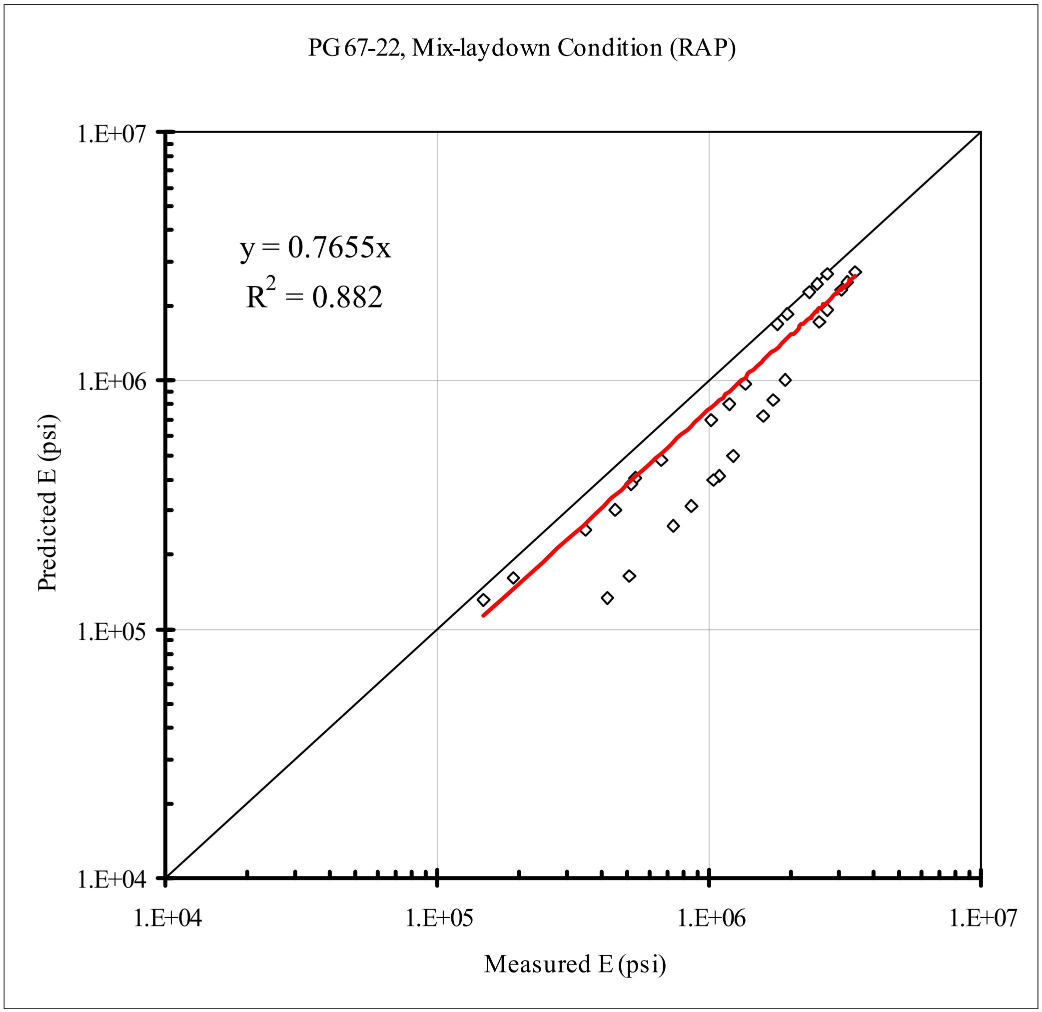


Figure 7-51. Measured values versus predicted values of dynamic modulus for RAP materials (Asphalt binder PG 67-22, mix-laydown condition)

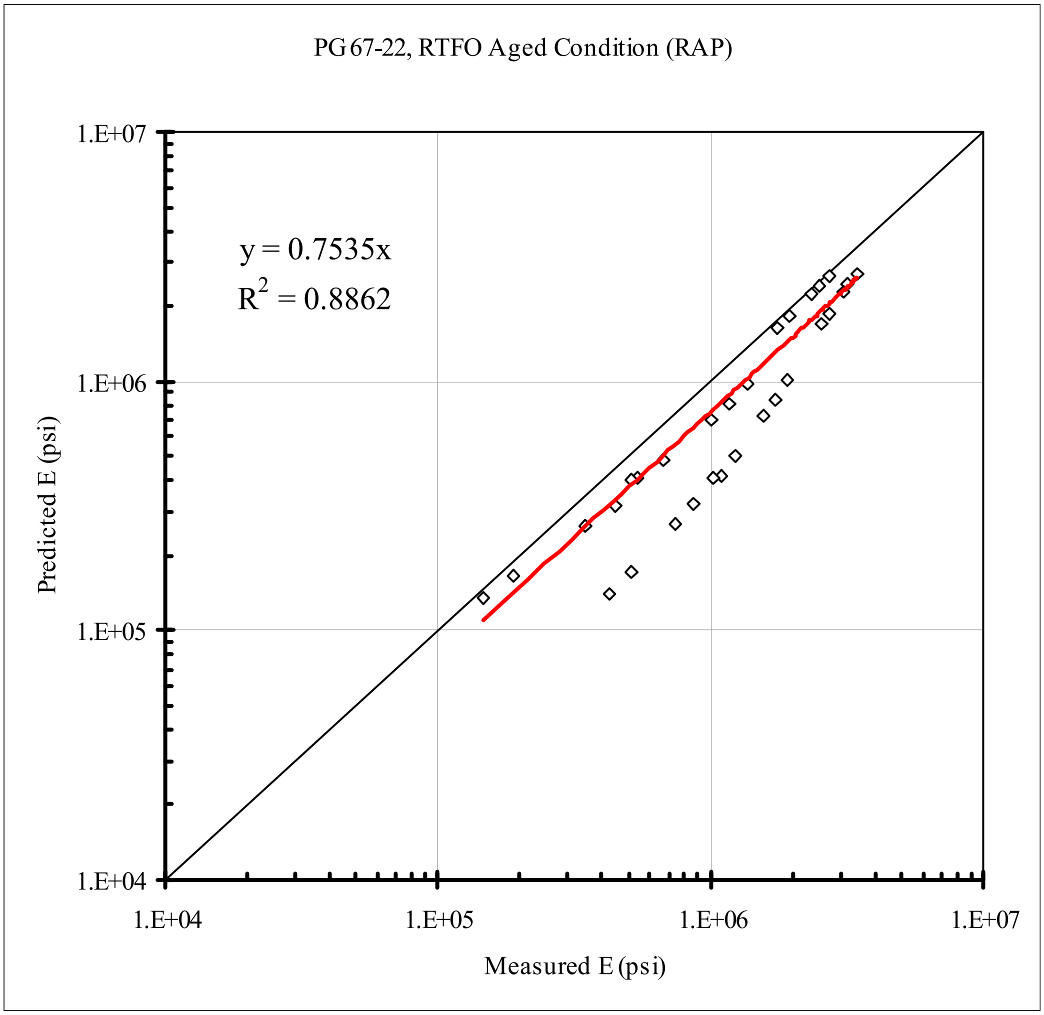


Figure 7-52. Measured values versus predicted values of dynamic modulus for RAP materials (Asphalt binder PG 67-22, RTFO aged condition)

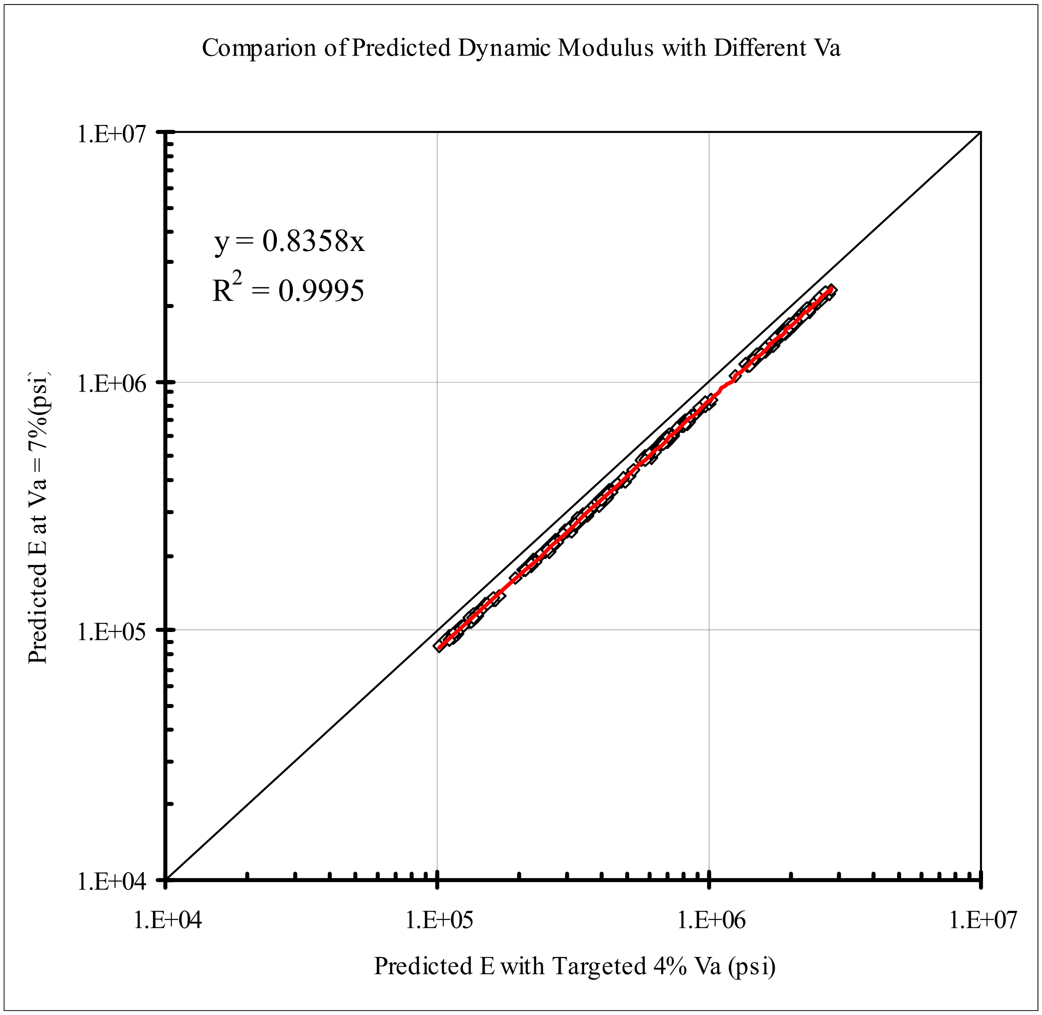


Figure 7-53. Comparison of predicted values of dynamic modulus with targeted 4% air voids versus predicted dynamic modulus values at 7.0% air voids

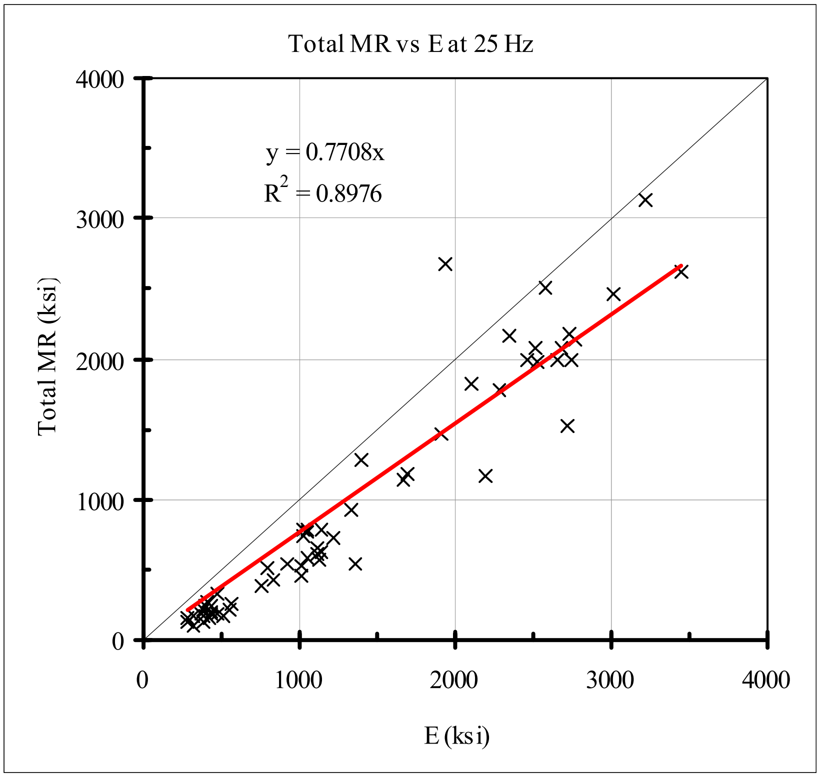


Figure 7-54. Total resilient modulus vs. dynamic modulus at 25 Hz

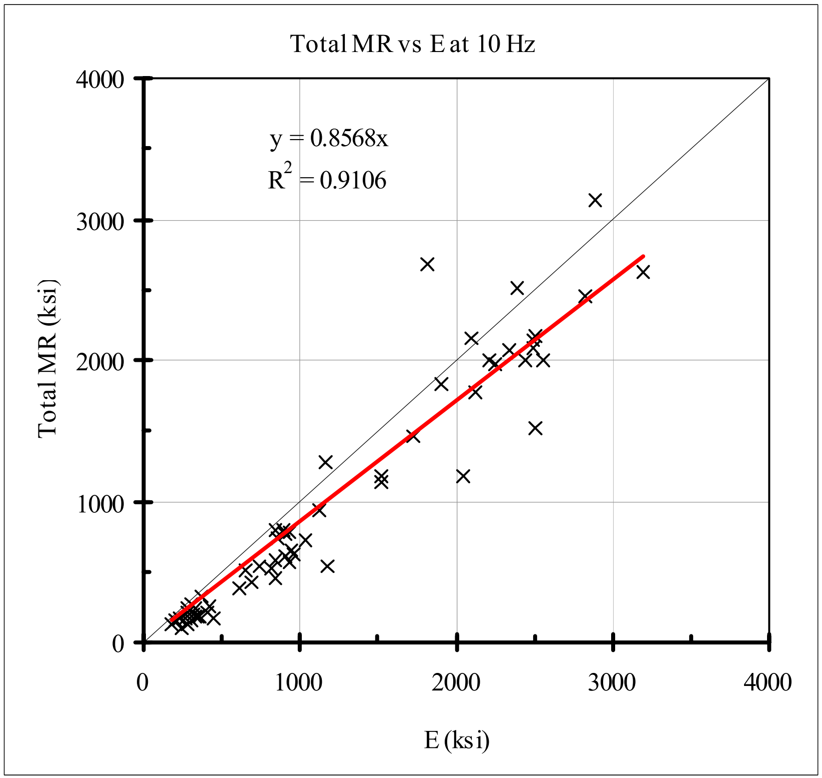


Figure 7-55. Total resilient modulus vs. dynamic modulus at 10 Hz

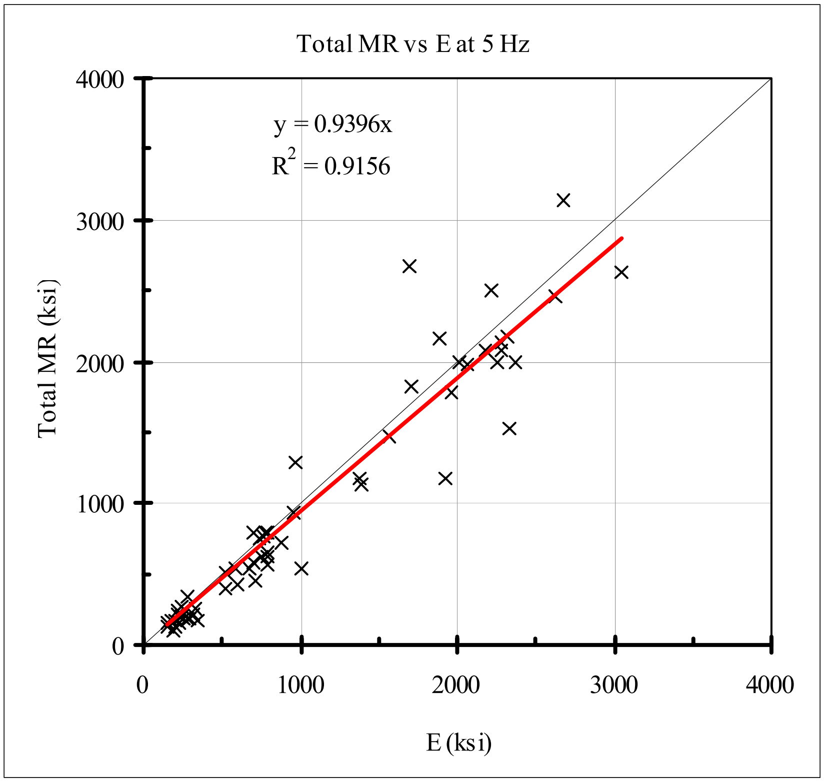


Figure 7-56. Total resilient modulus vs. dynamic modulus at 5 Hz

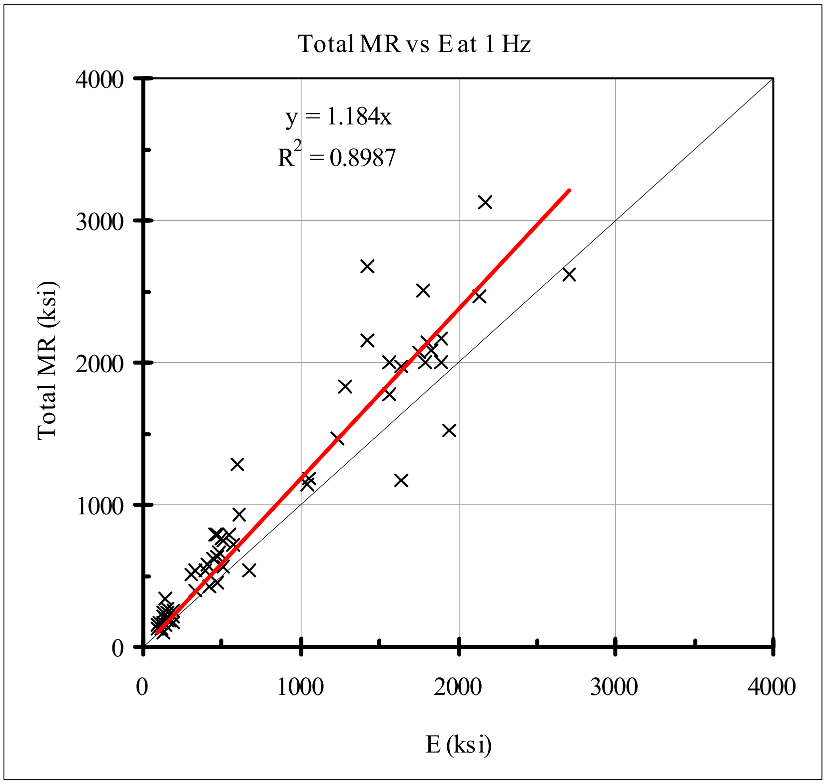


Figure 7-57. Total resilient modulus vs. dynamic modulus at 1 Hz

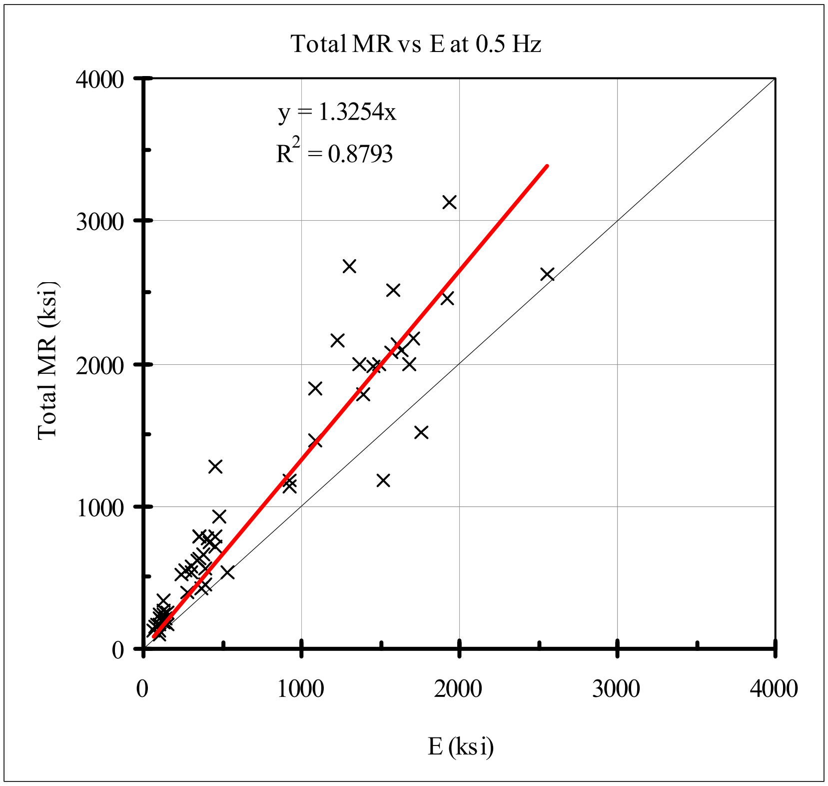


Figure 7-58. Total resilient modulus vs. dynamic modulus at 0.5 Hz

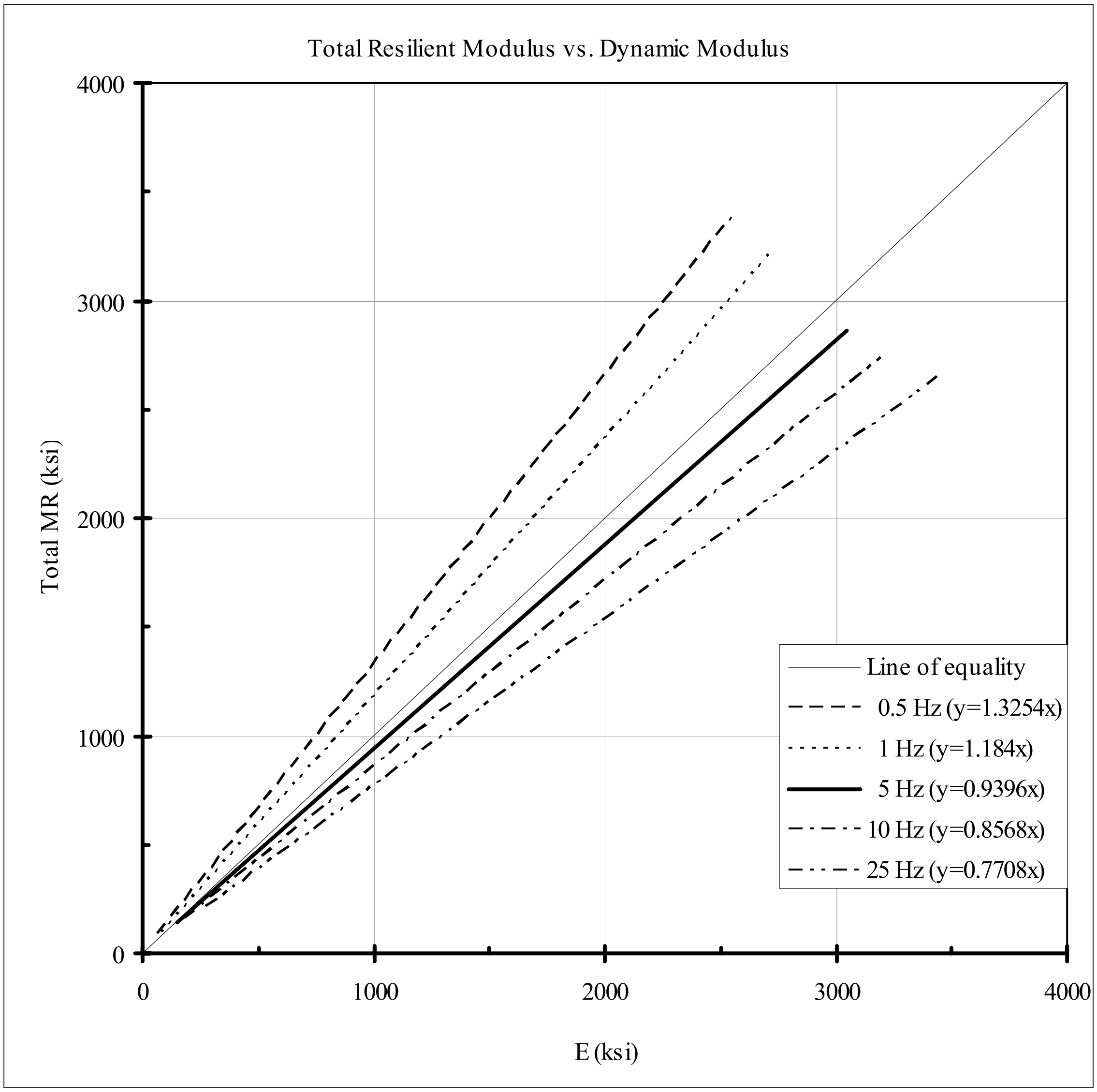


Figure 7-59. Total resilient modulus versus dynamic modulus at various loading frequencies

CHAPTER 8

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

8.1 Summary

The primary objective of this study was to evaluate the dynamic complex modulus test and indirect tensile test for implementing the AASHTO M-E Design Guide for Pavement Structures in Florida. The specific goals of the study were to develop the dynamic testing capabilities, to perform the dynamic complex modulus test and indirect diametral test, and to establish a database for referencing available resilient modulus and dynamic modulus values for targeted Florida asphalt concrete mixtures. To achieve the objectives and goals, a complete dynamic testing system was purchased to perform the temperature controlled dynamic tests. A laboratory experimental program was also developed to evaluate 20 selected Superpave asphalt concrete mixtures with a range of aggregates and mix designs.

The 20 mix designs were contributed by companies involved in the production and use of hot mix asphalt in Florida. The 20 mixtures included the following types of aggregates: 14 Georgia granite materials, one Nova Scotia granite, one North Florida limestone, two Central Florida limestone materials, one South Florida oolite, and one Alabama limestone. One type of asphalt binder, PG 67-22 (AC-30), was used for all mixtures tested. To verify the volumetric properties of the mixtures, the maximum theoretical specific gravity was measured in a laboratory using the Rice maximum specific gravity method for each of the 20 mixtures. The DMT specimens were cored from the 150 mm diameter Superpave samples.

The 20 asphalt concrete mixtures were tested for both dynamic complex modulus and indirect tensile resilient modulus.

The AASHTO TP31 test procedure was generally followed to perform the indirect diametral test. However, the measurement and analysis system developed for the SHRP IDT was also applied. The deformation measurement system was modified in the SHRP IDT in order to accurately measure Poisson's ratio. The SHRP IDT analytical approach was used to determine the indirect diametral resilient modulus and Poisson's ratio. All of the IDT data were processed and stored in a database using Microsoft Access (Appendix B).

The dynamic complex modulus tests were conducted at three temperature levels: 5, 25, and 40°C (41, 77, and 104°F). For all temperatures tested, the following frequencies were used: 25, 10, 5, 1, and 0.5 Hz. All of the dynamic modulus and phase angle test results were also processed and stored in the database (Appendix B).

The master curves for all 20 mixtures were developed and constructed using the time-temperature superposition principle. The Witczak prediction model was adopted to perform the comparison between predicted and measured dynamic modulus for all mixture series. The comparison indicated that the Witczak prediction model worked very well for the Florida asphalt concrete mixtures tested in this study.

A comparative study was also made between the dynamic modulus and resilient modulus test results. The linear regression analysis indicated that the total resilient modulus increased with an increase in dynamic modulus at a specific loading frequency. The resilient modulus values were comparable to the dynamic modulus values at the loading frequency of 4 Hz.

8.2 Conclusions

Based on the test results, analyses, and findings of this study, the conclusions may be drawn as follows:

General

1. A complete dynamic testing system was purchased to perform the temperature controlled dynamic tests for Florida asphalt concrete mixtures.
2. A laboratory experimental program was developed to evaluate 20 selected Superpave asphalt concrete mixtures with a range of aggregates and mix designs.
3. The 20 mixtures included: 14 Georgia granite materials, one Nova Scotia granite, one North Florida limestone, two Central Florida limestone materials, one South Florida oolite, and one Alabama limestone. One type of asphalt binder, a PG 67-22 (AC-30), was used for all mixtures tested.
4. The maximum theoretical specific gravity was measured using the Rice test for each mixture. The dynamic modulus test specimens were cored from the 150 mm diameter Superpave sample. The targeting air void was approximately 4.0% for all of the tested DMT and IDT specimens.
5. The 20 mixtures were tested for both the dynamic complex modulus and indirect diametral resilient modulus. All of the modulus data were processed and stored in a database using Microsoft Access.

Indirect Diametral Test (IDT)

6. The resilient modulus and Poisson's ratio values were determined using the SHRP IDT analytical approach (Roque and Buttlar 1992) for the indirect diametral tests.

The computed results were within a reasonable range for the Poisson's ratio (total and instantaneous) and the resilient modulus (total and instantaneous).

7. The resilient modulus decreased with an increase in test temperature. The average instantaneous resilient modulus was higher than the average total resilient modulus at the same temperature level.
8. The Poisson's ratio had a tendency to increase with an increase in the test temperature level.
9. The SHRP IDT procedure worked well at the three levels of test temperature (5, 25, and 40 degree C) based on the observations made during the entire period of the testing program.

Dynamic Complex Modulus Test (DMT)

10. All 20 mixtures were tested at three temperature levels (5, 25, and 40 degree C) and at the following frequencies: 25, 10, 5, 1, and 0.5 Hz. The dynamic modulus test results were comparable with those from other research studies.
11. The dynamic modulus decreased with an increase in the testing temperature at a specific loading frequency. At a constant testing temperature, the dynamic modulus increased with an increase in the loading frequency. These trends are in agreement with other studies.
12. At testing temperatures of 5°C and 25°C, the phase angle decreased with an increase in frequency. At the temperature of 40°C, with an increase in frequency, the phase angle had a tendency to increase at low frequencies (below 5 Hz) and decrease at higher frequencies, possibly due to a combined effect of the softer binder and more aggregates contribution.

13. At higher frequencies (5 Hz and above), the phase angle increased with an increase in testing temperature; at lower frequencies, the phase angle as a function of the temperature was more complicated.
14. The Master Curves for same type of materials were similar in shape and close to each other; due possibly, to only one binder type (PG 67-22) that was used for the mixtures.
15. The Witczak prediction model provided a good estimation of the dynamic modulus values. The coefficient of regression analysis was approximately 94% for the mixtures.
16. With an assumed air void of 7%, the estimated dynamic modulus was approximately 83.6% of that with an air void of 4%, for the selected Florida mixture designs in this study.

Comparison between Resilient Modulus and Dynamic Modulus

17. The dynamic modulus values measured at a loading frequency of 4 Hz may be comparable with the resilient modulus values obtained from the indirect diametral test at the same temperature level.

8.3 Recommendations

1. The Witczak dynamic modulus prediction model may be adopted for estimating the modulus characteristics of commonly used Florida HMA mixtures with a reasonable confidence level.
2. The SHRP IDT test may be adopted for characterizing the resilient modulus and tensile properties of HMA mixtures at various temperature levels.

3. It would be desirable to carry out more research work in evaluating the SHRP IDT test at high temperature levels.
4. The DMT test worked well for characterizing HMA mixtures at various temperature levels and frequencies, which is more realistic in flexible pavement.
5. The DMT test might have difficulties in distinguishing the effect of the aggregate type based on the sigmoidal fitting of the test results, because only one Florida asphalt binder (PG 67-22) was used in this study.
6. Great effort was devoted to preparing and coring the DMT specimens. The process of preparing the DMT specimen could be streamlined.
7. Additional HMA mixtures with unmodified and modified asphalt binders may be evaluated for characterizing the resilient modulus and dynamic modulus properties of Florida HMA mixtures.

REFERENCES

1. AASHTO, 1996. AASHTO provisional standards: TP-9. Washington, DC. American Association of State Highway and Transportation Officials.

2. AASHTO, 1996. AASHTO provisional standards: TP-31. Washington, DC: American Association of State Highway and Transportation Officials

3. American Association of State Highway and Transportation Official (AASHTO), 1993. "AASHTO Design Guide", AASHTO, Washington, D.C.

4. ASTM, 1985. Annual book of ASTM standards: D 4123. Vol. 4.20. Philadelphia, PA. American Society for Testing and Materials.

5. ASTM, 1997. Annual Book of ASTM Standards: D 3497, ASTM, Philadelphia, PA, Vol. 4.20.

6. Bari, J. and M. W. Witczak, 2005, "An Evaluation of the Effect of Lime Modification on Dynamic Modulus Stiffness of HMA for Use with the New NCHRP 1-37A M-E Pavement Design Guide Procedures", TRB, 2005 Annual Meeting.

7. Barksdale, R. D. and J. Alba, NCHRP, 1997, "Laboratory Determination of Resilient Modulus for Flexible Pavement design", Project 1-28 Final Report.

8. Birgisson, B., G. Sholar and R. Roque, 2005, "Evaluation of Predicted Dynamic Modulus for Florida Mixtures", TRB, 2005 Annual Meeting.

9. Birgisson, B., R. Roque, J. Kim, L. V. Pham, 2004, "The Use of Complex Modulus to Characterize the Performance of Asphalt Mixtures and Pavements in Florida", Final report, The Florida Department of Transportation, BC 354, RPWO #22, Gainesville, FL.

10. Bonaquist, R. and D. W. Christensen, 2005, "A Practical Procedure for Developing Dynamic Modulus Master Curve for Pavement Structural Design", TRB (Transportation Research Board) 2005 Annual Meeting.

11. Buttlar, W. G. and R. Roque, 1994, "Development and Evaluation of the Strategic highway Research Program Measurement and Analysis System for Indirect Tensile Testing at Low Temperatures", Transportation Research Record, No. 1454, TRB, Washington, D.C., pp. 163-171.

12. Kim, J. S., 2002, "Complex Modulus form Indirect Tension Testing", Master's Thesis, University of Florida.

13. Kim, Y. R. and G. Chehab, 2004, "Development of Viscoelastoplastic Continuum Damage Model for Asphalt-Aggregate Mixtures", Final Report to Arizona State University, As Part of NCHRP 9-19 Project "Superpave Support and Performance Models Management", North Carolina State University.

14. King, M., M. Momen and Y. R. Kim, 2005, "Typical Dynamic Moduli Values of Hot Mix Asphalt in North Carolina and Their Prediction", TRB, 2005 Annual Meeting.

15. Loulizi, A., G. W. Flintsch, I. L. Al-Qadi and D. Mokarem, 2006, "Comparison Between Resilient Modulus and Dynamic Modulus of Hot-Mix Asphalt as material Properties for Flexible Pavement Design", TRB, 2006 Annual Meeting.

16. LTPP, Protocol P07 2001. "Test Method for Determining the Creep Compliance, Resilient Modulus and Strength of Asphalt Materials Using the Indirect Tensile Test Device". Long-Term Pavement Performance Team.

17. NCHRP Project 9-29, Simple Performance Tester for Superpave Mix Design, 2001, "First Article Equipment Specifications for the Simple Performance Test System", Sterling, Virginia.

18. NCHRP, 2004, 1-37A-2002 Design Guide (Draft).

19. Pellinen, T. K., 2001, "Investigation of the Use of Dynamic Modulus as an Indicator of Hot-Mix Asphalt Performance", Ph.D. Dissertation, Arizona State University.

20. Pellinen, T. K. and M. W. Witczak, 2002, "Stress Dependent Master Curve Construction for Dynamic (Complex) Modulus", Preprint for Journal of the Association of Asphalt Paving Technologists.

21. Roque, R. and W. G. Buttlar, 1992, "The Development of a Measurement and Analysis System to Accurately Determine Asphalt Concrete Properties Using the Indirect Tensile Mode", Journal of the Association of Asphalt Paving Technologists, Vol. 61, pp. 304-332.

22. Roque, R., W. G. Buttlar, B. E. Ruth, M. Tia, S. W. Dickison and B. Reid, 1997, "Evaluation of SHRP Indirect Tension Tester to Mitigate Cracking in Asphalt Concrete Pavements and Overlays", Final Report, The Florida Department of Transportation, B-9885, Gainesville, FL.

23. Schwartz, C. W., 2005, "Evaluation of the Witczak Dynamic Modulus Prediction Model", TRB, 2005 Annual Meeting.

24. Yoder, E. J. and M. W. Witczak, 1975, “Principles of Pavement Design”, John Wiley & Sons, Inc.

25. Witczak, M. W., 1999, “A Comparison of the Dynamic (Complex) Modulus Test (E^*) and Indirect Diametral Test (M_r) for AC Mixtures”.

26. Witczak, M. W. and J. Bari, 2004, “Development of Master Curve (E^*) Database for Lime Modified Asphalt Mixtures”, Arizona State University Research Project.

27. Witczak, M. W., K. Kaloush, T. Pellinen and M. El-Basyouny, 2002, “Simple Performance Test for Superpave Mix Design”, NCHRP (National Cooperative Highway Research Program) Report 465, Washington D.C.

28. Witczak, M. W., T. K. Pellinen and M. M. El-Basyouny, 2002, “Pursuit of the Simple Performance Test for Asphalt Concrete Fracture/Cracking”, Journal of the Association of Asphalt Paving Technologists, Vol. 71, pp. 767-778.

29. Witczak, M. W. and O. A. Fonseca, 1996, “Revised Prediction Model for Dynamic (Complex) Modulus of Asphalt Mixtures”, Transportation Research Record 1540, TRB, Washington, D.C., pp. 15-23.

APPENDIX A

Superpave Mix Designs Sorted by Test Series

(State of Florida Department of Transportation)

Superpave Mix Designs Sorted by Test Series

Series	Mix Design	Size	Type	Load	Application	Rap	# 7	# 67	S-1-A	S-1-B	# 78	#89	5/16"	W-10	M-10	Stone	Sand	Asphalt
				Level			Stone	Stone	Stone	Stone	Stone	Stone	Stone	Screenings	Screenings	Screenings		
S-1	SP 03-2460A	12.5		C	Structural	A0704					43	51		20			CWR	AC-30?
						A0704-3					GA-553	GA-553		GA-553			Quincy	
S-2	LD 00-2502A	12.5	Fine	D	Structural				41	51				20			Starvation Hill	PG 67-22
S-3	LD 02-2529A	12.5	Coarse	D	Structural				41	51				20				PG 67-22
S-4	SP 02-2180A	9.5	Fine	B	Structural							51		20	21		A/C	PG 67-22
												GA-553		GA-553	GA-553		Mayo	
S-5	SP 03-2921A	9.5	Coarse	D	Structural							51		20	21			PG 67-22
												GA-553		GA-553	GA-553			
S-6	SP 03-2922A	19.0	Coarse	D	Structural			42			43	51			21			PG 67-22
								GA-553			GA-553	GA-553			GA-553			
S-7	SP 04-3034A	12.5	Coarse	D	Structural			42			43	51		20	21			PG 67-22
								GA-553			GA-553	GA-553		GA-553	GA-553			
S-8	SP 03-2610A	12.5	Fine	C	Structural					52		51				20		PG 67-22
										AL-149		AL-149				AL-149		
S-9	SP 03-2627A	12.5	Fine	C	Structural				42	51						20		PG 67-22
									87-145	87-145						87-145		
S-10	SP 04-3225A	12.5	Fine	C	Structural						43	51	21				TM-35	PG 67-22
											GA-553	GA-553	GA-206				Hill	

S-11	SP 02-2194A	12.5	Coarse	D	Structural		44					54				22		PG 67-22
							NS-315					NS-315				NS-315		
S-12	SP 03-2452A	12.5	Coarse	D	Structural						54			21	22			PG 67-22
											GA-383			GA-383	GA-383			
S-13	SP 03-2941A	19.0	Fine	C	Structural			42			43	51		20			JCH	PG 67-22
								GA-553			GA-553	GA-553		GA-553			Ruben	
S-14	SP 03-2351A	12.5	Fine	B	Structural						43	51		20			A/C	PG 67-22
											GA-553	GA-553		GA-553			Sunny Hills	
S-15	SP 05-4015A	12.5	Fine	C	Structural						43	51		20			A/C	PG 67-22
											GA-553	GA-553		GA-553			Grandin	
S-16	SPM 05-4044A	9.5	Fine	B	Structural							51		20	21		A/C	PG 67-22
												GA-553		GA-553	GA-554		Compass Lake	
S-17	SPM 05-4051A	9.5	Fine	C	Structural							51		20			A/C	PG 67-22
												GA-553		GA-553			Compass Lake	
S-18	SP 05-4061A	12.5	Fine	C	Structural	A0638		41				53		20			A/C	PG 67-22
								38-286				38-268		GA-553			Quincy	
S-19	SP 05-4100A	12.5	Fine	C	Structural						43	51		20			A/C	PG 67-22
											GA-553	GA-553		GA-553			Quincy	
S-20	SP 02-2052A	12.5	FC	C	Friction						43	51		20			A/C	PG 67-22
											GA-553	GA-553		GA-553			Quincy	

S-1 SP 03-2460A (TL-C)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. SP 03-2460A (TL-C) (S-1) CTQP Qualified Mix Designer

Contractor C. W. Roberts Address 1201 Aenon Church Rd, Tallahassee, m Fl 32304

Phone No. 850-575-0162 Fax No. 850-570-0304 E-mail

Submitted By Type Mix SP-12.5 Intended Use of Mix Structural

Design Traffic Level C Gyrations @ N des 75 QC Technician

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. Crushed RAP	A0704	C. W. Roberts Contracting	Stockpile A0704-3	07 / 15 / 2002
2. #78 Stone	43	Junction City Mining, L. L. C.	TM-565 GA-553	07 / 15 / 2002
3. #89 Stone	51	Junction City Mining, L. L. C.	TM-565 GA-553	07 / 15 / 2002
4. W-10 Screenings	20	Junction City Mining, L. L. C.	TM-565 GA-553	07 / 15 / 2002
5. SAND		C. W. Roberts Contracting	Quincy	07 / 15 / 2002
6.				07 / 15 / 2002

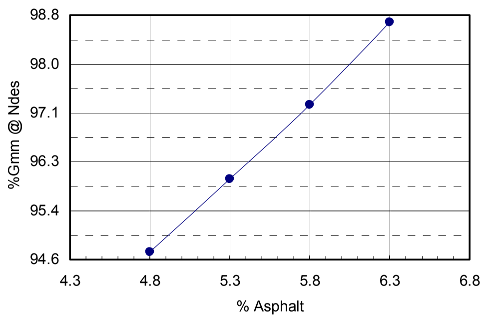
PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

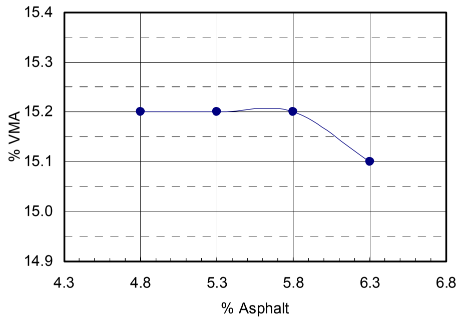
Blend		19%	25%	10%	35%	11%		JOB MIX	CONTROL	RESTRICTED
Number		1	2	3	4	5	6	FORMULA	POINTS	ZONE
	3/4" 19.0mm								100	
E	1/2" 12.5mm	100	100	100	100	100		100	90 - 100	
Z	3/8" 9.5mm	95	60	100	100	100		89	- 90	
I	No. 4 4.75mm	79	10	35	100	100		67		
S	No. 8 2.36mm	65	5	7	70	100		50	28 - 58	39.1 - 39.1
	No. 16 1.18mm	55	3	4	40	100		37		25.6 - 31.6
E	No. 30 600μm	41	2	3	24	89		27		19.1 - 23.1
V	No. 50 300μm	30	1	2	15	28		14		
E	No. 100 150μm	20	1	1	8	6		8		
I	No. 200 75μm	8.8	1.0	1.0	7.0	1.0		5.6	2 - 10	
S	G_{SB}	2.568	2.808	2.799	2.770	2.626		2.725		

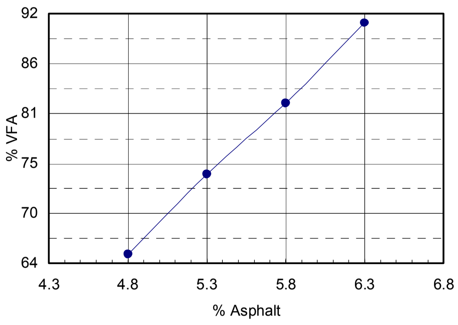
S-1 SP 03-2460A (TL-C)

HOT MIX DESIGN DATA SHEET

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
4.8	2.428	2.563	5.3	15.2	65	4.2	1.3	87.7	95.7
5.3	2.441	2.543	4.0	15.2	74	4.7	1.2	89.0	97.0
5.8	2.454	2.523	2.7	15.2	82	5.2	1.1	90.3	98.3
6.3	2.470	2.503	1.3	15.1	91	5.7	1.0	91.7	99.7







Optimum Asphalt 5.30 %

FAA 🟥 %

Mixing Temperature 320 °F 160 °C

Lab. Density 152.3 Lbs/Ft^3 2441 Kg/m^3

%G_{mm} @ N_{des} 96.0

Compaction Temperature 290 °F 143 °C

Type Anti-strip here (QPL#)

VMA 15.2 %

NCAT Oven Calibration Factor ______ %

(+To Be Added)/(-To Be Subtracted)

Additives Antistrip 0.5 %

S-2 LD 00-2502A (TL-D)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. LD 00-2502A (TL-D) (S-2) CTQP Qualified Mix Designer ______

Contractor V. E. Whitehurst & Sons, Inc. Address Gainesville, Fl.

Phone No. (352) 337-3160 Fax No. ______ E-mail richardg@andersoncolumbia.com

Submitted By Patrick Upshaw Type Mix Fine SP-12.5 Intended Use of Mix Structural

Design Traffic Level D Gyrations @ N des 100 QC Technician ______

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. S-1-A Stone	41	Rinker Materials Corp.	TM-489 87-089	09 / 11 / 2000
2. S-1-B Stone	51	Rinker Materials Corp.	TM-489 87-089	09 / 11 / 2000
3. Screenings	20	Anderson Mining Corp.	29-361	09 / 11 / 2000
4. Local Sand		V. E. Whitehurst & Sons, Inc.	Starvation Hill	09 / 11 / 2000
5. PG 67-22		Citgo		09 / 11 / 2000
6.				

PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

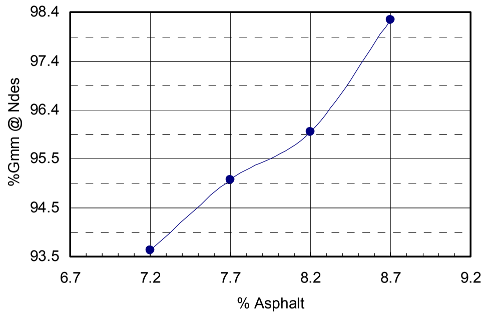
	Blend	12%	25%	48%	15%			JOB MIX	CONTROL	RESTRICTED
	Number	1	2	3	4	5	6	FORMULA	POINTS	ZONE
SIEVE SIZE	3/4" 19.0mm	99	100	100	100			100	100	
	1/2" 12.5mm	45	100	100	100			93	90 - 100	
	3/8" 9.5mm	13	99	100	100			89	- 90	
	No. 4 4.75mm	5	49	90	100			71		
	No. 8 2.36mm	4	10	72	100			53	28 - 58	39.1 - 39.1
	No. 16 1.18mm	4	4	54	100			42		25.6 - 31.6
	No. 30 600μm	4	3	41	96			35		19.1 - 23.1
	No. 50 300μm	4	3	28	52			22		
	No. 100 150μm	3	2	14	10			9		
	No. 200 75μm	2.7	1.9	5.9	2.2			4.0	2 - 10	
	G_{SB}	2.327	2.337	2.299	2.546			2.346		

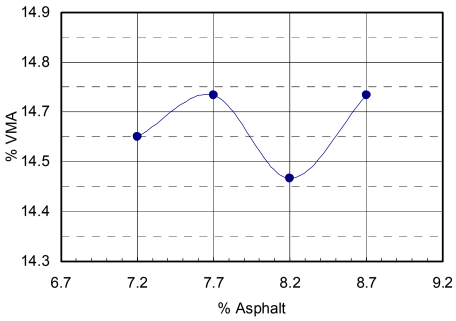
LD 00-2502A (TL-D)

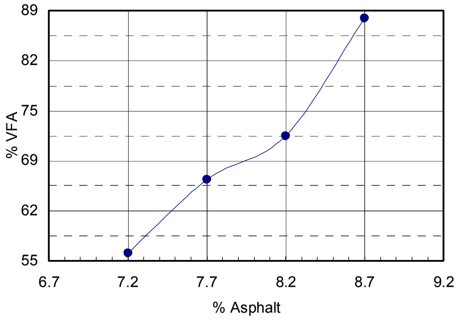
S-2 LD 00-2502A (TL-D)

HOT MIX DESIGN DATA SHEET

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
7.2	2.159	2.306	6.4	14.6	56	3.9	1.0	86.7	94.7
7.7	2.168	2.281	5.0	14.7	66	4.6	0.9	88.1	96.3
8.2	2.185	2.276	4.0	14.5	72	5.0	0.8	88.8	97.0
8.7	2.193	2.232	1.7	14.7	88	6.1	0.7	91.0	99.5







Optimum Asphalt 8.20 %

FAA 🟥 %

Mixing Temperature 310 °F 154 °C

Lab. Density 136.3 Lbs/Ft^3 2185 Kg/m^3

%G_{mm} @ N_{des} 96.0

Compaction Temperature 300 °F 149 °C

Type Anti-strip here (QPL#)

VMA 14.5 %

NCAT Oven Calibration Factor %

(+To Be Added)/(-To Be Subtracted)

Additives Antistrip 0.5 %

S-3 LD 00-2529A (TL-D)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. LD 02-2529A (TL-D) (S-3) CTQP Qualified Mix Designer

Contractor V. E. Whitehurst & Sons, Inc. Address Gainesville, Fl.

Phone No. (352) 528-2101 Fax No. (352) 528-3857 E-mail

Submitted By Howie Moseley Type Mix Coarse SP-12.5 Intended Use of Mix Structural

Design Traffic Level D Gyrations @ N des 100 QC Technician

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. S-1-A Stone	41	Rinker Materials Corp.	TM-489 87-089	10 / 18 / 2002
2. S-1-B Stone	51	Rinker Materials Corp.	TM-489 87-089	10 / 18 / 2002
3. Screenings	20	Anderson Mining Corp.	29-361	09 / 20 / 2002
4. PG 67-22		El Paso Merchant Energy		
5.				
6.				

PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

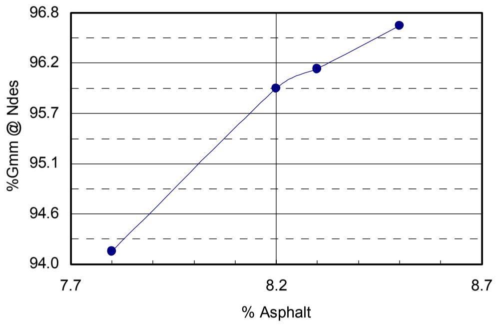
	Blend	13%	55%	32%				JOB MIX	CONTROL	RESTRICTED
	Number	1	2	3	4	5	6	FORMULA	POINTS	ZONE
	3/4" 19.0mm	100	100	100				100	100	
E	1/2" 12.5mm	52	100	100				94	90 - 100	
Z	3/8" 9.5mm	20	99	100				89	- 90	
I	No. 4 4.75mm	5	48	92				56		
S	No. 8 2.36mm	3	11	74				30	28 - 58	39.1 - 39.1
	No. 16 1.18mm	3	3	56				20		25.6 - 31.6
E	No. 30 600µm	3	2	43				15		19.1 - 23.1
V	No. 50 300µm	2	2	27				10		
E	No. 100 150µm	2	2	16				6		
I	No. 200 75µm	1.7	1.5	8.1				3.6	2 - 10	
S	G_{SB}	2.301	2.310	2.316				2.311		

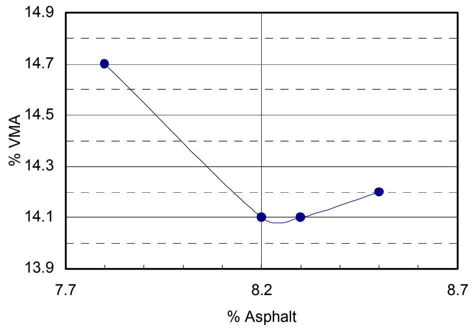
LD 00-2529A (TL-D)

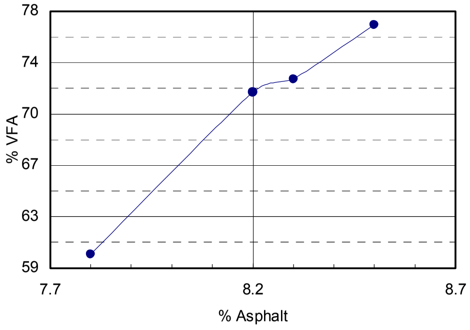
S-3 LD 00-2529A (TL-D)

HOT MIX DESIGN DATA SHEET

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
7.8	2.138	2.271	5.9	14.7	60	4.3	0.8	81.7	96.8
8.2	2.162	2.253	4.0	14.1	72	4.8	0.8	82.9	97.7
8.3	2.164	2.250	3.8	14.1	73	4.9	0.7	83.0	97.9
8.5	2.168	2.243	3.3	14.2	77	5.1	0.7	83.5	98.3







Optimum Asphalt 8.20 %

FAA 🟥 %

Mixing Temperature 310 °F 154 °C

Lab. Density 134.9 Lbs/Ft^3 2162 Kg/m^3

%G_{mm} @ N_{des} 96.0

Compaction Temperature 300 °F 149 °C

VMA 14.1 %

NCAT Oven Calibration Factor ______ %

(+To Be Added)/(-To Be Subtracted)

Type Anti-strip here (QPL#)

Additives Antistrip 0.5 %

S-4 SP 02-2180A (TL-B)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. SP 02-2180A (TL-B) (S-4) CTQP Qualified Mix Designer ____

Contractor Anderson Columbia Company Address P.O. Box 1829, Lake City, Fl 32056

Phone No. 386-752-7585 Fax No. 386-755-5430 E-mail richardg@andersoncolumbia.com

Submitted By Asphalt Technologies, Inc Type Mix Fine SP-9.5 Intended Use of Mix Structural

Design Traffic Level B Gyrations @ N des 75 QC Technician ____

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. #89 Stone	51	Junction City Mining	Ga-553	11 / 04 / 2002
2. W-10 Screenings	20	Junction City Mining	Ga-553	11 / 04 / 2002
3. M-10 Screenings	21	Junction City Mining	Ga-553	11 / 04 / 2002
4. Sand		Anderson Columbia Company	Mayo	11 / 04 / 2002
5.				
6.				

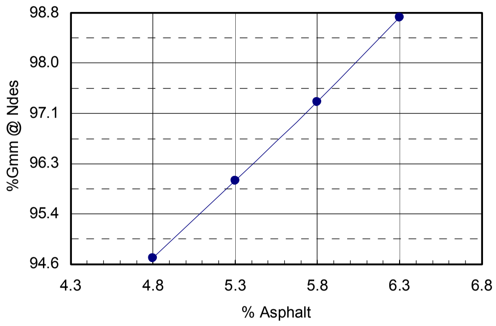
PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

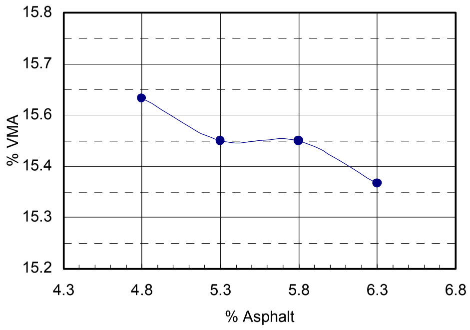
Blend		40%	15%	25%	20%			JOB MIX	CONTROL	RESTRICTED
Number		1	2	3	4	5	6	FORMULA	POINTS	ZONE
SIEVE SIZE	3/4" 19.0mm	100	100	100	100			100		
	1/2" 12.5mm	100	100	100	100			100	100	
	3/8" 9.5mm	100	100	100	100			100	90 - 100	
	No. 4 4.75mm	35	100	100	100			74	- 90	
	No. 8 2.36mm	5	60	66	100			48	32 - 67	47.2 - 47.2
	No. 16 1.18mm	3	42	48	96			39		31.6 - 37.6
	No. 30 600μm	2	24	33	76			28		23.5 - 27.5
	No. 50 300μm	1	15	25	35			16		
	No. 100 150μm	1	8	18	6			7		
	No. 200 75μm	1.0	4.0	13.0	1.0			4.5	2 - 10	
	G_{SB}	2.799	2.770	2.746	2.626			2.745		

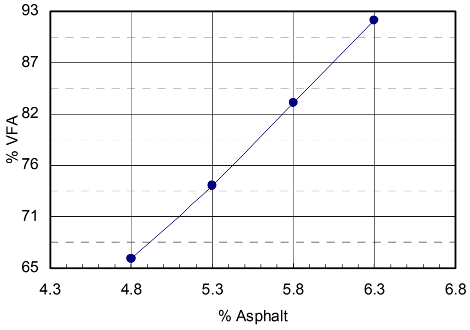
S-4 SP 02-2180A (TL-B)

HOT MIX DESIGN DATA SHEET

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
4.8	2.434	2.570	5.3	15.6	66	4.4	1.0	88.7	95.5
5.3	2.448	2.550	4.0	15.5	74	4.9	0.9	90.0	96.8
5.8	2.462	2.530	2.7	15.5	83	5.4	0.8	91.3	98.1
6.3	2.478	2.510	1.3	15.4	92	5.9	0.8	92.7	99.5







Optimum Asphalt 5.30 %

FAA 🟥 %

Mixing Temperature 310 °F 154 °C

Lab. Density 152.8 Lbs/Ft^3 2448 Kg/m^3

%G_{mm} @ N_{des} 96.0

Compaction Temperature 300 °F 149 °C

Type Anti-strip here (QPL#)

VMA 15.5 %

NCAT Oven Calibration Factor ______ %

(+To Be Added)/(-To Be Subtracted)

Additives Antistrip 0.5 %

S-5 SP 03-2921A (TL-D)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. SP 03-2921A (TL-D) (S-5) CTQP Qualified Mix Designer

Contractor Halifax Paving, Inc Address 860 Hull Road, Ormond Beach, Fl 32174

Phone No. 386-673-7205 Fax No. 386-673-7207 E-mail halifaxpaving@cfl.rr.com

Submitted By Asphalt Technologies, Inc Type Mix Coarse SP-9.5 Intended Use of Mix Structural

Design Traffic Level D Gyrations @ N des 100 QC Technician

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. # 89 Stone	51	Junction City Mining	Ga-553	10 / 20 / 2003
2. W-10 Screenings	20	Junction City Mining	Ga-553	10 / 20 / 2003
3. M-10 Screenings	21	Junction City Mining	Ga-553	10 / 20 / 2003
4.				
5.				
6.				

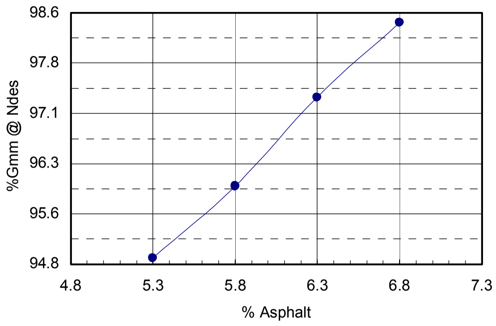
PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

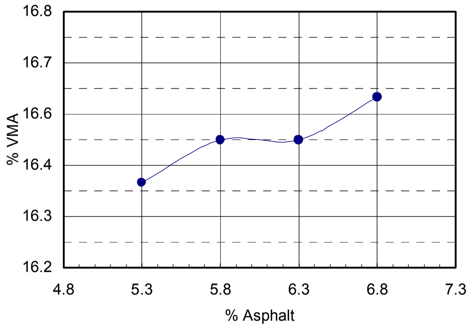
Blend		45%	25%	30%				JOB MIX	CONTROL	RESTRICTED
Number		1	2	3	4	5	6	FORMULA	POINTS	ZONE
SIEVE SIZE	3/4" 19.0mm	100	100	100				100		
	1/2" 12.5mm	100	100	100				100	100	
	3/8" 9.5mm	100	100	100				100	90 - 100	
	No. 4 4.75mm	35	100	100				71	- 90	
	No. 8 2.36mm	5	70	75				42	32 - 67	47.2 - 47.2
	No. 16 1.18mm	4	42	52				28		31.6 - 37.6
	No. 30 600μm	3	24	37				18		23.5 - 27.5
	No. 50 300μm	2	15	27				13		
	No. 100 150μm	2	8	20				9		
	No. 200 75μm	2.0	7.0	14.0				6.9	2 - 10	
	G_{SB}	2.799	2.770	2.746				2.776		

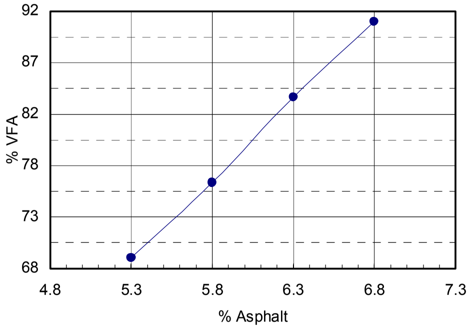
S-5 SP 03-2921A (TL-D)

HOT MIX DESIGN DATA SHEET

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
5.3	2.451	2.583	5.1	16.4	69	4.7	1.5	85.5	96.2
5.8	2.460	2.563	4.0	16.5	76	5.2	1.3	86.6	97.3
6.3	2.474	2.542	2.7	16.5	84	5.8	1.2	87.9	98.6
6.8	2.484	2.523	1.5	16.6	91	6.2	1.1	89.1	99.8







Optimum Asphalt 5.80 %

Lab. Density 153.5 Lbs/Ft^3 2460 Kg/m^3

VMA 16.5 %

FAA 🟥 %

%G_{mm} @ N_{des} 96.0

NCAT Oven ______ %

Mixing Temperature 310 °F 154 °C

Compaction Temperature 300 °F 149 °C

Type Anti-strip here (QPL#)

Additives Antistrip 0.5 %

S-6 SP 03-2922A (TL-D)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. SP 03-2922A (TL-D) (S-6) CTQP Qualified Mix Designer

Contractor Halifax Paving, Inc Address 860 Hull Road, Ormond Beach, Fl 32174

Phone No. 386-673-7205 Fax No. 386-673-7207 E-mail halifaxpaving@cfl.rr.com

Submitted By Asphalt Technologies, Inc Type Mix Coarse SP-19.0 Intended Use of Mix Structural

Design Traffic Level D Gyrations @ N des 100 QC Technician

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. # 67 Stone	42	Junction City Mining	Ga-553	11 / 07 / 2003
2. # 78 Stone	43	Junction City Mining	Ga-553	11 / 07 / 2003
3. # 89 tone	51	Junction City Mining	Ga-553	11 / 07 / 2003
4. M-10 Screenings	21	Junction City Mining	Ga-553	11 / 07 / 2003
5.				
6.				

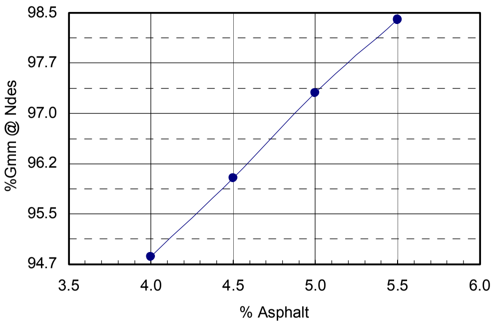
PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

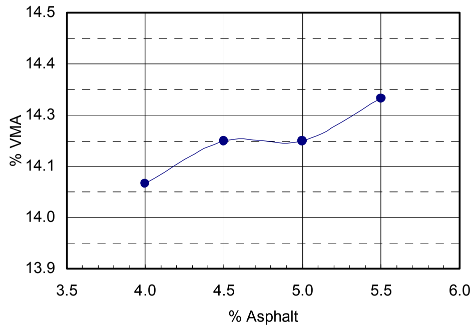
Blend		24%	15%	21%	40%			JOB MIX FORMULA	CONTROL POINTS	RESTRICTED ZONE
Number		1	2	3	4	5	6			
SIEVE SIZE	3/4" 19.0mm	100	100	100	100			100	90 - 100	
	1/2" 12.5mm	60	100	100	100			90	- 90	
	3/8" 9.5mm	30	60	100	100			77		
	No. 4 4.75mm	6	15	35	100			51		
	No. 8 2.36mm	2	4	5	75			32	23 - 49	34.6 - 34.6
	No. 16 1.18mm	1	2	4	52			22		22.3 - 28.3
	No. 30 600µm	1	1	3	37			16		16.7 - 20.7
	No. 50 300µm	1	1	2	27			12		
	No. 100 150µm	1	1	2	20			9		
	No. 200 75µm	1.0	1.0	2.0	14.0			6.4	2 - 8	
	G_{SB}	2.808	2.809	2.799	2.746			2.781		

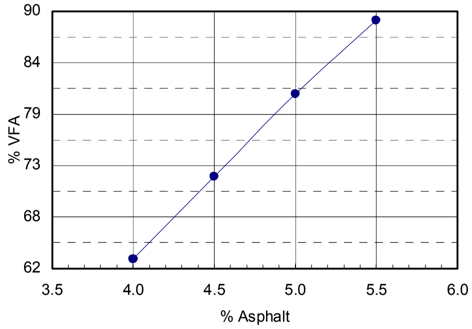
S-6 SP 03-2922A (TL-D)

HOT MIX DESIGN DATA SHEET

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
4.0	2.488	2.624	5.2	14.1	63	3.7	1.7	86.7	96.3
4.5	2.499	2.603	4.0	14.2	72	4.2	1.5	87.9	97.5
5.0	2.512	2.582	2.7	14.2	81	4.7	1.4	89.2	98.8
5.5	2.522	2.563	1.6	14.3	89	5.2	1.2	90.3	99.9







Optimum Asphalt 4.50 %

FAA 🟥 %

Mixing Temperature 310 °F 154 °C

Lab. Density 155.9 Lbs/Ft^3 2499 Kg/m^3

%G_{mm} @ N_{des} 96.0

Compaction Temperature 300 °F 149 °C

VMA 14.2 %

NCAT Oven Calibration Factor ______ %

(+To Be Added)/(-To Be Subtracted)

Type Anti-strip here (QPL#)

Additives Antistrip 0.5 %

S-7 SP 04-3034A (TL-D)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. SP 04-3034A (TL-D) (S-7) CTQP Qualified Mix Designer ____________

Contractor Anderson Columbia Company, Inc Address P.O. Box 1829, Lake City, Fl 32056

Phone No. 386-752-4921 Fax No. 386-752-6906 E-mail richardg@andersoncolumbia.com

Submitted By Asphalt Technologies, Inc Type Mix Coarse SP-12.5 Intended Use of Mix Structural

Design Traffic Level D Gyrations @ N des 100 QC Technician ____________

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. # 67 Stone	42	Junction City Mining	Ga-553	01 / 05 / 2004
2. # 78 Stone	43	Junction City Mining	Ga-553	01 / 05 / 2004
3. # 89 Stone	51	Junction City Mining	Ga-553	01 / 05 / 2004
4. W-10 Screenings	20	Junction City Mining	Ga-553	01 / 05 / 2004
5. M-10 Screenings	21	Junction City Mining	Ga-553	01 / 05 / 2004
6.				

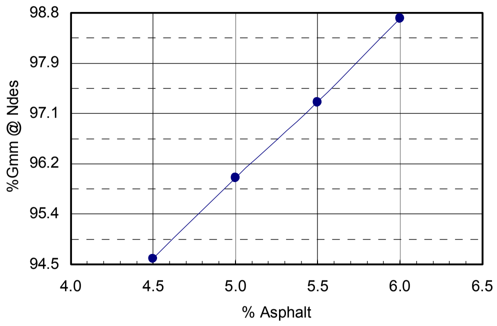
PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

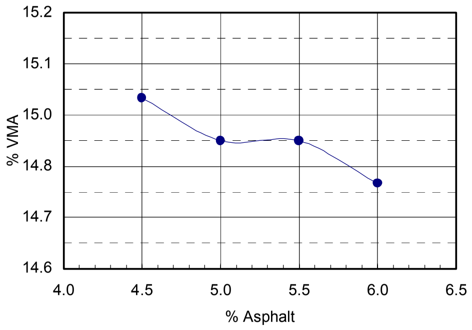
	Blend	15%	15%	30%	15%	25%		JOB MIX	CONTROL	RESTRICTED
	Number	1	2	3	4	5	6	FORMULA	POINTS	ZONE
SIEVE SIZE	3/4" 19.0mm	100	100	100	100	100		100	100	
	1/2" 12.5mm	69	100	100	100	100		95	90 - 100	
	3/8" 9.5mm	33	60	100	100	100		84	- 90	
	No. 4 4.75mm	3	10	35	100	100		52		
	No. 8 2.36mm	2	4	5	70	75		32	28 - 58	39.1 - 39.1
	No. 16 1.18mm	2	3	4	42	52		21		25.6 - 31.6
	No. 30 600µm	1	2	3	26	40		15		19.1 - 23.1
	No. 50 300µm	1	1	2	15	23		9		
	No. 100 150µm	1	1	1	10	17		6		
	No. 200 75µm	1.0	1.0	1.0	7.0	14.0		5.2	2 - 10	
	G_{SB}	2.808	2.809	2.770	2.770	2.746		2.775		

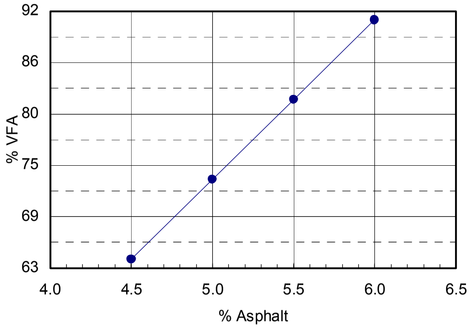
S-7 SP 04-3034A (TL-D)

HOT MIX DESIGN DATA SHEET

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
4.5	2.469	2.610	5.4	15.0	64	4.0	1.3	86.0	96.0
5.0	2.485	2.589	4.0	14.9	73	4.5	1.2	87.4	97.4
5.5	2.498	2.568	2.7	14.9	82	5.0	1.0	88.7	98.7
6.0	2.515	2.548	1.3	14.8	91	5.5	0.9	90.1	99.9







Optimum Asphalt 5.00 %

FAA 🟥 %

Mixing Temperature 310 °F 154 °C

Lab. Density 155.1 Lbs/Ft^3 2485 Kg/m^3

%G_{mm} @ N_{des} 96.0

Compaction Temperature 300 °F 149 °C

Type Anti-strip here (QPL#)

VMA 14.9 %

NCAT Oven ______ %

Additives Antistrip 0.5 %

S-8 03-2610A (TL-C)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. SP 03-2610A (TL-C) (S-8) CTQP Qualified Mix Designer

Contractor C. W. Roberts Contracting Address 1201 Aenon Church Rd, Tallahassee, Fl 32304

Phone No. 850-5570-0162 Fax No. 850-575-3034 E-mail qc2krat@aol.com

Submitted By Asphalt Technologies, Inc Type Mix Fine SP-12.5 Intended Use of Mix Structural

Design Traffic Level C Gyrations @ N des 75 QC Technician

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. S-1 Stone	52	Vulcan Materials Co.	Al-149	05 / 28 / 2001
2. #89 Stone	51	Vulcan Materials Co.	Al-149	05 / 28 / 2001
3. Stone Screenings	20	Vulcan Materials Co.	Al-149	05 / 28 / 2001
4. Stone Sand	22	Vulcan Materials Co.	Al-149	05 / 28 / 2001
5. Sand		Red Bay Sand Co.	Red Bay Bank	05 / 28 / 2001
6. PG 67-22				

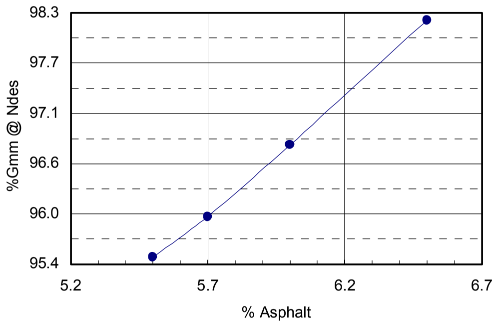
PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

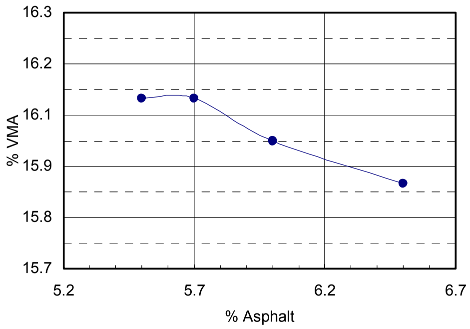
Blend		25%	15%	20%	20%	20%		JOB MIX FORMULA	CONTROL POINTS	RESTRICTED ZONE
Number		1	2	3	4	5	6			
	3/4" 19.0mm	100	100	100	100	100		100	100	
E	1/2" 12.5mm	84	100	100	100	100		96	90 - 100	
Z	3/8" 9.5mm	62	98	100	100	100		90	- 90	
I	No. 4 4.75mm	32	37	96	98	100		72		
S	No. 8 2.36mm	5	10	70	80	95		52	28 - 58	39.1 - 39.1
	No. 16 1.18mm	4	6	33	46	82		34		25.6 - 31.6
E	No. 30 600μm	4	4	25	28	57		24		19.1 - 23.1
V	No. 50 300μm	2	3	19	13	20		11		
E	No. 100 150μm	2	2	16	6	3		6		
I	No. 200 75μm	1.0	1.0	13.5	3.7	2.0		4.2	2 - 10	
S	G_{SB}	2.707	2.714	2.702	2.698	2.626		2.689		

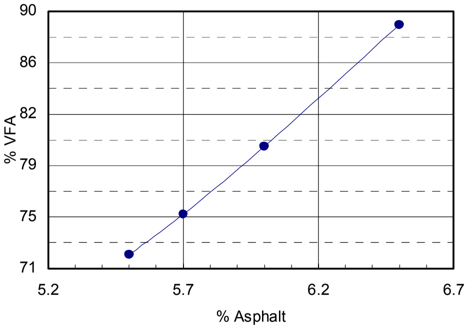
S-8 03-2610A (TL-C)

HOT MIX DESIGN DATA SHEET

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}/P_{be}$	$\%G_{mm}$ @ N_{ini}	$\%G_{mm}$ @ N_{max}
5.5	2.388	2.501	4.5	16.1	72	5.0	0.8	88.2	96.4
5.7	2.393	2.494	4.0	16.1	75	5.2	0.8	88.4	96.9
6.0	2.402	2.482	3.2	16.0	80	5.5	0.8	89.4	97.7
6.5	2.420	2.464	1.8	15.9	89	6.0	0.7	90.8	99.1







Optimum Asphalt 5.70 %

Lab. Density 149.3 Lbs/Ft³ 2393 Kg/m³

VMA 16.1 %

FAA 🟥 %

$\%G_{mm}$ @ N_{des} 96.0

NCAT Oven Calibration Factor ____ %

(+To Be Added)/(-To Be Subtracted)

Mixing Temperature 310 °F 154 °C

Compaction Temperature 300 °F 149 °C

Type Anti-strip here (QPL#)

Additives Antistrip 0.5 %

S-9 SP 03-2627A (TL-C)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. SP 03-2627A (TL-C) (S-9) CTQP Qualified Mix Designer

Contractor Community Asphalt Corporation Address 5100 29th Court, Vero Beach, Fl 32967

Phone No. 772-770-3850 Fax No. 772-567-4364 E-mail ksloane@ctilabs.net

Submitted By CT I, Inc Type Mix Fine SP-12.5 Intended Use of Mix Structural

Design Traffic Level C Gyrations @ N des 75 QC Technician

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. S-1-A Stone	42	Tarmac, Florida	87-145	05 / 08 / 2003
2. S-1-B Stone	51	Tarmac, Florida	87-145	05 / 08 / 2003
3. Coarse Screenings	20	Tarmac, Florida	87-145	05 / 08 / 2003
4.				
5.				
6. PG 67-22				

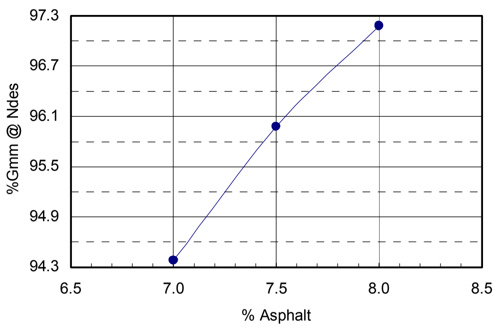
PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

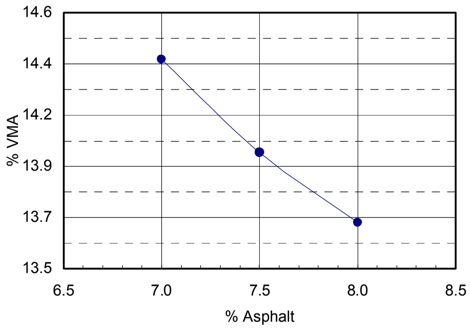
Blend		18%	28%	54%				JOB MIX	CONTROL	RESTRICTED
Number		1	2	3	4	5	6	FORMULA	POINTS	ZONE
SIEVE SIZE	3/4" 19.0mm	100	100	100				100	100	
	1/2" 12.5mm	80	100	100				96	90 - 100	
	3/8" 9.5mm	42	95	100				88	- 90	
	No. 4 4.75mm	9	46	100				69		
	No. 8 2.36mm	4	6	95				54	28 - 58	39.1 - 39.1
	No. 16 1.18mm	3	3	68				38		25.6 - 31.6
	No. 30 600µm	3	3	48				27		19.1 - 23.1
	No. 50 300µm	3	3	33				19		
	No. 100 150µm	3	3	20				12		
	No. 200 75µm	2.0	2.0	3.7				2.9	2 - 10	
	G_{SB}	2.337	2.354	2.425				2.389		

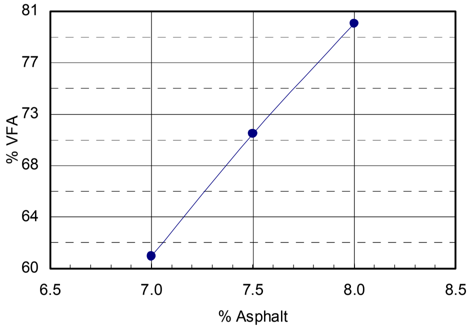
S-9 SP 03-2627A (TL-C)

HOT MIX DESIGN DATA SHEET

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
7.0	2.200	2.331	5.6	14.4	61	4.1	0.7	88.6	95.2
7.5	2.220	2.313	4.0	14.0	71	4.7	0.6	88.0	92.9
8.0	2.240	2.305	2.8	13.7	80	5.0	0.6	89.4	96.1







Optimum Asphalt 7.50 %

FAA 🟥 %

Mixing Temperature 310 °F 154 °C

Lab. Density 138.5 Lbs/Ft^3 2220 Kg/m^3

%G_{mm} @ N_{des} 96.0

Compaction Temperature 300 °F 149 °C

VMA 14.0 %

NCAT Oven Calibration Factor ____ %

(+To Be Added)/(-To Be Subtracted)

Type Anti-strip here (QPL#)

Additives Antistrip 0.5 %

S-10 SP 04-3225A (TL-C)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. SP 04-3225A (TL-C) (S-10) CTQP Qualified Mix Designer

Contractor V.E. Whitehurst & Sons Address Route 1, Box 440, Williston, Fl, 32696

Phone No. 1, Box 440, Williston, Fl, Fax No. 352-528-3857 E-mail

Submitted By Asphalt Technologies, Inc. Type Mix Fine SP-12.5 Intended Use of Mix Structural

Design Traffic Level C Gyrations @ N des 75 QC Technician

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. #78 Stone	43	J.C.M., Lake City Terminal	TM-561 Ga-553	02 / 21 / 2002
2. #89 Stone	51	J.C.M., Lake City Terminal	TM-561 Ga-553	02 / 21 / 2002
3. W-10 Screenings	21	J.C.M., Lake City Terminal	TM-561 Ga-206	02 / 21 / 2002
4. Sand		V.E. Whitehursr & Sons	Starvation Hill	02 / 21 / 2002
5.				
6. PG 67-22				

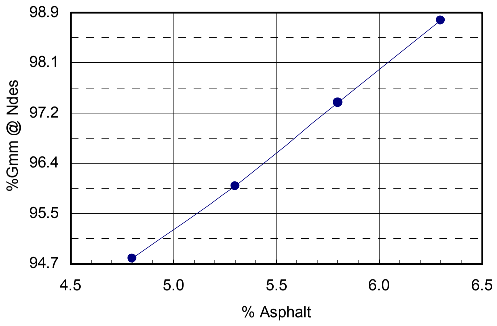
PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

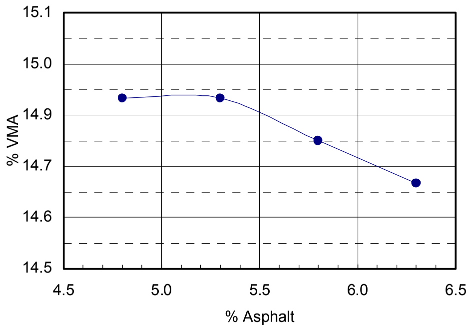
	Blend	25%	28%	32%	15%			JOB MIX	CONTROL	RESTRICTED
	Number	1	2	3	4	5	6	FORMULA	POINTS	ZONE
SIEVE SIZE	3/4" 19.0mm	100	100	100	100			100	100	
	1/2" 12.5mm	93	100	100	100			98	90 - 100	
	3/8" 9.5mm	60	100	100	100			90	- 90	
	No. 4 4.75mm	10	35	93	100			57		
	No. 8 2.36mm	4	5	70	100			40	28 - 58	39.1 - 39.1
	No. 16 1.18mm	2	4	53	100			34		25.6 - 31.6
	No. 30 600μm	1	3	39	95			28		19.1 - 23.1
	No. 50 300μm	1	2	22	56			16		
	No. 100 150μm	1	1	7	11			4		
	No. 200 75μm	1.0	1.0	4.0	3.0			2.3	2 - 10	
	G_{SB}	2.809	2.799	2.660	2.626			2.729		

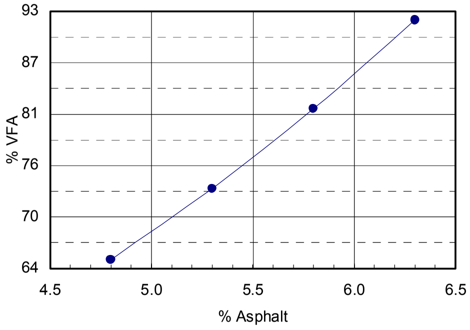
S-10 SP 04-3225A (TL-C)

HOT MIX DESIGN DATA SHEET

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
4.8	2.440	2.574	5.2	14.9	65	4.1	0.6	87.8	95.9
5.3	2.452	2.554	4.0	14.9	73	4.6	0.5	89.0	97.1
5.8	2.468	2.534	2.6	14.8	82	5.1	0.5	90.4	98.5
6.3	2.483	2.514	1.2	14.7	92	5.6	0.4	91.7	99.9







Optimum Asphalt 5.30 %

FAA 🟥 %

Mixing Temperature 310 °F 154 °C

Lab. Density 153.0 Lbs/Ft³ 2452 Kg/m³

%G_{mm} @ N_{des} 96.0

Compaction Temperature 300 °F 149 °C

Type Anti-strip here (QPL#)

VMA 14.9 %

NCAT Oven Calibration Factor ______ %

(+To Be Added)/(-To Be Subtracted)

Additives Antistrip 0.5 %

S-11 SP 02-2194A (TL-D)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. SP 02-2194A (TL-D) (S-11) CTQP Qualified Mix Designer

Contractor Grubbs Construction Company Address 11191 Camp Mine Road, Brooksville, Fl 34601

Phone No. 352-754-5115 Fax No. 352-754-1209 E-mail lawby@grubbsconstruction.com

Submitted By Florida Crushed Stone Type Mix Coarse SP-12.5 Intended Use of Mix Structural

Design Traffic Level D Gyrations @ N des 100 QC Technician

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. #7 Granit	44	Martin Marietta Aggregates	TM-322 NS-312	02 / 23 / 2001
2. #89 Granite	54	Martin Marietta Aggregates	TM-322 NS-312	02 / 23 / 2001
3. Granite Screenings	22	Martin Marietta Aggregates	TM-322 NS-312	02 / 23 / 2001
4. PG 67-22	22			
5.				
6.				

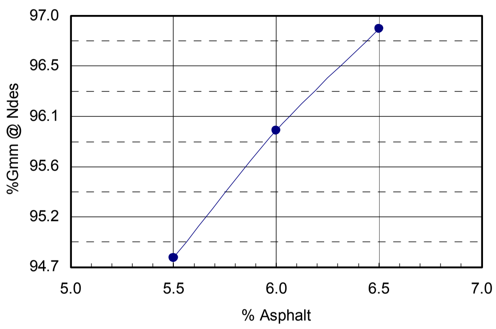
PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

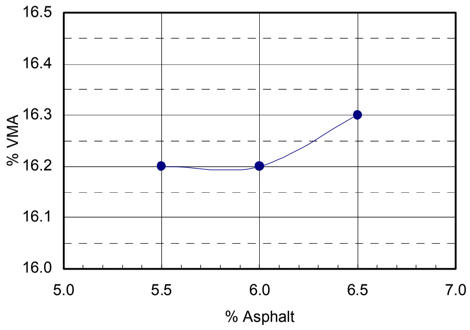
	Blend	33%	20%	47%				JOB MIX FORMULA	CONTROL POINTS	RESTRICTED ZONE
	Number	1	2	3	4	5	6			
	3/4" 19.0mm	100	100	100				100	100	
E	1/2" 12.5mm	95	100	100				98	90 - 100	
Z	3/8" 9.5mm	71	93	100				89	- 90	
I	No. 4 4.75mm	16	37	96				58		
S	No. 8 2.36mm	3	7	75				38	28 - 58	39.1 - 39.1
	No. 16 1.18mm	2	4	48				24		25.6 - 31.6
E	No. 30 600µm	2	2	31				16		19.1 - 23.1
V	No. 50 300µm	2	2	19				10		
E	No. 100 150µm	1	1	10				5		
I	No. 200 75µm	1.0	1.0	6.0				3.4	2 - 10	
S	G_{SB}	2.627	2.625	2.580	2.626			2.604		

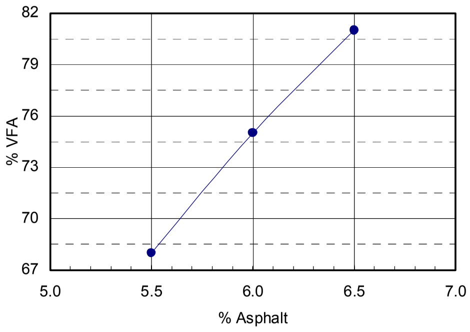
S-11 SP 02-2194A (TL-D)

HOT MIX DESIGN DATA SHEET

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
5.5	2.308	2.435	5.2	16.2	68	4.9	0.7	84.7	96.1
6.0	2.322	2.420	4.0	16.2	75	5.4	0.6	86.9	97.3
6.5	2.330	2.405	3.1	16.3	81	5.8	0.6	87.8	98.1







Optimum Asphalt 6.00 %

Lab. Density 144.9 Lbs/Ft³ 2322 Kg/m³

VMA 16.2 %

FAA 🟥 %

%G_{mm} @ N_{des} 96.0

NCAT Oven Calibration Factor ______ %
(+To Be Added)/(-To Be Subtracted)

Mixing Temperature 310 °F 154 °C

Compaction Temperature 300 °F 149 °C

Type Anti-strip here (QPL#)
Additives Antistrip 0.5 %

S-12 SP 03-2452A (TL-D)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Contractor C. W. Roberts Contracting Address 4208 CR-124A, Wildwood, Fl, 34785

Phone No. 850-575-0162 Fax No. 850-575-0304 E-mail qc2krat@aol.com

Submitted By Q.A.T.L.,L.L.C. Type Mix Coarse SP-12.5 Intended Use of Mix Structural

Design Traffic Level D Gyrations @ N des 100

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. #78 Stone	54	Conrad Yelvington Distributors	TM-518 GA383	03 / 12 / 2003
2. W-10 Screenings	21	Conrad Yelvington Distributors	TM-518 GA383	03 / 12 / 2003
3. M-10 Screenings	22	Conrad Yelvington Distributors	TM-518 GA383	03 / 12 / 2003
4. PG 67-22				
5.				
6.				

PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

	Blend	55%	25%	20%				JOB MIX	CONTROL	RESTRICTED
	Number	1	2	3	4	5	6	FORMULA	POINTS	ZONE
SIEVE SIZE	3/4" 19.0mm	100	100	100				100	100	
	1/2" 12.5mm	99	100	100				99	90 - 100	
	3/8" 9.5mm	55	100	100				75	- 90	
	No. 4 4.75mm	3	93	93				44		
	No. 8 2.36mm	1	62	67				29	28 - 58	39.1 - 39.1
	No. 16 1.18mm	1	38	47				19		25.6 - 31.6
	No. 30 600μm	1	24	33				13		19.1 - 23.1
	No. 50 300μm	1	15	23				9		
	No. 100 150μm	1	10	17				6		
	No. 200 75μm	0.2	4.6	12.8				4.5	2 - 10	
	G_{SB}	2.721	2.656	2.703				2.701		

The mix properties of the Job Mix Formula have been conditionally verified, pending successful final verification during production at the assigned plant, the mix design is approved subject to F.D.O.T. specifications.

No. 200 reflects the aggregate changes expected during production.

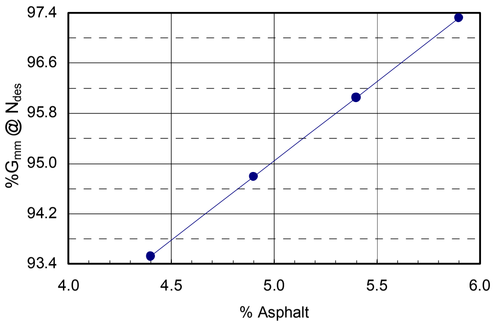
SP 03-2452A (TL-D) (S-12)

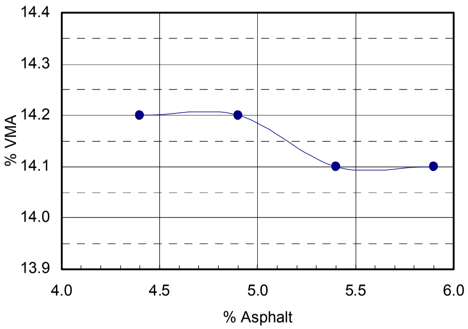
S-12 SP 03-2452A (TL-D)

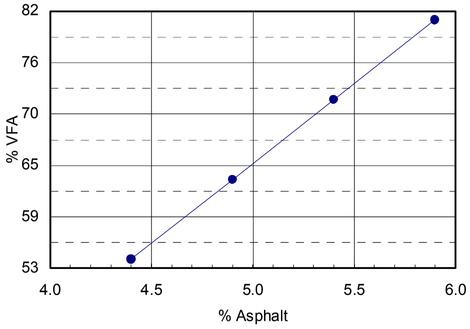
HOT MIX DESIGN DATA SHEET

SP 03-2452A (TL-D) (S-12)

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
4.4	2.425	2.593	6.5	14.2	54	3.28	1.4	84.6	96.9
4.9	2.437	2.571	5.2	14.2	63	3.82	1.2	84.9	97.3
5.4	2.454	2.555	4.0	14.1	72	4.26	1.1	86.0	97.8
5.9	2.467	2.535	2.7	14.1	81	4.77	0.9	87.1	98.2







Optimum Asphalt 5.4 %

FAA 45 %

Mixing Temperature 305 °F 152 °C

Lab. Density 153.1 Lbs/Ft^3 0 Kg/m^3

%G_{mm} @ N_{des} #DIV/0!

Additives Arr-Maz Ad-here LOF 65-00 (M-0014) Antistrip 0.5 %

VMA 14.1 %

NCAT Oven Calibration Factor -0.07 %

(+To Be Added)/(-To Be Subtracted)

S-13 SP 03-2941A (TL-C)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. SP 03-2941A (TL-C) (S-13) CTQP Qualified Mix Designer

Contractor John C Hipp Construction Co Address 12719 NW 146th Pl, Alachua, Fl 32615

Phone No. 386-462-2047 Fax No. 386-462-4141 E-mail hippave@hotmail.com

Submitted By Asphalt Technologies, Inc Type Mix Fine SP-19.0 Intended Use of Mix Structural

Design Traffic Level C Gyrations @ N des 75 QC Technician

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. # 67 Stone	42	Junction City Mining	Ga-553	11 / 13 / 2003
2. # 78 Stone	43	Junction City Mining	Ga-553	11 / 13 / 2003
3. # 89 tone	51	Junction City Mining	Ga-553	11 / 13 / 2003
4. W-10 Screenings	20	Junction City Mining	Ga-553	11 / 13 / 2003
5. Sand		John C Hipp Construction Co	Ruben	11 / 13 / 2003
6.				

PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

	Blend	25%	10%	10%	40%	15%		JOB MIX	CONTROL	RESTRICTED
	Number	1	2	3	4	5	6	FORMULA	POINTS	ZONE
	3/4" 19.0mm	100	100	100	100	100		100	90 - 100	
E	1/2" 12.5mm	59	100	100	100	100		90	- 90	
Z	3/8" 9.5mm	30	60	100	100	100		79		
I	No. 4 4.75mm	6	12	35	100	100		61		
S	No. 8 2.36mm	1	2	5	70	100		44	23 - 49	34.6 - 34.6
	No. 16 1.18mm	1	2	4	47	100		35		22.3 - 28.3
E	No. 30 600µm	1	1	3	27	96		26		16.7 - 20.7
V	No. 50 300µm	1	1	2	17	74		18		
E	No. 100 150µm	1	1	2	10	24		8		
I	No. 200 75µm	1.0	1.0	2.0	7.0	7.0		4.4	2 - 8	
S	G_{SB}	2.808	2.809	2.799	2.770	2.626		2.763		

The mix properties of the Job Mix Formula have been conditionally verified, pending successful final verification during production at the assigned plant, the mix design is approved subject to F.D.O.T. specifications.

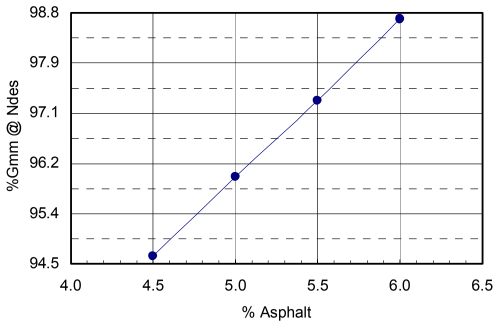
No. 200 reflects the aggregate changes expected during production.

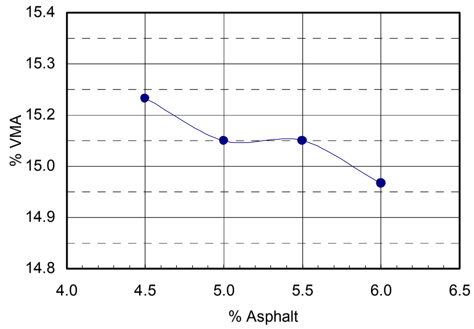
SP 03-2941A (TL-D)

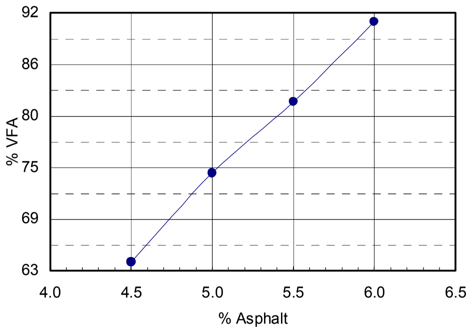
S-13 SP 03-2941A (TL-C)

HOT MIX DESIGN DATA SHEET

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
4.5	2.453	2.592	5.4	15.2	64	4.1	1.1	87.7	95.7
5.0	2.468	2.571	4.0	15.1	74	4.6	1.0	89.0	97.0
5.5	2.482	2.551	2.7	15.1	82	5.1	0.9	90.3	98.3
6.0	2.498	2.531	1.3	15.0	91	5.7	0.8	91.7	99.8







Optimum Asphalt 5.00 %

FAA 🟥 %

Mixing Temperature 310 °F 154 °C

Lab. Density 154.0 Lbs/Ft^3 2468 Kg/m^3

%G_{mm} @ N_{des} 96.0

Compaction Temperature 300 °F 149 °C

Type Anti-strip here (QPL#)

VMA 15.1 %

NCAT Oven Calibration Factor ______ %

(+To Be Added)/(-To Be Subtracted)

Additives Antistrip 0.5 %

S-14 SP 03-2351A (TL-B)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. SP 03-2351A (TL-B) (S-14) CTQP Qualified Mix Designer __________
Contractor Anderson Columbia Company Address P.O. Box 1829, Lake City, Fl 32056
Phone No. 386-752-7585 Fax No. 386-755-5430 E-mail richardg@andersoncolumbia.com
Submitted By Asphalt Technologies, Inc Type Mix Fine SP-12.5 Intended Use of Mix Structural
Design Traffic Level B Gyrations @ N des 75 QC Technician __________

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. #78 Stone	51	Junction City Mining	Ga-553	01 / 20 / 2003
2. #89 Stone	20	Junction City Mining	Ga-553	01 / 20 / 2003
3. W-10 Screenings	21	Junction City Mining	Ga-553	01 / 20 / 2003
4. Sand		Anderson Columbia Company	Sunny Hills	01 / 20 / 2003
5.				
6. PG 67-22				

PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

	Blend	25%	35%	15%	25%			JOB MIX	CONTROL	RESTRICTED
	Number	1	2	3	4	5	6	FORMULA	POINTS	ZONE
	3/4" 19.0mm	100	100	100	100			100	100	
E	1/2" 12.5mm	100	100	100	100			100	90 - 100	
Z	3/8" 9.5mm	60	100	100	100			90	- 90	
I	No. 4 4.75mm	10	35	100	100			55		
S	No. 8 2.36mm	5	8	70	100			40	28 - 58	39.1 - 39.1
	No. 16 1.18mm	2	4	46	100			34		25.6 - 31.6
E	No. 30 600μm	1	3	29	88			28		19.1 - 23.1
V	No. 50 300μm	1	2	17	50			16		
E	No. 100 150μm	1	1	9	10			4		
I	No. 200 75μm	1.0	1.0	7.0	5.0			2.9	2 - 10	
S	G_{SB}	2.809	2.799	2.770	2.626			2.752		

The mix properties of the Job Mix Formula have been conditionally verified, pending successful final verification during production at the assigned plant, the mix design is approved subject to F.D.O.T. specifications.

No. 200 reflects the aggregate changes expected during production.

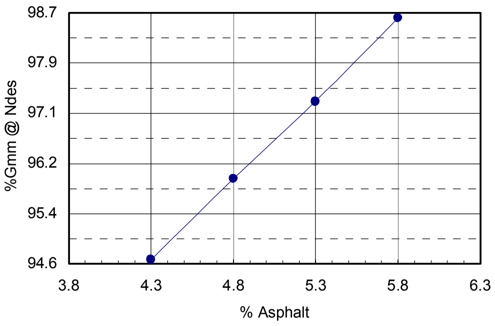
SP 03-2351A (TL-B)

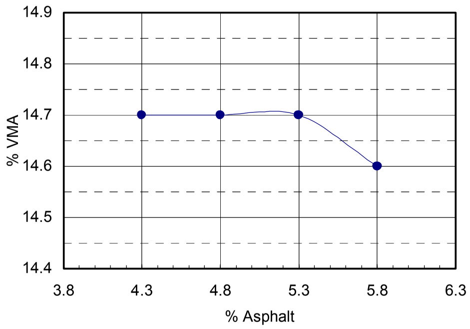
S-14 SP 03-2351A (TL-B)

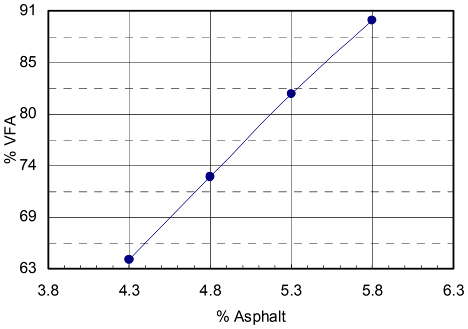
HOT MIX DESIGN DATA SHEET

SP 03-2351A (TL-B)

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
4.3	2.452	2.590	5.3	14.7	64	4.0	0.7	88.7	95.7
4.8	2.467	2.570	4.0	14.7	73	4.4	0.7	90.0	97.0
5.3	2.480	2.550	2.7	14.7	82	4.9	0.6	91.3	98.3
5.8	2.495	2.530	1.4	14.6	90	5.5	0.5	92.6	99.6







Optimum Asphalt 4.80 %

FAA 🟥 %

Mixing Temperature 310 °F 154 °C

Lab. Density 153.9 Lbs/Ft^3 2467 Kg/m^3

%G_{mm} @ N_{des} 96.0

Compaction Temperature 300 °F 149 °C

VMA 14.7 %

NCAT Oven Calibration Factor ____ %
(+To Be Added)/(-To Be Subtracted)

Type Anti-strip here (QPL#)
Additives Antistrip 0.5 %

S-15 SP 05-4015A (TL-C)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. SP 05-4015A (TL-C) (S-15) CTQP Qualified Mix Designer ________

Contractor Anderson Columbia Company Address P.O. Box 1829, Lake City, Fl 32056

Phone No. 386-752-7585 Fax No. 386-755-5430 E-mail richardg@andersoncolumbia.com

Submitted By Asphalt Technologies, Inc Type Mix Fine SP-12.5 Intended Use of Mix Structural

Design Traffic Level C Gyrations @ N des 75 QC Technician ________

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. #78 Stone	43	Junction City Mining	Ga-553	02 / 22 / 2005
2. #89 Stone	51	Junction City Mining	Ga-553	02 / 22 / 2005
3. W-10 Screenings	20	Junction City Mining	Ga-553	02 / 22 / 2005
4. Sand		Florida Rock Industries	Grandin	02 / 22 / 2005
5.				
6. PG 67-22				

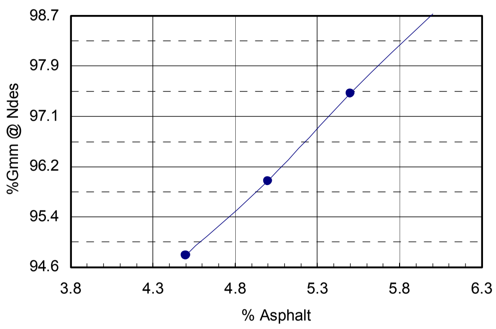
PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

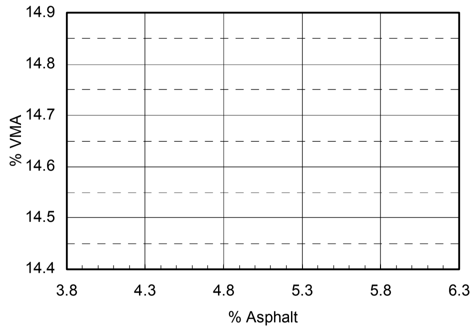
	Blend	25%	25%	35%	15%			JOB MIX	CONTROL	RESTRICTED
	Number	1	2	3	4	5	6	FORMULA	POINTS	ZONE
SIEVE SIZE	3/4" 19.0mm	100	100	100	100			100	100	
	1/2" 12.5mm	95	100	100	100			99	90 - 100	
	3/8" 9.5mm	60	100	100	100			90	- 90	
	No. 4 4.75mm	10	35	100	100			61		
	No. 8 2.36mm	4	5	70	100			42	28 - 58	39.1 - 39.1
	No. 16 1.18mm	2	4	46	100			33		25.6 - 31.6
	No. 30 600μm	1	3	29	97			26		19.1 - 23.1
	No. 50 300μm	1	2	17	75			18		
	No. 100 150μm	1	1	9	20			7		
	No. 200 75μm	1.0	1.0	6.0	1.0			2.8	2 - 10	
	G_{SB}	2.809	2.799	2.770	2.626			2.764		

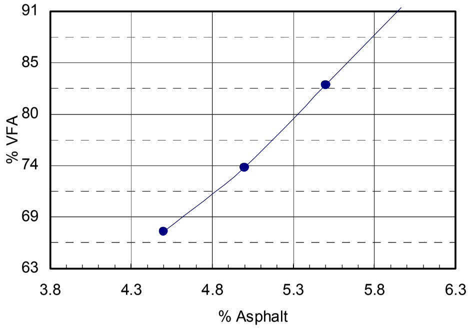
S-15 SP 05-4015A (TL-C)

HOT MIX DESIGN DATA SHEET

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
4.5	2.443	2.577	5.2	15.6	67	4.4	0.6	87.8	95.8
5.0	2.455	2.557	4.0	15.6	74	4.9	0.6	89.0	97.0
5.5	2.472	2.537	2.6	15.5	83	5.4	0.5	90.4	98.4
6.0	2.485	2.517	1.3	15.5	92	5.9	0.5	91.7	99.7







Optimum Asphalt 5.00 %

FAA 🟥 %

Mixing Temperature 310 °F 154 °C

Lab. Density 153.2 Lbs/Ft^3 2455 Kg/m^3

%G_{mm} @ N_{des} 96.0

Compaction Temperature 300 °F 149 °C

Type Anti-strip here (QPL#)

VMA 15.6 %

NCAT Oven Calibration Factor ____ %

(+To Be Added)/(-To Be Subtracted)

Additives Antistrip 0.5 %

S-16 SPM 05-4044A (TL-C)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. SPM 05-4044A (TL-C) (S-16) CTQP Qualified Mix Designer

Contractor Anderson Columbia Company Address P.O. Box 1829, Lake City, Fl 32056

Phone No. 386-752-7585 Fax No. 386-755-5430 E-mail richardg@andersoncolumbia.com

Submitted By Asphalt Technologies, Inc Type Mix Fine SP-9.5 Intended Use of Mix Structural

Design Traffic Level B Gyrations @ N des 75 QC Technician

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. #89 Stone	51	Junction City Mining	Ga-553	07 / 29 / 2004
2. W-10 Screenings	20	Junction City Mining	Ga-553	07 / 29 / 2004
3. M-10 Screenings	21	Junction City Mining	Ga-553	07 / 29 / 2004
4. Sand		Anderson Columbia Company	Compass Lake	07 / 29 / 2004
5.				
6. PG 67-22				

PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

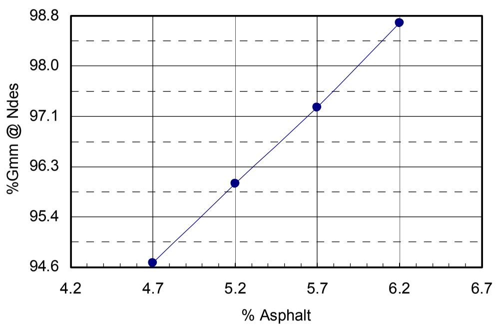
Blend		40%	25%	17%	18%			JOB MIX	CONTROL	RESTRICTED
Number		1	2	3	4	5	6	FORMULA	POINTS	ZONE
	3/4" 19.0mm	100	100	100	100			100		
E	1/2" 12.5mm	100	100	100	100			100	100	
Z	3/8" 9.5mm	100	100	100	100			100	90 - 100	
I	No. 4 4.75mm	35	100	100	100			74	- 90	
S	No. 8 2.36mm	5	67	78	100			50	32 - 67	47.2 - 47.2
	No. 16 1.18mm	4	44	52	100			39		31.6 - 37.6
E	No. 30 600µm	3	25	38	97			31		23.5 - 27.5
V	No. 50 300µm	2	15	26	78			23		
E	No. 100 150µm	1	10	20	17			9		
I	No. 200 75µm	1.0	6.0	15.0	6.5			5.6	2 - 10	
S	G_{SB}	2.799	2.770	2.746	2.626			2.750		

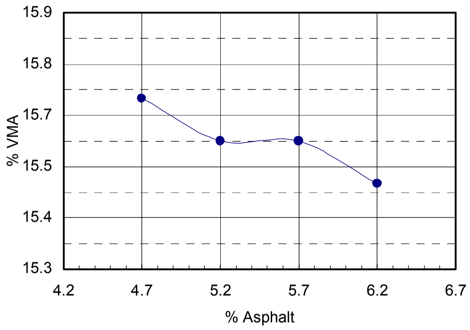
SPM 05-4044A (TL-C)

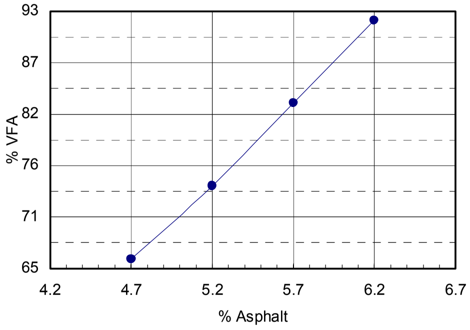
S-16 SPM 05-4044A (TL-C)

HOT MIX DESIGN DATA SHEET

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
4.7	2.433	2.570	5.3	15.7	66	4.4	1.3	87.5	96.7
5.2	2.448	2.550	4.0	15.6	74	4.9	1.1	88.8	97.0
5.7	2.461	2.530	2.7	15.6	83	5.4	1.0	90.1	98.3
6.2	2.477	2.510	1.3	15.5	92	5.9	0.9	91.5	99.7







Optimum Asphalt 5.20 %

FAA 🟥 %

Mixing Temperature 330 °F 166 °C

Lab. Density 152.8 Lbs/Ft^3 2448 Kg/m^3

%G_{mm} @ N_{des} 96.0

Compaction Temperature 325 °F 163 °C

Type Anti-strip here (QPL#)

VMA 15.6 %

NCAT Oven Calibration Factor ________ %

(+To Be Added)/(-To Be Subtracted)

Additives Antistrip 0.5 %

S-17 SPM 05-4051A (TL-C)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. SPM 05-4051A (TL-C) (S-17) CTQP Qualified Mix Designer

Contractor Anderson Columbia Company Address P.O. Box 1829, Lake City, Fl 32056

Phone No. 386-752-7585 Fax No. 386-755-5430 E-mail richardg@andersoncolumbia.com

Submitted By Asphalt Technologies, Inc Type Mix Fine SP-9.5 Intended Use of Mix Structural

Design Traffic Level C Gyrations @ N des 75 QC Technician

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. #89 Stone	51	Junction City Mining	Ga-553	03 / 01 / 2002
2. W-10 Screenings	20	Junction City Mining	Ga-553	03 / 01 / 2002
3. Sand		Anderson Columbia Company	Compass Lake	03 / 01 / 2002
4.				
5.				
6. PG 67-22				

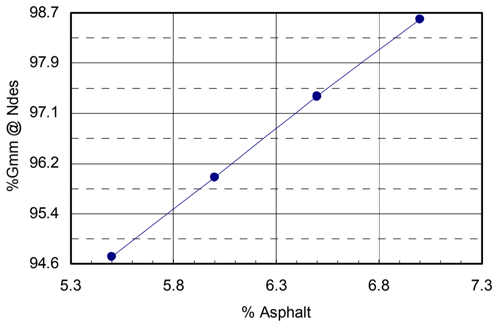
PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

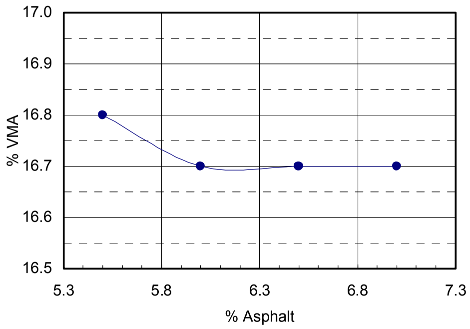
	Blend	38%	40%	22%				JOB MIX	CONTROL	RESTRICTED
	Number	1	2	3	4	5	6	FORMULA	POINTS	ZONE
	3/4" 19.0mm	100	100	100				100		
E	1/2" 12.5mm	100	100	100				100	100	
Z	3/8" 9.5mm	100	100	100				100	90 - 100	
I	No. 4 4.75mm	35	100	100				75	- 90	
S	No. 8 2.36mm	5	60	100				48	32 - 67	47.2 - 47.2
	No. 16 1.18mm	4	40	100				40		31.6 - 37.6
E	No. 30 600µm	3	24	88				30		23.5 - 27.5
V	No. 50 300µm	2	15	43				16		
E	No. 100 150µm	1	8	9				6		
I	No. 200 75µm	1.0	4.0	4.5				3.0	2 - 10	
S	G_{SB}	2.799	2.770	2.626				2.748		

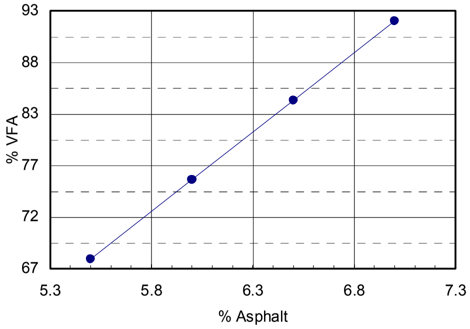
S-17 SPM 05-4051A (TL-C)

HOT MIX DESIGN DATA SHEET

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
5.5	2.420	2.555	5.3	16.8	68	4.9	0.6	87.7	95.8
6.0	2.434	2.535	4.0	16.7	76	5.4	0.6	89.0	97.1
6.5	2.448	2.515	2.7	16.7	84	5.9	0.5	90.3	98.4
7.0	2.460	2.495	1.4	16.7	92	6.4	0.5	91.6	99.7







Optimum Asphalt 6.00 %

Lab. Density 151.9 Lbs/Ft^3 2434 Kg/m^3

VMA 16.7 %

FAA 🟥 %

%G_{mm} @ N_{des} 96.0

NCAT Oven Calibration Factor ____ %
(+To Be Added)/(-To Be Subtracted)

Mixing Temperature 310 °F 154 °C

Compaction Temperature 300 °F 149 °C

Type Anti-strip here (QPL#)
Additives Antistrip 0.5 %

S-18 SP 05-4061A (TL-C)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. SP 05-4061A (TL-C) (S-18) CTQP Qualified Mix Designer
Contractor C.W.Roberts Contracting, Inc Address 1201 Aenon Church Rd, Tallahassee, Fl, 32304
Phone No. 850-575-0162 Fax No. 850-575-0304 E-mail gthaw@cwrcontracting.com
Submitted By Asphalt Technologies, Inc Type Mix Fine SP-12.5 Recycle Intended Use of Mix Structural
Design Traffic Level C Gyrations @ N des 75 QC Technician

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. Crushed RAP	4-Jan	C.W. Roberts Contracting, Inc	A0638	03 / 09 / 2005
2. #67 Stone	41	E.R. Jahna	38-286	03 / 09 / 2005
3. #89 Stone	53	E.R. Jahna	38-268	03 / 09 / 2005
4. W-10 Screenings	20	C.W. Roberts Contracting, Inc	TM-565 Ga-553	03 / 09 / 2005
5. Sand			Quincy	03 / 09 / 2005
6. PG 67-22				

PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

Blend		22%	25%	10%	28%	15%		JOB MIX FORMULA	CONTROL POINTS	RESTRICTED ZONE
Number		1	2	3	4	5	6			
	3/4" 19.0mm	100	100	100	100	100		100	100	
E	1/2" 12.5mm	100	63	100	100	100		91	90 - 100	
Z	3/8" 9.5mm	95	36	98	100	100		83	- 90	
I	No. 4 4.75mm	79	10	50	100	100		68		
S	No. 8 2.36mm	65	2	11	70	100		51	28 - 58	39.1 - 39.1
	No. 16 1.18mm	55	2	4	40	100		39		25.6 - 31.6
E	No. 30 600µm	41	2	3	24	89		30		19.1 - 23.1
V	No. 50 300µm	30	2	2	15	28		16		
E	No. 100 150µm	20	2	2	8	6		8		
I	No. 200 75µm	8.8	2.0	3.0	7.0	1.0		4.8	2 - 10	
S	G_{SB}	2.568	2.404	2.446	2.770	2.626		2.572		

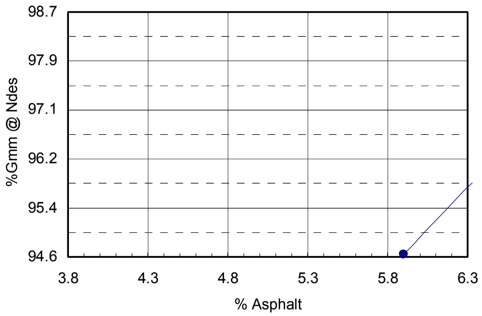
SP 05-4061A (TL-C)

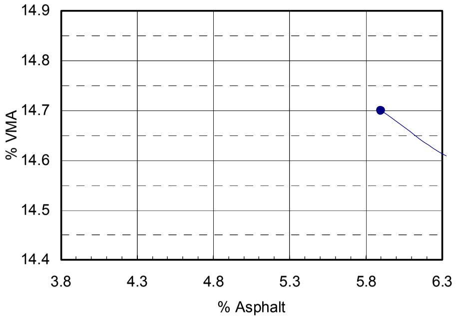
S-18 SP 05-4061A (TL-C)

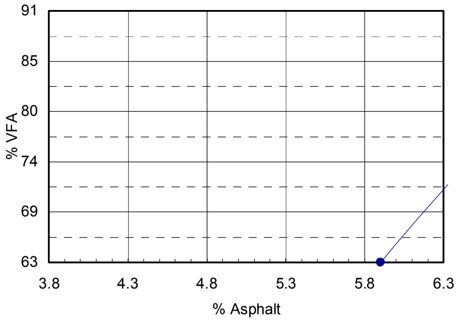
HOT MIX DESIGN DATA SHEET

SP 05-4061A (TL-C)

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
5.9	2.331	2.463	5.4	14.7	63	4.1	1.2	87.7	95.7
6.4	2.348	2.445	4.0	14.6	73	4.6	1.0	89.0	97.0
6.9	2.359	2.428	2.8	14.6	81	5.1	0.9	90.2	98.2
7.4	2.372	2.410	1.6	14.6	89	5.7	0.8	91.4	99.4







Optimum Asphalt 6.40 %

FAA 🟥 %

Mixing Temperature 310 °F 154 °C

Lab. Density 146.5 Lbs/Ft³ 2348 Kg/m³

%G_{mm} @ N_{des} 96.0

Compaction Temperature 300 °F 149 °C

Type Anti-strip here (QPL#)

VMA 14.6 %

NCAT Oven Calibration Factor ____ %
(+To Be Added)/(-To Be Subtracted)

Additives Antistrip 0.5 %

Optimum Asphalt = 6.40%
Asphalt using 22% Milled Material @ 5.9% = 1.30%
PG 64-22 to be added = 5.10%

S-19 SP 05-4100A (TL-C)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. SP 05-4100A (TL-C) (S-19) CTQP Qualified Mix Designer

Contractor C.W.Roberts Contracting, Inc Address 4208 CR 124-A, Wildwood, Fl. 34785

Phone No. 352-330-2540 Fax No. 352-330-2562 E-mail ctibbs@cwrcontracting.com

Submitted By Asphalt Technologies, Inc Type Mix Fine SP-12.5 Intended Use of Mix Structural

Design Traffic Level C Gyrations @ N des 75 QC Technician

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. #78 Stone		Junction City Mining	TM-621 GA-553	04 / 12 / 2005
2. #89 Stone	51	Junction City Mining	TM-621 GA-553	04 / 12 / 2005
3. W-10 Screenings	20	Junction City Mining	TM-621 GA-553	04 / 12 / 2005
4. Sand		C.W. Roberts Contracting, Inc	Quincy	04 / 12 / 2005
5.				
6. PG 67-22				

PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

	Blend	25%	25%	30%	20%			JOB MIX	CONTROL	RESTRICTED
	Number	1	2	3	4	5	6	FORMULA	POINTS	ZONE
	3/4" 19.0mm	100	100	100	100			100	100	
E	1/2" 12.5mm	100	100	100	100			100	90 - 100	
Z	3/8" 9.5mm	60	100	100	100			90	- 90	
I	No. 4 4.75mm	10	30	100	100			60		
S	No. 8 2.36mm	4	5	70	100			43	28 - 58	39.1 - 39.1
	No. 16 1.18mm	2	2	42	100			34		25.6 - 31.6
E	No. 30 600µm	1	1	25	96			27		19.1 - 23.1
V	No. 50 300µm	1	1	16	68			19		
E	No. 100 150µm	1	1	10	18			7		
I	No. 200 75µm	1.0	1.0	7.0	2.1			3.0	2 - 10	
S	G_{SB}	2.809	2.799	2.770	2.626			2.756		

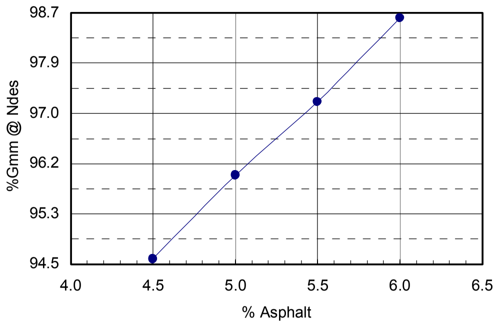
SP 05-4100A (TL-C)

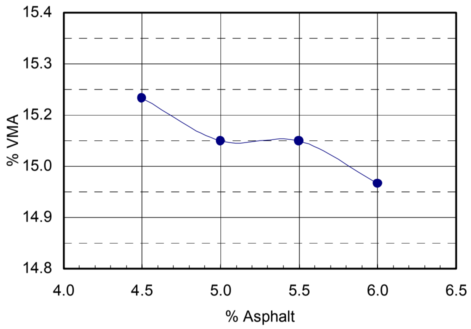
S-19 SP 05-4100A (TL-C)

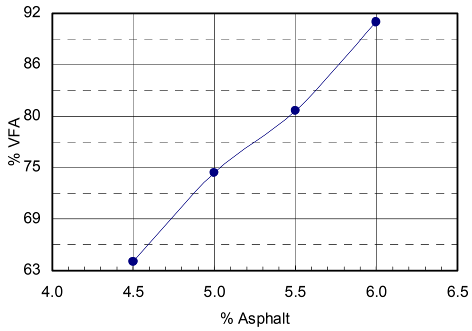
HOT MIX DESIGN DATA SHEET

SP 05-4100A (TL-C)

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
4.5	2.447	2.587	5.4	15.2	64	4.1	0.7	87.6	95.8
5.0	2.464	2.567	4.0	15.1	74	4.6	0.7	89.0	97.2
5.5	2.476	2.547	2.8	15.1	81	5.1	0.6	90.2	98.4
6.0	2.492	2.527	1.4	15.0	91	5.6	0.5	91.6	99.8







Optimum Asphalt 5.00 %

Lab. Density 153.8 Lbs/Ft^3 2464 Kg/m^3

VMA 15.1 %

FAA 🟥 %

%G_{mm} @ N_{des} 96.0

NCAT Oven ______ %

Mixing Temperature 310 °F 154 °C

Compaction Temperature 300 °F 149 °C

Arr-Maz Ad-Here LOF 65-00(S916-1012)

Additives Antistrip 0.5 %

S-20 SP 02-2052A (TL-B)

STATE OF FLORIDA DEPARTMENT OF TRANSPORTATION
STATEMENT OF SOURCE OF MATERIALS AND JOB MIX FORMULA FOR BITUMINOUS CONCRETE

SUBMIT TO THE STATE MATERIALS ENGINEER, CENTRAL BITUMINOUS LABORATORY, 2006 NORTHEAST WALDO ROAD., GAINESVILLE, FLA. 32609

Project No. SP 02-2052A (TL-B) (S-20) CTQP Qualified Mix Designer ____________

Contractor C. W. Roberts Address 1201 Aenon Church Rd, Tallahassee, m Fl 32304

Phone No. 850-575-0162 Fax No. 850-570-0304 E-mail ____________

Submitted By ____________ Type Mix FC-12.5 Intended Use of Mix Friction Course

Design Traffic Level C Gyrations @ N des 75 QC Technician ____________

TYPE MATERIAL	F.D.O.T. CODE	PRODUCER	PIT NO.	DATE SAMPLED
1. # 78 Stone	43	Junction City Mining, L. L. C.	GA-553	07 / 15 / 2002
2. # 89 Stone	51	Junction City Mining, L. L. C.	GA-553	07 / 15 / 2002
3. W-10 Screenings	20	Junction City Mining, L. L. C.	GA-553	07 / 15 / 2002
4. Sand		C. W. Roberts Contracting	Quincy	07 / 15 / 2002
5. AC-30				07 / 15 / 2002
6.				07 / 15 / 2002

PERCENTAGE BY WEIGHT TOTAL AGGREGATE PASSING SIEVES

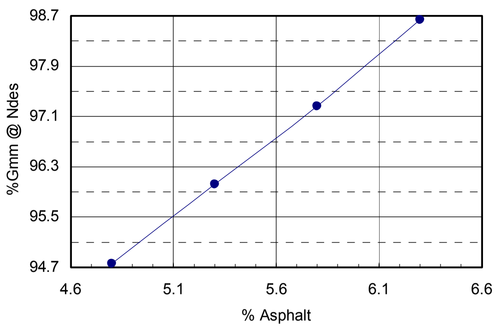
	Blend	25%	28%	27%	20%			JOB MIX	CONTROL	RESTRICTED
	Number	1	2	3	4	5	6	FORMULA	POINTS	ZONE
	3/4" 19.0mm	100	100	100	100			100	100	
E	1/2" 12.5mm	93	100	100	100			98	90 - 100	
Z	3/8" 9.5mm	60	100	100	100			90	- 90	
I	No. 4 4.75mm	10	35	100	100			59		
S	No. 8 2.36mm	4	5	66	100			40	28 - 58	39.1 - 39.1
	No. 16 1.18mm	2	3	46	100			34		25.6 - 31.6
E	No. 30 600μm	1	2	29	89			26		19.1 - 23.1
V	No. 50 300μm	1	2	17	28			11		
E	No. 100 150μm	1	1	9	6			4		
I	No. 200 75μm	1.0	1.0	4.5	1.0			3.5	2 - 10	
S	G_{SB}	2.809	2.799	2.770	2.626			2.757		

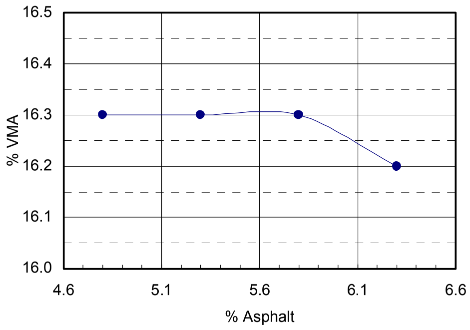
SP 02-2052A (TL-B)

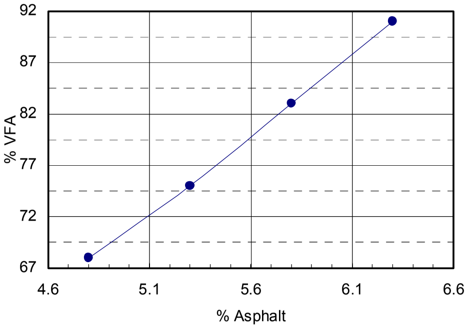
S-20 SP 02-2052A (TL-B)

HOT MIX DESIGN DATA SHEET

P_b	G_{mb} @ N_{des}	G_{mm}	V_a	VMA	VFA	P_{be}	$P_{0.075}$ / P_{be}	%G_{mm} @ N_{ini}	%G_{mm} @ N_{max}
4.8	2.425	2.559	5.2	16.3	68	4.7	0.7	87.6	95.8
5.3	2.438	2.539	4.0	16.3	75	5.2	0.7	88.8	97.0
5.8	2.450	2.519	2.7	16.3	83	5.7	0.6	90.1	98.3
6.3	2.465	2.499	1.4	16.2	91	6.2	0.6	91.4	99.6







Total Asphalt Rubber 5.10 %

Lab. Density 151.3 Lbs/Ft^3 2425 Kg/m^3

VMA 16.3 %

FAA 🟥 %

%G_{mm} @ N_{des} 94.8

NCAT Oven ______ %

Mixing Temperature 320 °F 160 °C

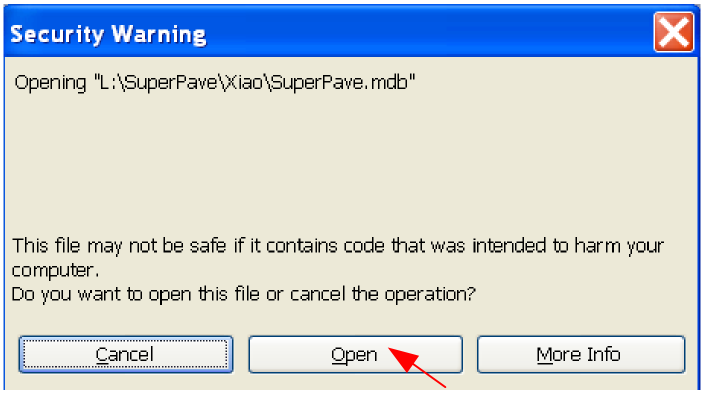
Compaction Temperature 290 °F 143 °C

Type Anti-strip here (QPL#)

Additives Antistrip 0.5 %

APPENDIX B
DATABASE “SuperPave.mdb” USER MANUAL

Step 1: Open SuperPave.mdb and click “Open” on the security warning dialog.

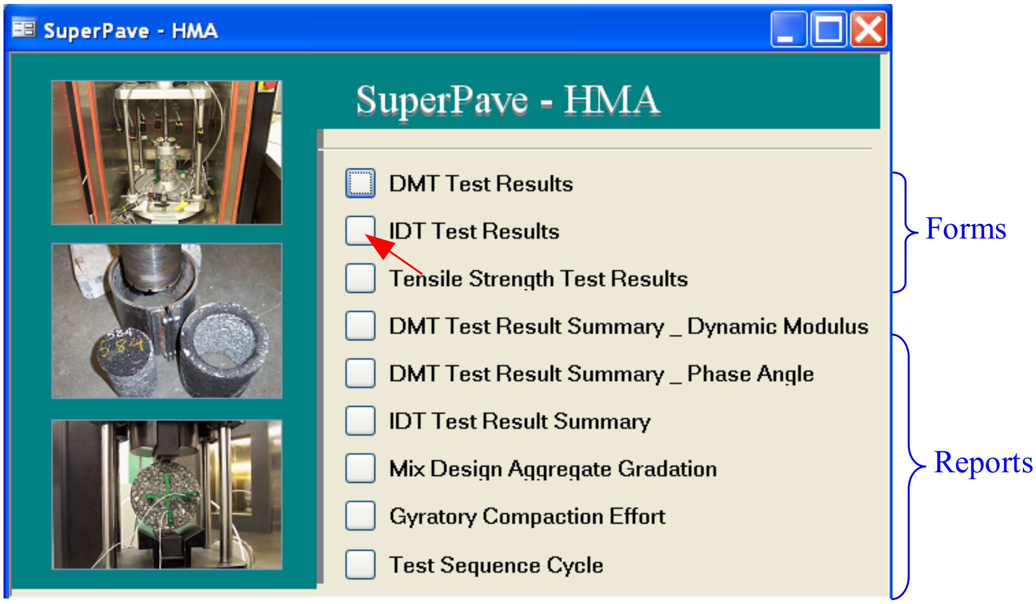


Security Warning

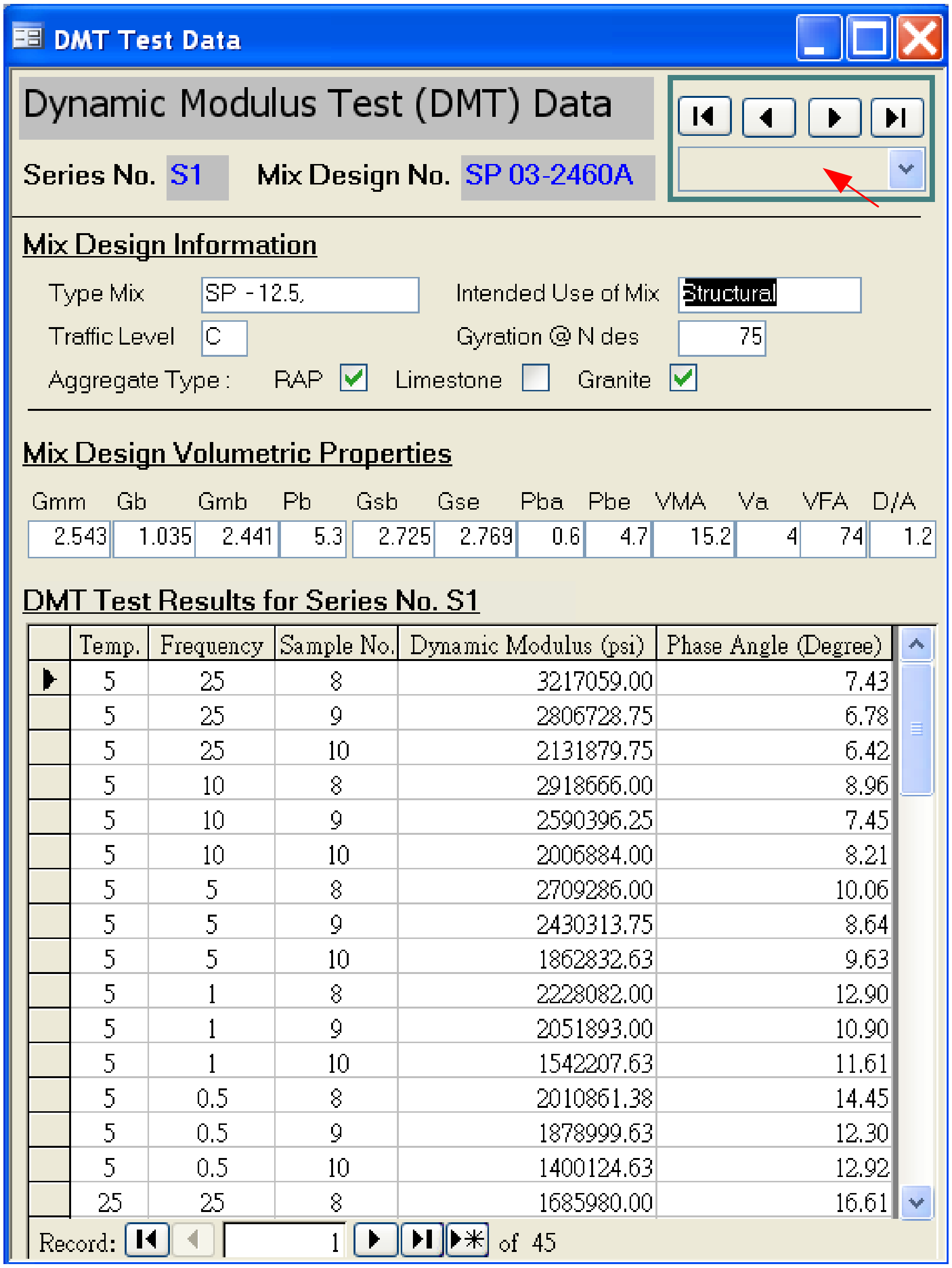
Opening "L:\SuperPave\Xiao\SuperPave.mdb"

This file may not be safe if it contains code that was intended to harm your computer.
Do you want to open this file or cancel the operation?

Step 2: Click on the main switchboard functions to go to the desired sub-forms. Three individual test data search forms, three test data summary reports, and three mix design information reports are built in.



DMT Test Results: The Dynamic Modulus Test (DMT) data can be accessed by clicking on the "DMT Test Results" on the main switchboard. The first data will show on the opening. The data can be searched by clicking the "First", "Next", "Previous", and the "Last" buttons. A specific test result can be accessed by choosing the Series No. from the Combo Box.



Dynamic Modulus Test (DMT) Data

Series No. S1 Mix Design No. SP 03-2460A

Mix Design Information

Type Mix: SP - 12.5,
Intended Use of Mix: Structural
Traffic Level: C
Gyration @ N des: 75
Aggregate Type : RAP ☑ Limestone ☐ Granite ☑

Mix Design Volumetric Properties

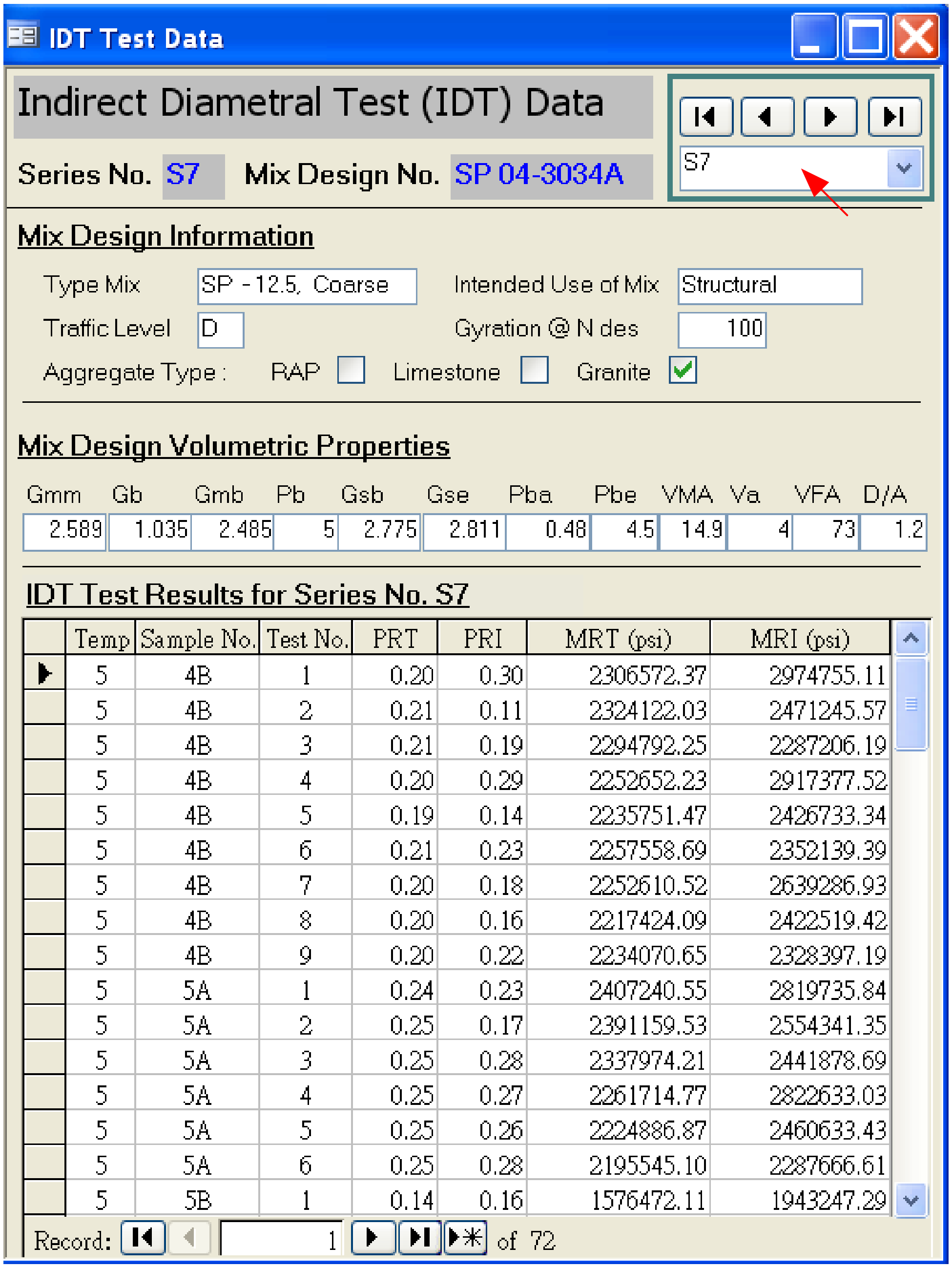
Gmm	Gb	Gmb	Pb	Gsb	Gse	Pba	Pbe	VMA	Va	VFA	D/A
2.543	1.035	2.441	5.3	2.725	2.769	0.6	4.7	15.2	4	74	1.2

DMT Test Results for Series No. S1

Temp.	Frequency	Sample No.	Dynamic Modulus (psi)	Phase Angle (Degree)
5	25	8	3217059.00	7.43
5	25	9	2806728.75	6.78
5	25	10	2131879.75	6.42
5	10	8	2918666.00	8.96
5	10	9	2590396.25	7.45
5	10	10	2006884.00	8.21
5	5	8	2709286.00	10.06
5	5	9	2430313.75	8.64
5	5	10	1862832.63	9.63
5	1	8	2228082.00	12.90
5	1	9	2051893.00	10.90
5	1	10	1542207.63	11.61
5	0.5	8	2010861.38	14.45
5	0.5	9	1878999.63	12.30
5	0.5	10	1400124.63	12.92
25	25	8	1685980.00	16.61

Record: 1 of 45

IDT Test Results: The Indirect Diametral Test (IDT) data can be accessed by clicking on the "IDT Test Results" on the main switchboard. The first data will show on the opening. The data can be searched by clicking the "First", "Next", "Previous", and the "Last" buttons. A specific test result can be accessed by choosing the Series No. from the Combo Box.



Indirect Diametral Test (IDT) Data

Series No. S7 Mix Design No. SP 04-3034A

S7

Mix Design Information

Type Mix: SP - 12.5, Coarse
Intended Use of Mix: Structural
Traffic Level: D
Gyration @ N des: 100
Aggregate Type : RAP ☐ Limestone ☐ Granite ☑

Mix Design Volumetric Properties

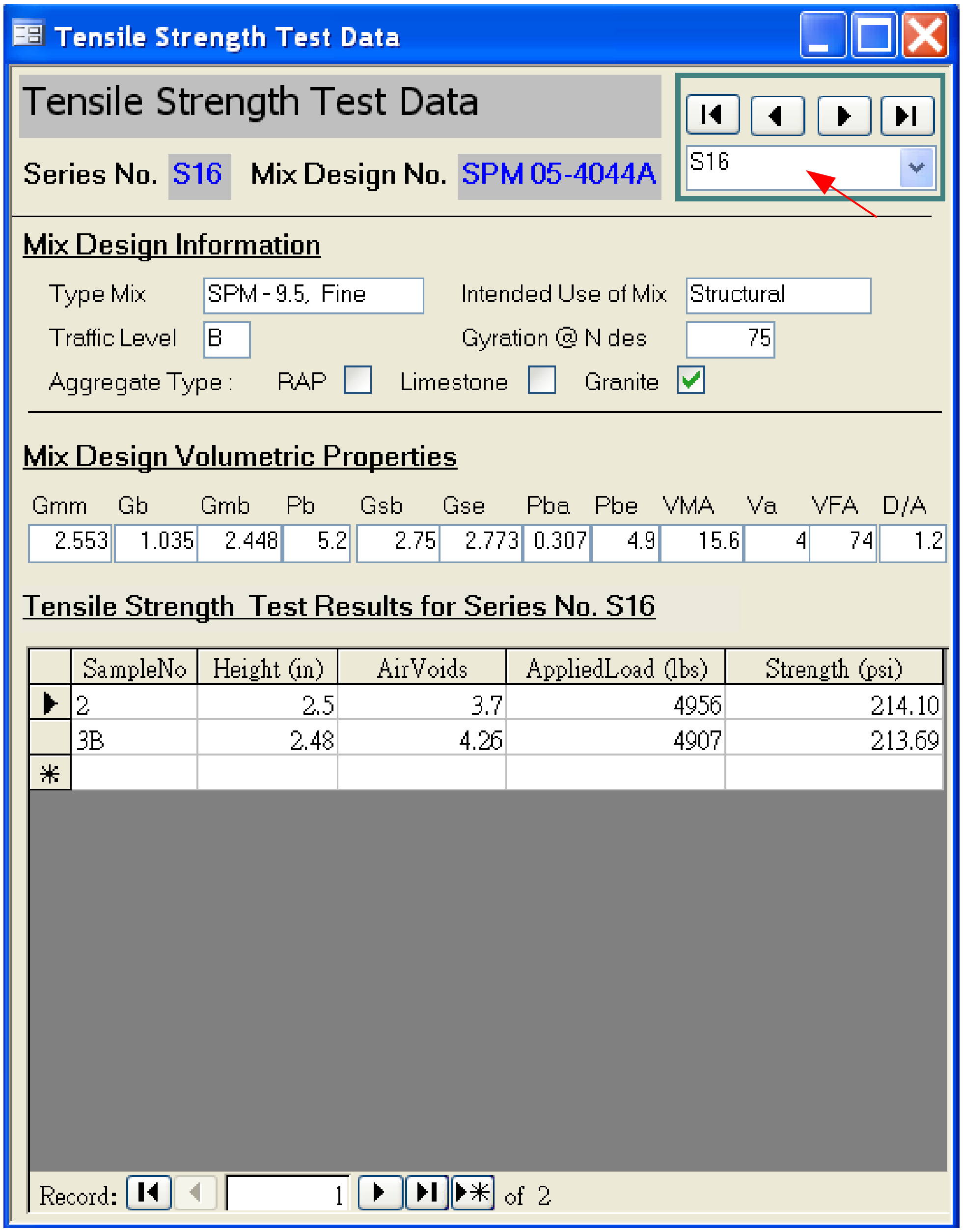
Gmm	Gb	Gmb	Pb	Gsb	Gse	Pba	Pbe	VMA	Va	VFA	D/A
2.589	1.035	2.485	5	2.775	2.811	0.48	4.5	14.9	4	73	1.2

IDT Test Results for Series No. S7

Temp	Sample No.	Test No.	PRT	PRI	MRT (psi)	MRI (psi)
5	4B	1	0.20	0.30	2306572.37	2974755.11
5	4B	2	0.21	0.11	2324122.03	2471245.57
5	4B	3	0.21	0.19	2294792.25	2287206.19
5	4B	4	0.20	0.29	2252652.23	2917377.52
5	4B	5	0.19	0.14	2235751.47	2426733.34
5	4B	6	0.21	0.23	2257558.69	2352139.39
5	4B	7	0.20	0.18	2252610.52	2639286.93
5	4B	8	0.20	0.16	2217424.09	2422519.42
5	4B	9	0.20	0.22	2234070.65	2328397.19
5	5A	1	0.24	0.23	2407240.55	2819735.84
5	5A	2	0.25	0.17	2391159.53	2554341.35
5	5A	3	0.25	0.28	2337974.21	2441878.69
5	5A	4	0.25	0.27	2261714.77	2822633.03
5	5A	5	0.25	0.26	2224886.87	2460633.43
5	5A	6	0.25	0.28	2195545.10	2287666.61
5	5B	1	0.14	0.16	1576472.11	1943247.29

Record: 1 of 72

Tensile Strength Test Results: The Tensile Strength Test data can be accessed by clicking on the "Tensile Strength Test Results" on the main switchboard. The first data will show on the opening. The data can be searched by clicking the "First", "Next", "Previous", and the "Last" buttons. A specific test result can be accessed by choosing the Series No. from the Combo Box.



Tensile Strength Test Data

Series No. S16 Mix Design No. SPM 05-4044A

Mix Design Information

Type Mix: SPM - 9.5, Fine

Intended Use of Mix: Structural

Traffic Level: B

Gyration @ N des: 75

Aggregate Type : RAP ☐ Limestone ☐ Granite ☑

Mix Design Volumetric Properties

Gmm	Gb	Gmb	Pb	Gsb	Gse	Pba	Pbe	VMA	Va	VFA	D/A
2.553	1.035	2.448	5.2	2.75	2.773	0.307	4.9	15.6	4	74	1.2

Tensile Strength Test Results for Series No. S16

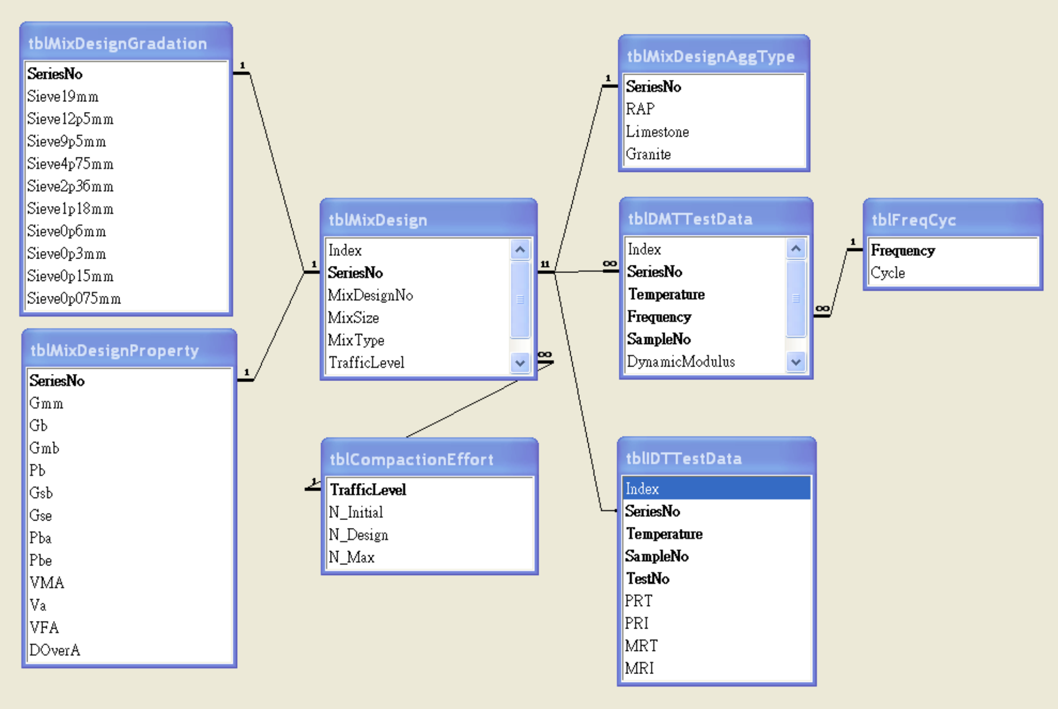
SampleNo	Height (in)	AirVoids	AppliedLoad (lbs)	Strength (psi)
2	2.5	3.7	4956	214.10
3B	2.48	4.26	4907	213.69

Record: 1 of 2

Test Data Summary Report: There are three test data summary reports in the database, which cover the summary of the dynamic modulus, phase angle, resilient modulus, and Poisson's ratio test data. However, the database administrator can add more reports anytime if needed.

Test Data Summary Report: There are three mix design property information reports in the database, which cover the mix design gradation data, gyratory compaction effort, and test sequence cycles. However, the database administrator can add more reports anytime if needed.

E-R Diagram



SuperPave.mdb Database Table List

Table name	Description
Switchboard Items	Main switchboard data
tblDMTTestData	Individual DMT test data
tblIDTTestData	Individual IDT test data
tblTensileStrengthTestdata	Individual Tensile Strength test data
tblDMTTestDataSum_DM	DMT Dynamic Modulus test data summary
tblDMTTestDataSum_PA	DMT Phase Angle test data summary
tblIDTTestDataSum	IDT Test Data summary
tblMixDesign	Mix Design basic information
tblMixDesignAggType	Mix Design aggregate types – RAP, Limestone, and Granite
tblMixDesignGradation	Mix Design gradation data
tblMixDesignProperty	Mix Design volumetric properties
tblSampleSize	Test sample size
tblCompactionEffort	Gyratory compaction effort
tblFreqCyc	Cycles for test sequences