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16. Abstract

Test Method Tex-531-C is the primary method of determining moisture damage susceptibility of hot mix in Texas. There are no known precision statements for this test method. Such a precision is required for reliable judgment of moisture susceptibility of the mixture. The repeatability and reproducibility of this test procedure were determined based on testing performed within a single laboratory and among several laboratories. This 10-month research began in August 1999 and was completed by June 2000. The limestone aggregates were treated with lime, as specified in the mix design, and the gravel aggregate was treated with a liquid antistripping agent. The mixtures with limestone aggregates had PG 64-22 binders while the gravel aggregate was mixed with a PG 70-22 binder according to the design procedure. Nine laboratories participated in the round-robin testing. On the average, the single-operator standard deviation of tensile strength for dry specimens was found to be 15 psi and that for moisture-conditioned specimens to be 12 psi. The reproducibility standard deviation of the tensile-strength ratio between different laboratories was found to be 10 percent on the average. The average coefficient of variation of the tensile-strength ratio was found to be approximately 8 percent for specimens compacted in one laboratory and tested in different laboratories. The average coefficient of variation of the tensile-strength ratio was found to be approximately 12 percent for specimens both compacted and tested in different laboratories. The differences noticed in the results from different laboratories could be influenced by many factors such as variability in compaction, conditioning, and indirect tensile testing. It is important to minimize the variability in these influencing factors in order to improve the precision of the test method.

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PRECISION OF THE MOISTURE SUSCEPTIBILITY TEST METHOD TEX-531-C: RESEARCH REPORT

by

Mansour Solaimanian
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Research Report 4909-1

Research Project 7-4909
Precision of Test Method Tex-531-C

Conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION

by the

CENTER FOR TRANSPORTATION RESEARCH
Bureau of Engineering Research
THE UNIVERSITY OF TEXAS AT AUSTIN

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IMPLEMENTATION STATEMENT

Through this research project, precision, repeatability, and reproducibility of Test Method Tex-531-C has been determined. This is the laboratory test procedure for prediction of moisture-induced damage to bituminous paving mixtures using molded specimens. The results indicate that modifications in the procedure are required to improve the precision of the method. Decision on quality of the material with regard to moisture susceptibility will be more reliable through improved precision. It is anticipated that the Texas Department of Transportation (TxDOT) will investigate the possibility of improving the precision of this test procedure based on the results of this project. The researchers recommend that TxDOT investigate the possibility of providing training to personnel to ensure that the testing procedure is followed as uniformly and as closely as possible among different laboratories.

ACKNOWLEDGMENTS

The success of this project was made possible through the cooperation and assistance of a number of dedicated people. Special thanks are extended to the personnel of the TxDOT Construction Division Materials Section, especially Mr. Dale Rand.

Special thanks are extended to Ms. Meli Sugarek (Corpus Christi District) and Tim Stagg (TxDOT Bridgeport Office), both of whom kindly accommodated our requests by providing us with the aggregates needed for the project. We are grateful to all the laboratories that, at our invitation, volunteered for the interlaboratory investigation. This participation was especially appreciated considering their busy schedules. The valuable data for this project was obtained from tests conducted by district laboratories in Atlanta, Austin, Beaumont, Pharr, and Waco, and by the TxDOT bituminous section, Rodriguez Engineering, Raba-Kistner Consultants, and The University of Texas at Austin. The authors also greatly acknowledge the support of the Center for Transportation Research, especially that provided by Mr. Ray Donley and Ms. Clair LaVaye. The financial support of the Texas Department of Transportation is greatly appreciated.

This report was prepared in cooperation with the Texas Department of Transportation.

DISCLAIMERS

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of either the Federal Highway Administration (FHWA) or the Texas Department of Transportation (TxDOT). This report does not constitute a standard, specification, or regulation.

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SUMMARY

Test Method Tex-531-C is the primary method of determining moisture damage susceptibility of hot mix in Texas. There are no known precision statements for this test method. Knowing the precision of the test procedure is important for reliable judgment of moisture susceptibility of the mixture. The repeatability and reproducibility of this test procedure were determined based on within and between-laboratory studies. This 10-month research study began in August 1999 and was completed in June 2000. Three different asphalt-aggregate mixes were evaluated in the study. Two of the mixes were with limestone aggregates and one was with gravel aggregate. The limestone aggregates were treated with lime, as specified in the mix design, and the gravel aggregate was treated with a liquid antistripping agent. The mixtures with limestone aggregates had PG 64-22 binders while the gravel aggregate was mixed with a PG 70-22 binder according to the design procedure. Nine laboratories participated in the round-robin testing. On the average, the single-operator standard deviation of tensile strength for dry specimens was found to be 15 psi and that for moisture-conditioned specimens to be 12 psi. The reproducibility standard deviation of the tensile-strength ratio between different laboratories was found to be 10 percent on the average. The average coefficient of variation of the tensile-strength ratio was found to be approximately 8 percent for specimens compacted in one laboratory and tested in different laboratories. The average coefficient of variation of the tensile-strength ratio was found to be approximately 12 percent for specimens both compacted and tested in different laboratories. The differences noticed in the results from different laboratories could be influenced by many factors such as variability in compaction, conditioning, and indirect tensile testing. It is important to minimize the variability in these influencing factors in order to improve the precision of the test method.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Moisture damage, also known as "stripping," continues to be a sporadic but persistent problem throughout Texas. Stuart *(1)* delivers a comprehensive state-of-the-art report on moisture susceptibility of asphalt mixtures.

The Texas Department of Transportation (TxDOT) has had extensive and diverse experience with the use of different aggregates with regard to stripping. Some aggregate sources in Texas have a good history of resistance to moisture damage when used in hot mix asphalt concrete (HMAC). Some others have been notorious in this regard. However, it still remains a challenge to the pavement industry to improve the current moisture damage tests for better and more reliable distinction between poor and good performers. A number of tests have been proposed and utilized by state highway agencies for the evaluation of moisture damage in HMAC. Some of these tests are:

- Modified Lottman Test (AAHSTO T 283)
- Texas Test Method 531-C
- Texas Test Method 530-C (Boiling Water Test)
- The Environmental Conditioning System

The AASHTO T 283 procedure (modified Lottman Test) is one of the most commonly used. Briefly, the test includes short-term aging, freezing (optional), limits on air voids (6 to 8 percent), and specimen saturation (55 to 80 percent). Six samples are prepared and compacted. Three samples are vacuum saturated and placed in a hot 60 °C water bath for 24 hours. After this period the specimens are considered conditioned. The other three samples remain unconditioned. All of the samples are brought to a constant temperature, and the indirect tensile strength is measured on both dry (unconditioned) and conditioned specimens.

Texas uses the Texas Test Method 531-C under the title of "prediction of moisture-induced damage to bituminous paving mixtures using molded specimens." The procedure is very similar to AASHTO T 283 in principle. Four specimens are used instead of three for each case. The freezing phase before conditioning the specimens in the water bath is mandatory in the Texas method, whereas it is optional in the AASHTO procedure. To accomplish the freezing part, the saturated specimens are conditioned in a freezer at –18 °C for a minimum of 15 hours. The most recent modification in the test method 531-C has been in the vacuum saturation process. The new requirement is to have the specimen vacuum saturated for 30 minutes rather than specifying the range of 60 to 80 percent saturation level that was required before. It is believed that, with specifying the 30-minute period, the degree of saturation will be closer to 80 percent at all times.

The boiling water test (Texas Test Method Tex-530-C, ASTM D 3625) involves immersion of the bituminous coated aggregate mixture in a container of boiling distilled water and leaving it under boiling condition for 10 minutes. Once the boiled mixture has cooled, visual observation is made to estimate the amount of retained bitumen coating, which is expressed as a percentage.

In the environmental conditioning system, a membrane-encapsulated specimen is subjected to cycles of temperature, repeated loading, and moisture conditioning. The specimen measures about 100 mm in diameter and 100 mm in height. The dry specimens are tested for triaxial resilient modulus. For conditioning specimens, they are subject to a vacuum of 51 cm Hg for 10 minutes. The vacuumed specimen remains in a 60 °C temperature for 6 hours under repeated loading (hot cycle). The specimen is cooled to 25 °C for at least 4 hours before its triaxial resilient modulus and water permeability are measured.

1.2 Precision, Accuracy, Repeatability, and Reproducibility of a Test Procedure

The focus of this study has been on the precision of Test Method Tex-531-C. Such a precision is required for reliable judgment of moisture susceptibility of the mixture. In general, to have confidence in the results, a test must be both repeatable and reproducible. The related terms are subsequently explained.

1.2.1 Precision and Accuracy

The quality of a test is judged by accuracy and precision of measurements. Accuracy is measured in terms of the proximity of average measured values to true values. Precision is measured in terms of variability of measured values. In other words, when a test method is applied to a large portion of a material (i.e., the test is repeated for different specimens from this large portion of the material), the results will not have the same value. A measure of the degree of agreement among test results describes the precision of the test method for that material. Greater variability among the test results is an indication of smaller precision. Various statistical measures and basic statistical principles provide a practical and convenient way to describe the precision of a testing procedure.

1.2.2 Repeatability and Reproducibility

These two terms deal with the variability of test results obtained under specific laboratory conditions. The repeatability of a test within a single laboratory deals with the variability among the test results obtained by one tester within that laboratory. The tests are performed by a single operator in the shortest practical period of time with a specific set of equipment using test specimens taken at random from a single quantity of material.

The reproducibility of a test among laboratories is defined from the results by multiple testers performing tests in their respective laboratories. In other words, reproducibility deals with the variability among different single-test results obtained in different laboratories, each of which has applied the test method to test specimens taken at random from a single quantity of material.

Repeatability and reproducibility are not sufficient, but are essential elements for a test to be considered reliable. An important factor for a test to be reliable is its capability to distinguish between poor and good performers, and its capability to provide meaningful results. If there are problems with repeatability and reproducibility of a test procedure, necessary steps must be taken to improve them.

The repeatability limit is presented by value r, which is the value below which the absolute difference between two single results obtained under repeatability conditions may be expected to lie with a probability of 95 percent. Assuming that the distribution of the random errors occurring in every single-test result is approximately normal, the repeatability r can be calculated as:

$$r = 2.8\ S_r^2 \qquad \text{(Eq. 1.1)}$$

Where S_r^2 is the repeatability variance, that is, the average of the within-laboratory variances S_j^2:

$$S_r = \sqrt{\sum_{j=1}^{n} S_j^2 \Big/ n} \qquad \text{(Eq. 1.2)}$$

where n is the number of laboratories for which S_j values are calculated. S_j represents the standard deviation for tests of the jth laboratory and is calculated as:

$$S_j = \sqrt{\frac{\sum_{i=1}^{p} \left(x_i - \bar{x} \right)^2}{p}} \qquad \text{(Eq. 1.3)}$$

where x_i and x represent the ith measurement and the average of measurements, respectively, for laboratory j. Parameter *p* represents the number of tests conducted in laboratory j.

The reproducibility limit is presented by value R, defined as the value below which the absolute difference between two single measurements obtained under reproducibility conditions may be expected to lie with a probability of 95 percent. Assuming that the distribution of the random error occurring in every single-test result is approximately normal, the reproducibility R can be calculated as follows:

$$R = 2.8\ S_R^2 \qquad \text{(Eq. 1.4)}$$

where S_R^2 is the reproducibility variance. The corresponding standard deviation is calculated as:

$$S_R = \sqrt{S_r^2 + S_L^2} \qquad \text{(Eq. 1.5)}$$

In equation 1.5, S_L^2 is the variance of average values from different laboratories and is calculated as:

$$S_L = \sqrt{\frac{\sum_{j=1}^{n}\left(x_j - \bar{x}_g\right)^2}{n}} \qquad \text{(Eq. 1.6)}$$

where x_j represents the average value for laboratory j, and x_g represents the average of averages for all laboratories. Parameter *n* refers to the number of laboratories involved.

1.3 Objective and Methodology

The main objective of this project was to determine the precision of the moisture susceptibility Test Method Tex-531-C. For this purpose, three aggregates with known performance and available historical data were obtained from a series of different sources. HMAC specimens for testing and evaluation were prepared using these aggregates. To investigate the test's precision, the specimens were tested according to Test Method Tex-531-C at The University of Texas at Austin and at eight other laboratories. All the compacted specimens were prepared in the central location and shipped to the participating laboratories for testing. In addition, for each aggregate, two aggregate batches were prepared and sent, along with the asphalt binder, to the participating laboratories. Mixing, compaction, and testing for this set of specimens were conducted within each laboratory.

For the within-laboratory investigation, eighty specimens were prepared and tested for each aggregate in the central laboratory (the asphalt research laboratory of The University of Texas at Austin). The data collected from all the tests was used to determine the repeatability and reproducibility of the Test Method Tex-531-C.

1.4 Implementation and Contribution to the Industry

The first important consideration regarding a laboratory test procedure is its precision, repeatability, and reproducibility. This research provided the required information on the precision of test method 531-C, which did not exist before. Such information is very important because this test procedure is currently used in Texas as the laboratory test to discriminate between good and poor performers regarding stripping.

1.5 Description of the Report Contents

The background information and the scope of the research program are provided in this chapter. The experimental program, material selection, and the performed tests are covered in Chapter 2. The results of the study and the corresponding analysis are presented in Chapter 3. Finally, Chapter 4 includes a summary along with conclusions and recommendations regarding this study.

CHAPTER 2

EXPERIMENTAL PROGRAM

2.1 GENERAL APPROACH

The objective of this project was to develop precision criteria for Test Method Tex-531-C. To achieve this goal, American Society for Testing and Materials (ASTM) designation E 691 *(standard practice for conducting an interlaboratory study to determine the precision of a test method)* was pursued. The researchers decided to approach the laboratory work in several steps. The first step was selecting and gathering aggregates from different sources. This step was followed by procurement of asphalt binders for preparing asphalt-aggregate mixtures corresponding to specific mix designs. Specimens were compacted using the Texas gyratory compactor (TGC), and then tested according to Test Method Tex-531-C. In addition to the extensive testing at The University of Texas (UT) asphalt laboratory, a series of specimens were prepared and shipped to eight different laboratories. The testing at UT was aimed at developing the test repeatability (within-laboratory project). The testing at different laboratories was performed to develop the test reproducibility (among-laboratory project). The final step included analysis of the collected data from within laboratory and among-laboratory data to develop the test method precision.

2.2 EQUIPMENT AND TESTS USED

Preparation and testing hot mix asphalt concrete specimens required the use of a series of test procedures and several pieces of equipment. The following lists the equipment utilized for this project:

- Three large-capacity ovens capable of maintaining high temperatures
- Two totally enclosed counterbalanced sieving machines
- Mechanical mixer, bowl, and hot plate
- Texas gyratory compactor (motorized gyratory-shear molding press, calibrated according to Test Method Tex-914-K)
- Pycnometer for measuring maximum theoretical specific gravity
- Precision Circulating Water Bath to maintain temperature at 60 °C
- Marshal Stability Tester AP 170-C with indirect tensile module
- Freezer to maintain temperature at –15 °C

The test procedures for the project included the following:

- Sieve Analysis of Fine and Coarse Aggregate (Test Method Tex-200-F)
- Laboratory Method of Mixing Bituminous Mixtures (Test Method Tex-205-F)
- Maximum Theoretical Specific Gravity of Bituminous Mixtures (Test Method Tex-227-F)
- Determination of Density of Compacted Bituminous Mixtures (Test Method Tex-207-F)
- Compacting Test Specimens of Bituminous Mixtures (Test Method Tex-206-F)
- Prediction of moisture-induced damage to bituminous paving mixtures using molded specimens (Test Method Tex-531-C)

All of the Texas test procedures are provided in the *Texas Manual of Testing Procedures* (Texas Department of Transportation, 1995-1997).

2.3 EXPERIMENTAL DESIGN

Two types of laboratory testing and study were pursued to achieve the objective of the research program:

- the repeatability of the test procedure within a laboratory
- the reproducibility of the test procedure among laboratories

For each case, a series of specimens were prepared and shipped to the testing laboratories. For the among-laboratories study, two types of specimens were prepared at the central laboratory (The University of Texas at Austin) and sent to the laboratories. The first set included the compacted specimens. The receiving laboratory participated in conditioning and testing these specimens. The second set consisted of aggregate batches and the asphalt binder. In this case, the receiving laboratory participated in mixing and compaction as well as in testing the specimens. Tables 1 and 2 indicate the materials and the number of specimens used for these two cases, respectively. For the latter case, each laboratory received two batches of aggregate, 7,000 grams each. These two batches were used to prepare the compacted test specimens, as well as the loose specimens, for determination of maximum theoretical specific gravity.

Table 2.1 presents the specimen matrix for this study. The work included procurement of three different aggregates as shown in the table.

Table 2.1. Specimen Preparation Program for Study of Reproducibility of the Test Procedure between Laboratories (compacted specimens sent to the laboratories from UT)

	Aggregates		
Lab. No.	Limestone 1	Limestone 2	Gravel
1	8	8	8
2	8	8	8
3	8	8	8
4	8	8	8
5	8	8	8
6	8	8	8
7	8	8	8
8	8	8	8
9	8	8	8

Numbers in the cells indicate the number of HMA specimens.
Total Number of Compacted Specimens: 216

Table 2.2. Specimen Preparation Program for Study of Reproducibility of the Test Procedure among Laboratories (aggregate batches sent to the laboratories from UT)

	Aggregates		
Lab. No.	Limestone 1	Limestone 2	Gravel
1	2	2	2
2	2	2	2
3	2	2	2
4	2	2	2
5	2	2	2
6	2	2	2
7	2	2	2
8	2	2	2
9	2	2	2

Numbers in the cells indicate the number of HMA specimens.
Total Number of Aggregate Batches: 54

For the within-laboratory study, all the work was concentrated in the central laboratory. Table 2.3 presents the design for the within-laboratory study.

Table 2.3. Specimen Preparation Program for Study of Repeatability of the Test Procedure within a Laboratory (central lab at UT)

	Aggregates		
	Limestone 1	Limestone 2	Gravel
No. of Specimen Sets	10	10	10
No. of Specimens in Each Set	8	8	8
Total Number of Specimens	80	80	80

Total Number of Specimens: 240

All of the specimen sets were tested according to Test Method Tex-531-C. The procedure requires testing both conditioned and dry specimens in the indirect tensile test. From the preceding tables, it can be seen that a total of 480 compacted specimens were prepared for the study. In addition, sixty batches of aggregates, each 7,000 grams, were prepared and shipped to the participating laboratories.

2.4 MATERIAL SELECTION AND PROCUREMENT

An important step of this research project was selection and procurement of the materials required for the program. Aggregates and binders for specific mix designs were received from different districts. The PG graded binders were either received from districts or from the suppliers.

2.4.1 Aggregates

Through coordination with the Texas Department of Transportation (TxDOT), three different aggregate sources were considered for this project. These aggregates are among typical aggregates used in Texas. As presented in Table 2.4, one gravel aggregate and two limestone aggregates were included in the study.

2.4.2 Binders

The binders used in the study were those originally used in design and construction. Aggregates and binders used for this study are presented in Table 2.4.

Table 2.4. Aggregates and Binders Used in This Research

Aggr. Code	Aggregate Type	Aggregate Source	Aggregate Producer	PG Binder	Binder Source	% AC	Mix Type
B	Limestone	Bridgeport, TX	TXI Ind.	64-22	D. Shamr.	4.8	D
C	Limestone	Hunter, TX	Colorado Matl's	64-22	Lion	5.0	Superpave
W	Gravel	Realitos, TX	Wright Matl's	7o-22	TF&A	4.6	C

2.5 MIX DESIGN

The Texas Department of Transportation District Laboratory of Corpus Christi was the source of mix design for aggregate W. This design was a type C design applied in a recent HMAC overlay construction on I-37. The design required using one percent of liquid antistripping agent. For aggregate B, the mix design was received from the TxDOT inspection office located at Bridgeport. This design was a type D design recently used for overlay construction on SH 175 in Montague County. For aggregate C, a 19 mm maximum nominal size Superpave design was used. The design was prepared at The University of Texas asphalt laboratory. For both aggregates B and C, one percent hydrated lime was used as the antistripping agent. Gradation and design information for all three mixes are presented in Appendix B.

2.6 Sieving and Batching

All aggregates were dried in the oven at 110 °C for 24 hours, followed by sieving. After sieving the aggregates were combined to deliver the required gradation for a specific design. Batches were properly proportioned using different material sizes. For each mix, a sufficient amount of the dried material was sieved to obtain fifty aggregate batches, each batch approximately 7,000 grams. These batches were used for preparing asphalt-aggregate specimens for the moisture susceptibility test and for determining the maximum theoretical specific gravity. Sieving was accomplished using the Gilson Test Master Sieving Machine™ model TM-3.

2.7 Mixing, Compacting, and Specific Gravity

2.7.1 Specific Gravity

The maximum theoretical specific gravity test, most commonly known as the Rice Test, was conducted on the loose mixtures according to Test Method Tex-227-F. The test was performed using a Pycnometer model H-1756 from Humboldt. The 4.5 liter H-1756 meets ASTM D2041. The test also uses a residual pressure manometer that meets ASTM D2041. A vacuum pump is also necessary for performing the test. A vacuum pump similar to the MA-28 (115V/60Hz) from Gilson Company, Inc., was used for performing the maximum theoretical specific gravity.

The bulk specific gravity of the compacted specimens was determined using an SG-20 Specific Gravity Bench with SGA-120 Tank, an Ohaus Balance with 0.1 grams accuracy, and an SGA-119 Specific Gravity cradle (SGA models from Gilson Company, Inc.). The specimens were left at the ambient temperature for at least 24 hours prior to the test.

2.7.2 Mixing and Compaction

The mixing procedure was performed using the specific aggregate gradation and the optimum binder content as established based on the mix design. The temperatures for mixing and compaction were selected based on the table provided by the materials section of TxDOT's construction division (Table 2.5). The binder grading presented in this table follows the Superpave performance grading. The asphalt and aggregate were properly heated in an oven for 1 ½ hours prior to mixing and for 2 hours prior to compacting.

Table 2.5. Mixing and Compacting Temperatures — TxDOT Recommendation

Binder	Compaction Temp, °F (°C)	Mixing Temp, °F (°C)
PG 64-22	250 (121)	290 (143)
PG 70-22	275 (135)	300 (149)
PG 76-22	300 (149)	325 (163)
PG 64-28	275 (135)	300 (149)
PG 70-28	300 (149)	325 (163)

The equipment used for mixing consists of a heating oven, a balance readable to 0.1 gram accuracy, a hot plate, a mechanical mixer and bowl, wisk, pans, spatulas, scoops, and the instruments necessary for gathering all the mix stuck on the bowl and wisk.

The prepared asphalt-aggregate mixtures were compacted with the aid of the Texas gyratory compactor according to Test Method Tex-206-F. For each specimen, approximately 900 grams of the mixture was placed in the compaction mold following the procedure. Briefly, compaction included the following steps:

- Placing the mold on the platen beneath the ram of the press
- Pumping the ram down into the center of the mold
- Pumping until pressure reaches 345 kPa (50 psi)
- Applying the gyration angle to the mold (5.8°)
- Applying three gyrations to the mold (automatically stops after three)
- Leveling the mold and applying one full stroke of the pump handle
- Repeating gyrations and one full stroke until pressure surges to 1,034 kPa (150 psi)
- Pumping the pressure up to 17,238 kPa (2,500 psi)
- Releasing the pressure gradually and pumping the ram up and out of the mold
- Extruding the specimen out of the mold

2.7. 3. Determination of Moisture Susceptibility (Test Method 531-C)

The moisture susceptibility of the mixes was determined according to test procedure Tex 531-C. The first phase of the method involves a trial-and-error procedure to determine the proper compactive effort to achieve the desired density range. The second phase involves preparing eight compacted specimens, conditioning four of the specimens, testing them in indirect tensile mode, and determining the tensile strength ratio (TSR). The steps in this procedure are briefly described as follows:

- Prepare asphalt-aggregate mixtures
- Compact trial specimens at different compactive efforts
- Determine maximum theoretical specific gravity using loose mixture
- Determine bulk specific gravity and air void of compacted specimens

- Determine compactive effort (number of compaction cycles) to deliver specimens with 7±1 percent voids
- Compact test specimens with the selected compactive effort
- Determine the bulk specific gravity and air void of the specimens
- Divide specimens into two groups, each with four specimens
- Subject one group of the specimens to moisture conditioning that requires the following steps:

  - Apply partial vacuum of 711 mm (28 in.) Hg to specimens for 30 minutes to achieve partial saturation.
  - Place the four vacuum-saturated specimens in plastic bags in a freezer at –18±3 °C (0 ±5 °F) for a minimum of 15 hours
  - Place specimens in a 60 ±3 °C (140 ±1.8 °F) water batch for 24±2 hours

- Remove specimens from 60 °C water bath and place in a 25 °C water bath for 3 to 4 hours
- Place the dry specimens in bags and place the bags in a 25 °C water bath for 3 to 4 hours
- Test the specimens with the indirect tensile loading to failure
- Determine the tensile strength (TS) for both conditioned and dry specimens
- Determine the tensile strength ratio (TSR)

Typically, conditioned specimens have a tensile strength lower than that of dry specimens. This loss of strength is considered to be caused by moisture conditioning through freezing and heating in the water bath. Therefore, TSR is typically less than 1. The smaller the TSR value, the greater the strength loss and, hence, the more susceptible the mix will be to moisture damage and stripping.

2.8 PARTICIPATING LABORATORIES

The success of this project was directly linked to the participation of qualified testing laboratories. Development of precision and reproducibility can be achieved only through an interlaboratory study (ILS).

Standard practice ASTM E 691 recommends that an ILS include thirty or more laboratories. However, because in many cases including such a large number of laboratories may not be practical, the practice allows for a fewer number of laboratories. Even so, under no circumstances is the final statement of precision of a test method allowed to be based on results from fewer than six laboratories. In general, it is important that enough number of laboratories are included so that a reasonable representation of the qualified laboratories is made. This way the loss or poor performance of a few will not be fatal to the study, and it will be possible to provide a reasonable and satisfactory estimate of the reproducibility.

For this project, selecting a large number of laboratories was not possible owing to budget and time constraints, as well as to the involvement of the laboratories in their own routine tasks. Eleven laboratories were selected, including the UT asphalt lab. Most of these laboratories typically have a heavy load of activities. Nonetheless, they were gracious enough to accommodate our request for participation in this study. This participation has been of extreme value to the accomplishment of the research needs. Without it, no precision could have been developed. It should be mentioned that the laboratories that participated in this program performed the required tests voluntarily and at no charge to the project. Originally, ten laboratories expressed willingness to participate, and materials were shipped to all of them. However, two of the laboratories did not conduct the tests owing to their heavy workload. Thus, the results from nine laboratories (including UT) were available for analysis and development of precision criteria.

The laboratories participating in the interlaboratory study (ILS) included:

- Austin District Laboratory (TxDOT)
- Atlanta District Laboratory (TxDOT)
- Beaumont District Laboratory (TxDOT)
- Pharr District Laboratory (TxDOT)
- Waco District Laboratory (TxDOT)
- Materials and Tests Section Bituminous Laboratory (TxDOT)
- Rodriguez Engineering
- Raba-Kistner Consultants
- The University of Texas at Austin

All of the selected laboratories were qualified to participate in the interlaboratory study. They all had proper laboratory facilities, testing equipment, and competent operators. The participants were all familiar with the test method, and they all had a reputation for reliable testing work.

2.9 Shipping Materials

The materials for each laboratory were properly packaged and labeled in the central facility (UT Austin) before shipping. One week after the materials were shipped to a specific laboratory, the lab was contacted to confirm that the material had arrived safely. From time to time, the laboratories were contacted to ascertain how the testing was progressing. This was done to compare the progress of all of the laboratories and to determine whether some laboratories were falling behind; if that were the case, they were advised accordingly. Each lab received three boxes labeled “B,” “C,” and “W” to distinguish them. Each box contained the following materials:

- Two batches of mixed aggregates, each batch approximately 7,000 grams.
- Two cans of binder, each can with approximately 500 grams of binder
- Eight 100 mm compacted HMA specimens
- One container of antistripping agent (lime or liquid)

The aggregates and binders in each box were labeled similarly so there would be no confusion as to which aggregate and binder should be mixed. For example, the binder labeled "B" and aggregates labeled "B" were to be mixed.

The package for each laboratory was accompanied by a document describing how the testing should be followed. The laboratories were requested to perform two sets of action to accomplish the objectives of this project. These two actions are subsequently explained.

2.9.1 Action A — On Compacted Specimens

Each box contained eight compacted specimens — the specimens were compacted in the central laboratory. The specific gravity and height of these specimens were measured in the participating laboratory. Four of these specimens were conditioned according to the conditioning procedure outlined in Test Method Tex-531-C (i.e., vacuum saturation, freezing, and hot water bath). The other four were maintained dry until all eight specimens were tested in the indirect tensile loading equipment as required by the Test Method Tex-531-C.

2.9.2 Action B — On Aggregate Batches and Binders

Each box contained aggregates and binders that were mixed in the participating laboratory to prepare the asphalt-aggregate mixtures. These mixes were compacted in the participating laboratory to prepare specimens for Test Method Tex-531-C. Each box contained two batches of aggregates. One batch was used to prepare (1) specimens for maximum theoretical specific gravity and (2) trial specimens at different number of gyrations. Trial specimens were needed to establish the compactive effort. The required procedure is outlined in "Note 1" of Test Method Tex-531-C. The second batch was used to prepare the eight specimens required for conditioning and testing according to Test Method Tex-531-C.

The laboratories were instructed to perform mixing and compacting specimens according to the information provided in Table 2.6.

Table 2.6. Required Information for Mixing and Compaction Temperatures

Aggregate Batch Code	Binder Batch Code	Antistripping	Percent Binder Content (by mass of mix)	Mixing Temperature °C (°F)	Compaction Temperature °C (°F)
B	B	1% lime	4.8	143 (290)	121 (250)
C	C	1% lime	5.0	143 (290)	121 (250)
W	W	1% Arras Adhere Plus	4.6	149 (300)	135 (275)

The aggregate batches did not contain the required lime. The lime was provided in special bags and was shipped to the participating laboratory along with the aggregates. The lime was to be added to the aggregate according to the procedure followed in the participating laboratory. In Table 2.6, the amount of lime is reported as a percent of the mass of the aggregate. For example, if the aggregate mass in each bag is 7,000 grams, the lime to be added will be 70 grams in the case of 1 percent lime.

CHAPTER 3

DISCUSSION OF RESULTS

The data from the tests conducted by different laboratories were collected and analyzed according to the American Society for Testing and Materials (ASTM) standard practice E 691. All the data are presented in a series of tables in Appendix A. The presented data, very comprehensive and self-explanatory, are properly categorized in different tables for easy identification and analysis.

3.1 Results for Within-Laboratory Study

Tables A.1 through A.6 (Appendix A) present the results for the within laboratory study for materials B, C, and W. The data in these tables are from the multiple tests conducted at the central laboratory (i.e., UT). Typically, it is desired that multiple tests for the same material be conducted at all the participating laboratories and that a pooled standard deviation be used for development of the precision criteria using equation 1.2. However, because of the magnitude of the testing, of the limitations of the participating laboratories in conducting the tests, and of budget and time constraints, the original proposal was designed to exclude the participating laboratories from conducting multiple tests for the same material. This proposal was precisely followed. Multiple tests of the same material for development of repeatability criteria were conducted only at the central laboratory. For each material, ten different sets of eight specimens were provided for this segment of the research and tested at the central laboratory. Summaries of the results from these tests are presented in Tables A.30 through A.33. The summary of statistics for tensile strength ratio (TSR) is presented in Table 3.1.

Table 3.1. Summary of Statistics for TSR values for Within-Laboratory Study

Material	B	C	W
Minimum	0.66	0.67	0.65*
Maximum	0.88	0.86	0.93
Average	0.78	0.77	0.87
S (Std. Dev.)	0.06	0.07	0.05
Coef. Of Var., %	7.5	9.4	5.6
95% limit	0.66 to 0.90	0.63 to 0.91	0.83 to 0.95

* 0.65 was found to be an outlier and, therefore, was not included in calculating the statistics presented in Table 3.1.

The results presented in Table 3.1 were obtained after the data were checked for the existence of outliers (see section 3.1.1). It can be seen that the standard deviation of TSR values for all three materials does not vary within a wide range (i.e., varying from 0.05 to

0.07). We believe the coefficient of variation and standard deviation values presented in Table 3.1 are quite reasonable, considering the great number of variables that can influence the results. These values are suggested as acceptable criteria for the materials tested in this program.

The two-tailed 95 percent limits are established considering the following formula:

Upper Limit = X + 1.96S
Lower Limit = X – 1.96S

where X is the average TSR and S is the standard deviation.

The number 1.96 is the z value from the normal probability curve for the 95 percent confidence level. For example, for material B there is 95 percent confidence that a single TSR measurement, under the specific conditions and procedures of testing exercised for this study, falls between 0.66 and 0.90. In other words, these two values indicate that 95 percent of individual test results from laboratories similar to those in this study can be expected to differ in absolute value from their average value by less than 0.12 (i.e., 95 percent will be within the range of 0.66 to 0.90). Similarly, confidence limits are established for materials C and W.

The repeatability limit r for the within-laboratory study is discussed in Section 3.2, along with discussion on the reproducibility limit R.

3.1.1 Statistical Tests for Outliers

Outliers are entries (TSR values) that deviate so widely from the comparable numbers that they can be considered irreconcilable with the other data. Several approaches exist for testing outliers. In all, the doubtful observation is included in the calculation of the numerical value of a sample statistic, which is then compared with a critical value based on the theory of random sampling to determine whether the doubtful observation is to be retained or rejected. The critical value is that value of the sample criterion that would be exceeded by chance with some specified probability on the assumption that all the observations did indeed constitute a random sample from a single pattern population or distribution. The specified probability, which is typically selected to be very small, is called the significance level and can be thought of as the risk of erroneously rejecting a good observation. Typical significance levels are 1 and 5 percent.

The criteria for testing outliers are based on an assumed, underlying normal (Gaussian) population. The identification of outliers was conducted according to ASTM E178-94, "Standard Practice for Dealing with Outlying Observation."

The one-sided test for outliers is based on homogeneity of variance under repeatability conditions. The test is applied to the highest value in a set of standard deviations or ranges; for this reason, it is called a one-sided test. However, it could also be applied to identify outliers at the low side. The test criterion, T_n, for testing at the high side is calculated as:

$$T_n = (X_h - X)/S \quad \text{(Eq. 3.1)}$$

where:

X = average of all TSR values,
X_h = the doubtful value (the largest value of the data set), and
S = estimate of the population standard deviation.

The hypothesis tested with both of these tests is that all observations in the samples come from the same normal population.

If the test is applied at the low side, T_n will be calculated as:

$$T_n = (X - X_l)/S \quad \text{(Eq. 3.2)}$$

where:

X_l = the doubtful value at the low side.

3.1.2 Checking for Outliers (Within-Laboratory Study)

We have accepted a significance level of 5 percent for testing the existence of outliers. We are checking for outliers at either the low or the high side, while believing that outliers cannot occur on both sides simultaneously. In other words, we are assuming that the factor causing extraneous variation existed only at the high side or the low side because it is very unlikely that two or more such events could have occurred, one being an extraneous variation on the high side and the other on the low side. With this point of view, we should calculate two critical T values, one at the high side and one at the low side, and choose the one that is larger. Therefore, the comparison of this T value should be against the critical value at a significance level of 0.025. Because two comparisons are made, the true significance level will be at 5 percent.

For the significance level of 5 percent and number of observations as 10 (number of TSR values for the within-laboratory study), the critical value T for a one-sided test at 0.025 is 2.290. Again, it should be noted that the significance level of 0.025 is selected from the table because both the low and the high side are evaluated. As can be seen from the results presented in Table 3.2, the lowest TSR value for material W appeared to be an outlier and not belonging to that population containing the other values. This lowest value has accordingly been excluded in calculating the statistics presented in Table 3.1.

Table 3.2. Determination of Outliers for Within Laboratory Study

Mat	Min. TSR	Max. TSR	Avg.* TSR	Std.* Dev.	T Low	T High	Critical T at 2.5% One-Sided Test	Outlier
B	0.66	0.88	0.78	0.06	2.00	1.67	2.29	
C	0.67	0.86	0.77	0.07	1.43	1.29	2.29	
W	0.65	0.93	0.86	0.08	2.63	0.88	2.29	0.65

* The average and standard deviations presented in Table 3.2 are calculated considering possible outliers and thus may differ from the values presented in Table 3.1.

3.2 Between-Laboratory Results

The detailed data obtained from the tests conducted by different laboratories are provided in Appendix A. Tables A.7 through A.15 present the detailed data obtained from all the laboratories. The summary of results for the specimens compacted at the testing laboratories is provided in Tables A.16 through A.21. The summary of results for the specimens compacted at the central laboratory and tested at the participating laboratories is provided in Tables A.22 through A.33. The statistics for the results are presented in Table 3.3.

Table 3.3. Summary of Statistics for TSR Values for Between-Laboratory Study (Specimens Compacted at the Participating Laboratory)

Material	B	C	W
Minimum	0.46	0.53	0.62*
Maximum	0.79	0.81	0.92
Average	0.66	0.66	0.89
S_L (Std. Dev.)	0.12	0.09	0.04
Coef. Of Var., %	18	14.1	4.6
S_r	0.06	0.07	0.05
S_R	0.13	0.12	0.06
95% r	0.16	0.20	0.14
95 % R	0.37	0.33	0.17

* The value 0.62 was found to be an outlier and therefore was not included in calculating the statistics presented in Table 3.3.

Table 3.4. Summary of Statistics for TSR Values for Between-Laboratory Study (Specimens Compacted at the Central Laboratory)

Material	B	C	W
Minimum	0.44*	0.62	0.59*
Maximum	0.88	0.84	0.96
Average	0.79	0.77	0.88
$\underline{S_L}$ (Std. Dev.)	0.06	0.07	0.06
Coef. Of Var., %	7.3	9.3	6.4
$\underline{S_r}$	0.06	0.07	0.05
$\underline{S_R}$	0.08	0.10	0.07
95% $\underline{r}$	0.16	0.20	0.14
95 % $\underline{R}$	0.22	0.28	0.20

* Values 0.44 and 0.59 were found to be outliers and therefore, were not included in calculating the statistics presented in Table 3.4.

The terms $\underline{S_r}$, $\underline{S_R}$, $\underline{r}$, and $\underline{R}$ denote repeatability standard deviation (within a laboratory), reproducibility standard deviation (among laboratories), repeatability limit (within a laboratory), and reproducibility limit (among laboratories), respectively. The terms are described in detail in Chapter 1.

The value of $\underline{r}$ equal to 0.16 for material B (Table 3.3) indicates that approximately 95 percent of all pairs of test results from laboratories similar to those in this study under repeatability conditions can be expected to differ in absolute value by less than 0.16. The same can be interpreted for materials C and W using their respective $\underline{r}$ values. Repeatability condition refers to the condition under which the test results are obtained using the same test method in the same laboratory by the same operator and with the same equipment.

The value of $\underline{R}$ equal to 0.39 for material B (Table 3.3) indicates that 95 percent of paired test results from two different laboratories similar to those in this study can be expected to differ in absolute value by less than 0.39. The same type of interpretation could be presented for materials C and W using their respective $\underline{R}$ values.

Similarly, $\underline{r}$ and $\underline{R}$ can be interpreted for all three materials from Table 3.4, which presents data for materials compacted at the central laboratory and tested at participating laboratories.

The repeatability standard deviation $\underline{S_r}$ and repeatability standard deviation $\underline{S_R}$ from both Tables 3.3 and 3.4 are indicative of slight variability for all materials, implying that within a single laboratory results are comparable for multiple tests of the same material.

Comparing results from Table 3.3 with those from Table 3.4 indicates that there is a higher variability in results for the materials that have been compacted and tested in the participating laboratories compared to those materials that have been compacted at the central laboratory and tested at the participating laboratory. This finding is expected because the variability in the mixing and compaction procedure is minimized when all of the specimens are compacted in the same laboratory. However, out of all the results, those presented for reproducibility standard deviation and reproducibility limit R in Table 3.3 indicate excessive variability for materials B and C. For material W, results seem quite satisfactory, and S_R and R for this material indicate very small variability (Table 3.3). Some improvements are needed to ensure uniformity of testing in all laboratories and to minimize the observed variability presented in Table 3.3.

3.2.1 Checking for Outliers (Among-Laboratory Study)

We have accepted a significance level of 5 percent in testing for the existence of outliers. Similar to what was explained for the within-laboratory study, we are checking for outliers at either the low or the high side (believing that outliers cannot occur on both sides simultaneously).

For the significance level of 5 percent and number of observations as 9 (number of laboratories), the critical value T for a one-sided test at 0.025 is 2.215. As can be seen from the results presented in Table 3.5, the lowest TSR value for material W appeared to be an outlier. For the specimens compacted at the central laboratory and tested at the participating laboratories, the lowest TSR values for materials B and C were considered outliers (Table 3.6).

Table 3.5. Determination of Outliers for Among-Laboratory Study Specimens Compacted at the Central Laboratory

	Min. TSR	Max. TSR	Avg.* TSR	Std.* Dev.	T Low	T High	Critical T at 2.5% One Sided Test	Outlier
B	0.46	0.84	0.68	0.13	1.79	1.27	2.29	
C	0.53	0.97	0.7	0.14	1.22	2.03	2.29	
W	0.62	0.92	0.86	0.10	2.44	0.68	2.29	0.62

* The calculated average and standard deviation presented in Table 3.5 include possible outliers and may differ from the values presented in Table 3.3.

Table 3.6. Determination of Outliers for Among-Laboratory Study Specimens Compacted at the Participating Laboratories

	Min. TSR	Max. TSR	Avg.* TSR	Std.* Dev.	T Low	T High	Critical T at 2.5% One-Sided Test	Outlier
B	0.44	0.88	0.75	0.13	2.42	1.02	2.29	0.44
C	0.62	0.84	0.77	0.07	2.09	0.94	2.29	
W	0.59	0.96	0.85	0.11	2.33	1.01	2.29	0.59

* The calculated average and standard deviation presented in Table 3.6 include possible outliers and may differ from the values presented in Table 3.4.

In summary, the single-operator standard deviation of tensile strength for dry specimens was found to be 15 psi and that for moisture-conditioned specimens to be 12 psi. The reproducibility standard deviation of the tensile-strength ratio between different laboratories was found to be 10 percent on the average. The average coefficient of variation of the tensile-strength ratio was found to be approximately 8 percent for specimens compacted in one laboratory and tested in different laboratories. The average coefficient of variation of the tensile-strength ratio was found to be approximately 12 percent for specimens both compacted and tested in different laboratories.

CHAPTER 4

CONCLUSIONS AND RECOMMENDATIONS

4.1 Summary

Test Method Tex-531-C is the primary method used to determine moisture damage susceptibility of hot mix in Texas. Through this research project, the precision, repeatability and reproducibility of Test Method Tex-531-C has been determined. Such precision is required for reliable judgment of moisture susceptibility of the mixture. The repeatability and reproducibility of this test procedure were determined based on within- and among-laboratory studies. This 10-month research effort began in August 1999 and was completed by June 2000. Two limestone aggregates and one gravel aggregate from TxDOT approved hot mix asphalt designs were included in the study. The limestone aggregates were treated with lime and the gravel aggregate was treated with a liquid antistripping agent. Nine laboratories participated in the round-robin testing.

4.2 Conclusions

The results indicated that the procedure has sufficient repeatability for all materials and reasonable reproducibility for the material treated with the liquid antistripping agent. However, for the two materials with lime treatment, some improvement is needed with respect to reproducibility, considering the variability in results obtained from different laboratories. The differences noticed in the results obtained from different laboratories could be the result of many factors, such as variability in compaction, conditioning, and indirect tensile testing. It is important to minimize the variability in these influencing factors in order to improve the precision of the test method. Better control of treatment with lime and liquid antistripping agents will also probably improve reproducibility of results. The following specific conclusions are drawn based on the results of the research:

The values for repeatability standard deviation (Sr) were 0.06, 0.07, and 0.05 for the three materials tested in this study, respectively (i.e., for B, C, and W.) The corresponding repeatability coefficients of variation were 7, 9, and 6 percent, respectively. The repeatability limits were 0.16, 0.20, and 0.14.

The reproducibility criteria were determined for two types of specimens:

- Group I: specimens compacted and tested at the participating laboratories
- Group II: specimens compacted at the central laboratory and tested at the participating laboratories

For group I, the values for the reproducibility coefficient of variation for the three materials were 18, 14, and 5 percent, respectively. The values for reproducibility standard deviation ($\underline{S}_R$) were 0.13, 0.12, and 0.06, and the 95 percent reproducibility limits were 0.37, 0.33, and 0.17.

For group II, the values for the reproducibility coefficient of variation for the three materials were 7, 9, and 6 percent, respectively. The values for reproducibility standard deviation ($\underline{S}_R$) were 0.08, 0.10, and 0.07, and the 95 percent reproducibility limits were 0.22, 0.28, and 0.20.

The repeatability standard deviation $\underline{S}_r$ and repeatability standard deviation $\underline{S}_R$ are indicative of slight variability for all materials, implying that within a single laboratory results are comparable for multiple tests of the same material.

There is higher variability in results for the materials that have been both compacted and tested in the participating laboratories, compared to those materials that have been compacted at the central laboratory and tested at the participating laboratory.

4.3 Recommendations

Considering the numerous steps involved in the test procedure, the values for repeatability are satisfactory and can be established as repeatability criteria.

Because the reproducibility standard deviation $\underline{S}_R$ is always greater than $\underline{S}_r$ (or at best equal to it), the reproducibility limit $\underline{R}$ is, therefore, always greater than the repeatability limit $\underline{r}$. However, the results for $\underline{S}_R$ and $\underline{R}$ for materials B and C for the case that these materials were compacted in the participating laboratories are somewhat larger than expected. Reducing $\underline{S}_R$ and $\underline{R}$ can be achieved through minimizing the differences among different laboratories. Efforts should be made to ensure that the laboratories use comparable equipment and practices. The variability in results obtained from different laboratories could be a result of many factors, such as differences in mixing and compaction, conditioning, and testing. In an effort to reduce this variability, the test procedure should be improved through better control of influencing factors. For example, standard procedures of adding antistripping additives are needed to potentially lessen variability among laboratories.

It should be noticed that in this study there was no analysis of the bias for the test procedure. A statement on bias furnishes guidelines on the relationship between a set of typical results produced by the test method under specific test conditions and a related set of accepted reference values. The bias of a test procedure is a generic concept related to a consistent or systematic difference between a set of test results from the process and an accepted reference value of the property being measured. An accepted reference value was not available for the materials tested. Therefore, no bias was established.

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3. Aschenbrener, T., R. B. McGernnis, and R. L. Terrel, "Comparison of Several Moisture Susceptibility Tests to Pavements of Known Field Performance," Colorado Department of Transportation, CDOT-DTD-R-93-22, 1993.

4. "Standard Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method," ASTM Designation D 4460, 1996 Annual Book of ASTM Standards, 1996.

APPENDIX A

Table A.1. Results for Test Tex 531-C for Within-Laboratory Study

(Tests at Central Laboratory, Material B)

Lab#		Central		TSR[3]	0.76
Gmm[1]		2.472	Spec. Molded@		UT
Cycles		7	MATERIAL		**B**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
B001	6.8	1.97	1,784	141.4	135.1
B003	6.9	1.98	1,636	129.0	
B005	6.7	1.97	1,717	135.8	
B007	7.1	1.98	1,708	134.3	
B002	6.6	1.97	1,173	93.0	102.6
B004	6.8	1.97	1,359	107.4	
B006	6.6	1.96	1,279	101.8	
B008	6.4	1.96	1,361	108.1	
Lab#		**Central**		TSR[3]	**0.88**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
B011	6.3	1.97	1,561	123.9	124.1
B015	6.3	1.97	1,579	125.1	
B013	6.5	1.97	1,588	125.7	
B017	6.6	1.98	1,547	121.9	
B012	6.4	1.97	1,404	111.0	108.9
B014	6.1	1.96	1,497	119.1	
B016	6.4	1.97	1,302	103.0	
B018	6.5	1.98	1,297	102.3	
Lab#		**Central**		TSR[3]	**0.74**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
B021	6.7	1.97	1,979	156.5	153.9
B023	6.7	1.97	1,940	153.7	
B025	7.1	1.98	1,926	151.9	
B027	6.3	1.96	1,927	153.5	
B022	6.8	1.98	1,573	124.1	114.2
B024	6.6	1.97	1,373	108.6	
B026	6.6	1.97	1,468	116.5	
B028	6.6	1.97	1,363	107.8	
Lab#		**Central**		TSR[3]	**0.77**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
B032	6.4	1.96	2,217	176.2	157.1
B034	6.5	1.96	1,795	142.7	
B036	6.7	1.96	1,883	149.6	
B038	6.3	1.95	2,003	159.9	
B031	6.8	1.98	1,608	127.0	120.4
B033	6.8	1.97	1,378	109.2	
B035	6.8	1.97	1,537	121.5	
B037	6.4	1.96	1,553	123.9	

Lab#		Central		TSR[3]	0.82
Gmm[1]		##	Spec. Molded@		UT
Cycles		7	MATERIAL		**B**
Spec.	Voids %	Hght inch	Load lbs	TS[2] psi	Avg. TS psi
B041	6.9	##	1,733	136.7	146.1
B043	7.0	##	1,902	149.8	
B045	6.8	##	1,962	155.5	
B047	6.7	##	1,809	142.5	
B042	6.8	##	1,503	118.4	120.5
B044	7.0	##	1,506	118.7	
B046	6.7	##	1,499	118.7	
B048	6.3	##	1,586	126.1	
Lab#		**Central**		TSR[3]	**0.80**
Spec.	Voids %	Hght inch	Load lbs	TS[2] psi	Avg. TS psi
B052	6.8	##	1,626	128.2	119.7
B054	6.8	##	1,542	122.2	
B056	6.9	##	1,482	116.9	
B058	6.6	##	1,407	111.6	
B051	7.0	##	1,279	100.5	95.6
B053	6.9	##	1,177	93.1	
B055	6.9	##	1,164	92.0	
B057	6.6	##	1,223	97.0	
Lab#		**Central**		TSR[3]	**0.81**
Spec.	Voids %	Hght inch	Load lbs	TS[2] psi	Avg. TS psi
B062	7.2	##	1,468	115.3	123.2
B064	7.4	##	1,583	124.0	
B066	7.0	##	1,561	123.1	
B608	7.0	##	1,647	130.3	
B061	7.6	##	1,201	94.2	100.3
B065	6.7	##	1,294	102.6	
B063	6.9	##	1,266	99.4	
B067	7.0	##	1,339	105.2	
Lab#		**Central**		TSR[3]	**0.75**
Spec.	Voids %	Hght inch	Load lbs	TS[2] psi	Avg. TS psi
B071	7.2	##	1,778	139.9	148.1
B073	6.6	##	1,895	149.8	
B075	7.5	##	1,884	148.7	
B077	7.0	##	1,951	153.9	
B072	7.4	##	1,363	107.1	110.3
B074	6.8	##	1,452	114.9	
B076	7.9	##	1,343	104.4	
B078	7.3	##	1,467	115.0	

Table A.1. Results for Test Tex 531-C for Within-Laboratory Study (Cont'd).

Lab#	Central			TSR(3)	0.66	Lab#	Central			TSR(3)	0.80
Gmm(1)		2.472	Spec. Molded@		UT	Gmm(1)		##	Spec. Molded@		UT
Cycles		7	MATERIAL		B	Cycles		7	MATERIAL		B
Spec.	Voids %	Hght. inch	Load lbs	TS(2) psi	Avg. TS psi	Spec.	Voids %	Hght inch	Load lbs	TS(2) psi	Avg. TS psi
B081	7.0	2.01	1,617	125.8	135.9	B091	7.0	##	1,494	116.8	117.3
B083	6.6	1.97	1,831	144.8		B093	7.0	##	1,527	120.1	
B085	6.7	1.98	1,797	141.3		B095	6.9	##	1,557	122.5	
B087	6.6	1.98	1,667	131.7		B907	6.9	##	1,397	110.0	
B082	6.6	1.93	1,090	88.2	90.0	B092	6.8	##	1,185	92.8	94.3
B084	6.6	1.99	1,189	93.3		B094	6.8	##	1,251	98.8	
B086	6.8	1.98	1,196	94.1		B906	6.9	##	1,167	91.1	
B088	6.7	1.98	1,070	84.4		B908	6.8	##	1,202	94.6	

Table A.2. Summary of Results for Material B
(Within-Laboratory Study)

Lab #	Air Void Dry	Air Void Wet	TS psi Dry	TS psi Wet	TSR
Cent.	6.9	6.6	135.1	102.6	0.76
Cent.	6.4	6.4	124.1	108.9	0.88
Cent.	6.7	6.7	153.9	114.2	0.74
Cent.	6.5	6.7	157.1	120.4	0.77
Cent.	6.7	6.7	135.9	90.0	0.66
Cent.	6.8	6.7	146.1	120.5	0.82
Cent.	6.8	6.8	119.7	95.6	0.80
Cent.	7.1	7.0	123.2	100.3	0.81
Cent.	7.1	7.3	148.1	110.3	0.75
Cent.	7.0	6.7	117.3	94.3	0.80
Min.	6.4	6.4	117.3	90.0	0.66
Max.	7.1	7.3	157.1	120.5	0.88
Avg.	**6.8**	**6.8**	**136.1**	**105.7**	**0.78**
Std.	**0.23**	**0.26**	**14.7**	**10.8**	**0.06**
COV,%	3.4	3.8	10.8	10.2	7.5

TS: Tensile Strength
TSR: Tensile Strength Ratio (Wet Strength Over Dry Strength)

Table A.3. Results for Test Tex 531-C for Within-Laboratory Study

(Tests at Central Laboratory, Material C)

Lab#		**Central**		**TSR**[3]	**0.84**	Lab#		**Central**		**TSR**[3]	**0.78**
Gmm[1]		2.415	Spec. Molded@		UT	Gmm[1]		2.415	Spec. Molded@		UT
Cycles		7	MATERIAL		**C**	Cycles		7	MATERIAL		**C**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi	Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
C11	7.0	2.05	2,048	156.0	150.5	C52	7.6	2.08	1,792	134.6	135.8
C13	7.7	2.06	1,986	150.3		C54	7.3	2.07	1,781	134.2	
C15	7.7	2.07	1,998	150.8		C56	8.0	2.08	1,802	135.2	
C17	7.8	2.07	1,919	144.8		C58	7.3	2.05	1,830	139.1	
C12	7.4	2.05	1,701	129.4	126.5	C51	8.9	2.09	1,379	102.8	106.2
C14	8.0	2.07	1,771	133.3		C53	7.8	2.07	1,392	105.2	
C16	7.6	2.06	1,558	118.0		C55	8.1	2.07	1,466	110.5	
C18	7.3	2.06	1,653	125.3		C57	7.5	2.06	1,405	106.3	
Lab#		**Central**		**TSR**[3]	**0.68**	Lab#		**Central**		**TSR**[3]	**0.72**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi	Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
C22	7.4	2.05	2,167	164.7	166.4	C61	8.3	2.06	1,856	140.6	140.6
C24	7.7	2.06	2,113	159.7		C63	7.5	2.09	1,914	143.0	
C26	7.4	2.06	2,149	162.5		C65	7.7	2.04	1,743	133.1	
C28	7.6	2.06	2,360	178.5		C67	7.2	2.07	1,931	145.9	
C21	7.2	2.05	-	-	113.9	C62	8.1	2.07	1,410	106.1	100.8
C23	7.5	2.05	-	-		C64	7.4	2.07	1,332	100.4	
C25	7.3	2.04	1,419	108.4		C66	7.8	2.09	1,410	105.5	
C27	7.6	2.07	1,584	119.5		C68	7.4	2.08	1,216	91.3	
Lab#		**Central**		**TSR**[3]	**0.84**	Lab#		**Central**		**TSR**[3]	**0.86**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi	Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
C32	7.4	2.07	1,953	147.5	140.2	C71	8.4	2.06	1,591	120.3	119.7
C34	7.3	2.07	1,935	145.8		C73	8.5	2.07	1,525	114.7	
C36	8.2	2.08	1,875	140.6		C75	8.2	2.07	1,587	119.4	
C38	7.8	2.08	1,697	127.0		C77	8.2	2.06	1,647	124.6	
C31	7.3	2.06	1,505	114.1	117.5	C72	8.8	2.07	1,280	96.6	102.5
C33	7.6	2.09	1,532	114.4		C74	8.2	2.05	1,404	107.0	
C35	7.7	2.06	1,649	125.2		C76	8.2	2.08	1,324	99.4	
C37	8.3	2.09	1,560	116.4		C78	8.7	2.07	1,419	106.8	
Lab#		**Central**		**TSR**[3]	**0.73**	Lab#		**Central**		**TSR**[3]	**0.75**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi	Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
C41	7.1	2.04	1,435	109.8	114.7	C82	7.9	2.06	1,643	124.2	126.0
C43	8.1	2.07	1,499	113.0		C84	7.9	2.06	1,715	130.1	
C45	7.7	2.03	1,581	121.7		C86	7.9	2.07	1,608	121.2	
C47	8.0	2.08	1,520	114.1		C88	7.9	2.07	1,706	128.6	
C42	7.8	2.06	1,127	85.6	84.2	C81	8.0	2.06	1,306	98.7	94.7
C44	8.3	2.09	1,142	85.4		C83	8.0	2.06	1,203	91.2	
C46	7.6	2.07	1,118	84.3		C85	7.9	2.06	1,211	91.8	
C48	7.9	2.07	1,086	81.7		C87	7.9	2.06	1,283	97.0	

Table A.3. Results for Test Tex 531-C for Within-Laboratory Study (Cont'd).

Lab#		Central		TSR(3)	0.86	Lab#		Central		TSR(3)	0.67
Gmm(1)		2.415	Spec. Molded@		UT	Gmm(1)		2.415	Spec. Molded@		UT
Cycles		7	MATERIAL		C	Cycles		7	MATERIAL		C
Spec.	Voids %	Hght. inch	Load lbs	TS(2) psi	Avg. TS psi	Spec.	Voids %	Hght. inch	Load lbs	TS(2) psi	Avg. TS psi
C91	8.0	2.09	1,506	112.7	110.1	C101	7.8	2.03	1,810	139.0	136.8
C93	7.7	2.07	1,602	120.7		C103	7.6	2.07	1,691	127.6	
C95	8.1	2.06	1,316	99.8		C105	8.0	2.04	1,873	143.4	
C97	7.9	2.08	1,428	107.2		C107	7.9	2.07	1,816	137.1	
C92	7.7	2.08	1,293	97.0	94.9	C102	8.0	2.05	1,245	94.8	91.3
C94	8.0	2.07	1,435	108.1		C104	7.8	2.04	1,228	93.9	
C96	7.8	2.05	1,243	94.7		C106	7.7	2.03	1,143	87.8	
C98	7.9	2.07	1,054	79.5		C108	7.9	2.05	1,167	88.7	

Table A.4. Summary of Results for Material C
(Within-Laboratory Study)

Lab #	Air Void Dry	Air Void Wet	TS psi Dry	TS psi Wet	TSR
Cent.	7.5	7.6	150.5	126.5	0.84
Cent.	7.5	7.4	166.4	113.9	0.68
Cent.	7.7	7.7	140.2	117.5	0.84
Cent.	7.7	7.9	114.7	84.2	0.73
Cent.	7.9	7.8	110.1	94.9	0.86
Cent.	7.6	8.1	135.8	106.2	0.78
Cent.	7.7	7.7	140.6	100.8	0.72
Cent.	8.3	8.5	119.7	102.5	0.86
Cent.	7.9	7.9	126.0	94.7	0.75
Cent.	7.8	7.8	136.8	91.3	0.67
Min.	7.5	7.4	110.1	84.2	0.67
Max.	8.3	8.5	166.4	126.5	0.86
Avg.	**7.8**	**7.8**	**134.1**	**103.3**	**0.77**
Std.	**0.24**	**0.31**	**17.1**	**13.0**	**0.07**
COV,%	3.1	3.9	12.7	12.6	9.4

TS: Tensile Strength
TSR: Tensile Strength Ratio (Wet Strength Over Dry Strength)

Table A.5. Results for Test Tex 531-C for Within-Laboratory Study

(Tests at Central Laboratory, Material W)

Lab#		**Central**		**TSR**[3]	**0.85**	Lab#		**Central**		**TSR**[3]	**0.93**
Gmm[1]		2.433	Spec. Molded@		UT	Gmm[1]		2.433	Spec. Molded@		UT
Cycles		7	MATERIAL		**W**	Cycles		7	MATERIAL		**W**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi	Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
W12	7.5	2.04	1,836	140.1	129.8	W51	6.3	1.98	2,313	182.6	167.0
W14	8.3	2.07	1,786	134.8		W53	6.5	1.97	1,902	150.5	
W16	7.7	2.06	1,699	128.4		W55	6.2	2.01	2,078	161.4	
W18	8.7	1.93	1,434	115.9		W57	6.0	1.98	2,203	173.6	
W11	8.3	2.07	1,293	97.3	110.9	W52	6.0	1.98	2,013	158.9	154.9
W13	7.2	2.04	1,569	120.0		W54	6.6	1.99	1,939	151.9	
W15	7.6	2.05	1,461	111.1		W56	7.0	1.99	1,955	153.3	
W17	7.9	2.07	1,530	115.1		W58	6.4	2.00	1,994	155.6	
Lab#		**Central**		**TSR**[3]	**0.88**	Lab#		**Central**		**TSR**[3]	**0.93**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi	Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
W21	7.1	2.01	1,759	136.5	145.9	W62	6.3	1.99	2,220	174.4	162.4
W23	6.8	2.01	1,934	149.8		W64	6.8	2.00	2,087	163.1	
W25	7.3	2.01	1,962	152.1		W66	6.7	1.99	2,042	160.2	
W27	7.0	2.02	1,879	145.3		W68	6.5	2.01	1,952	151.8	
W22	6.1	1.90	1,595	130.9	128.0	W61	6.6	1.99	1,909	149.5	151.3
W24	6.5	1.99	1,718	134.7		W63	5.7	1.98	1,995	157.5	
W26	7.3	2.03	1,635	125.6		W65	6.8	1.99	1,871	146.6	
W28	6.7	2.01	1,556	120.7		W67	6.0	2.00	1,943	151.8	
Lab#		**Central**		**TSR**[3]	**0.78**	Lab#		**Central**		**TSR**[3]	**0.90**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi	Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
W31	6.3	2.00	2,248	175.4	174.6	W71	6.6	1.97	2,317	183.2	185.6
W33	6.5	2.00	2,262	176.8		W73	6.1	1.97	2,297	182.4	
W35	6.2	2.00	2,206	171.9		W75	6.3	1.98	2,276	179.0	
W37	7.0	2.01	2,249	174.2		W77	6.1	1.97	2,502	197.7	
W32	6.2	1.99	1,686	132.5	136.5	W72	7.2	2.00	2,067	161.2	166.9
W34	6.7	2.02	1,623	125.6		W74	6.7	1.99	2,121	166.4	
W36	6.4	1.99	1,792	140.2		W76	6.8	1.99	2,126	166.8	
W38	6.2	1.99	1,884	147.5		W78	6.5	1.98	2,194	173.2	
Lab#		**Central**		**TSR**[3]	**0.86**	Lab#		**Central**		**TSR**[3]	**0.87**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi	Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
W41	6.7	2.00	2,300	179.6	182.8	W82	7.2	1.99	2,303	180.8	180.4
W43	7.4	1.97	2,345	186.2		W84	7.3	2.01	2,285	177.8	
W45	6.8	1.98	2,221	175.2		W86	6.3	1.98	2,425	190.9	
W47	6.7	1.99	2,420	190.1		W88	7.3	2.03	2,234	172.0	
W42	6.9	2.00	1,990	155.3	157.1	W81	6.4	1.99	2,034	159.8	156.5
W44	7.1	1.98	1,978	156.2		W83	7.1	2.00	1,994	155.8	
W46	6.1	1.99	2,005	157.2		W85	6.9	2.00	1,969	153.7	
W48	7.3	1.99	2,040	159.6		W87	6.5	1.99	2,004	156.8	

Table A.5. Results for Test Tex 531-C for Within Laboratory Study (Cont'd)

Lab#		**Central**		**TSR[3]**	**0.84**	Lab#		**Central**		**TSR[3]**	**0.65**
Gmm[1]		2.433	Spec. Molded@		UT	Gmm[1]		2.433	Spec. Molded@		UT
Cycles		7	MATERIAL		**W**	Cycles		7	MATERIAL		**W**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi	Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
W091	6.3	1.99	2,213	173.7	173.9	W102	6.8	1.98	2,331	183.7	190.1
W093	7.1	2.00	2,205	172.2		W104	7.4	2.02	2,173	168.1	
W095	6.7	1.99	2,285	178.8		W106	7.2	1.99	2,495	195.3	
W097	7.1	1.98	2,173	170.9		W108	6.5	1.99	2,717	213.2	
W092	6.3	1.98	1,552	122.3	146.9	W101	6.8	1.99	1,264	99.1	123.8
W094	6.9	2.01	1,783	138.1		W103	7.3	1.99	1,445	113.0	
W096	6.6	1.99	2,085	163.4		W105	6.8	1.99	1,667	130.8	
W098	5.9	1.97	2,070	163.8		W107	7.1	1.99	1,942	152.3	

Table A.6. Summary of Results for Material W

(Within-Laboratory Study)

Lab #	Air Void Dry	Air Void Wet	TS psi Dry	TS psi Wet	TSR
Cent.	8.0	7.7	129.8	110.9	0.85
Cent.	7.1	6.6	145.9	128.0	0.88
Cent.	6.5	6.4	174.6	136.5	0.78
Cent.	6.9	6.9	182.8	157.1	0.86
Cent.	6.8	6.4	173.9	146.9	0.84
Cent.	6.3	6.5	167.0	154.9	0.93
Cent.	6.6	6.3	162.4	151.3	0.93
Cent.	6.3	6.8	185.6	166.9	0.90
Cent.	7.0	6.7	180.4	156.5	0.87
Cent.	6.9	6.4	190.1	123.8	0.65
Min.	6.3	6.3	129.8	110.9	0.65
Max.	8.0	7.7	190.1	166.9	0.93
Avg.	**6.7**	**6.6**	**171.6**	**149.8**	**0.87**
Std.	**0.33**	**0.21**	**13.0**	**12.4**	**0.05**
COV,%	4.9	3.2	7.6	8.3	5.6

Results from the first set of tests (line 1 in Table A.6) and the last set of tests are not included in calculating the statistics.

TS: Tensile Strength

TSR: Tensile Strength Ratio (Wet Strength Over Dry Strength)

Table A.7. Results for Test Tex 531-C for Laboratory 1 (Between-Laboratory Study)

Lab#		1		**TSR**(3)	**0.58**
Gmm(1)		2.455	Spec. Molded@		Lab 1
Cycles			MATERIAL		**B**
Spec.	Voids %	Hght. inch	Load lbs	TS(2) psi	Avg. TS psi
1D	8.1	2.03	1,384	106.4	107.0
2D	7.9	2.01	1,345	104.4	
3D	8.3	2.02	1,375	106.2	
4D	8.1	2.04	1,450	110.9	
5W	8.0	2.03	801	61.6	61.8
6W	8.3	2.03	801	61.6	
7W	8.2	2.03	772	59.3	
8W	7.5	2.01	837	65.0	

Lab#		1		**TSR**(3)	**0.80**
Gmm(1)		2.472	Spec. Molded@		Central
Cycles			MATERIAL		**B**
Spec.	Voids %	Hght. inch	Load lbs	TS(2) psi	Avg. TS psi
1D	5.9	1.94	1,651	132.8	137.8
2D	6.1	1.97	1,712	135.6	
3D	6.0	1.95	1,751	140.1	
4D	6.1	1.96	1,795	142.9	
5W	5.9	1.95	1,365	109.2	109.6
6W	6.0	1.97	1,370	108.5	
7W	6.1	1.96	1,333	106.1	
8W	6.0	1.96	1,441	114.7	

Lab#		1		**TSR**(3)	**0.61**
Gmm(1)		2.414	Spec. Molded@		Lab 1
Cycles			MATERIAL		**C**
Spec.	Voids %	Hght. inch	Load lbs	TS(2) psi	Avg. TS psi
1D	7.2	2.00	1,465	114.3	115.6
2D	7.6	2.01	1,516	117.7	
3D	7.2	2.01	1,521	118.0	
4D	7.4	2.01	1,448	112.4	
5W	7.5	2.02	942	72.7	70.8
6W	7.9	2.02	899	69.4	
7W	7.7	2.03	796	61.2	
8W	6.2	1.98	1,016	80.0	

Lab#		1		**TSR**(3)	**0.80**
Gmm(1)		2.414	Spec. Molded@		Central
Cycles			MATERIAL		**C**
Spec.	Voids %	Hght. inch	Load lbs	TS(2) psi	Avg. TS psi
1D	7.6	2.06	1,487	112.6	112.3
2D	8.1	2.07	1,448	109.1	
3D	7.9	2.07	1,497	112.8	
4D	7.9	2.07	1,521	114.6	
5W	7.7	2.05	1,206	91.8	89.6
6W	7.9	2.07	1,138	85.8	
7W	7.5	2.05	1,243	94.6	
8W	8.3	2.02	1,116	86.2	

Lab#		1		**TSR**(3)	**0.91**
Gmm(1)		2.445	Spec. Molded@		Lab 1
Cycles			MATERIAL		**W**
Spec.	Voids %	Hght. inch	Load lbs	TS(2) psi	Avg. TS psi
1D	6.5	1.97	2,359	186.8	177.7
2D	6.2	1.97	2,127	168.4	
3D	6.6	1.99	2,141	167.8	
4D	6.9	1.99	2,393	187.6	
5W	6.5	1.98	1,904	150.0	161.1
6W	7.0	1.99	1,968	154.3	
7W	6.7	1.99	2,224	174.3	
8W	6.1	1.97	2,095	165.9	

(1) Gmm = Measured Maximum Theor. Sp. Gr.
(2) TS = Tensile Strength
(3) TSR = Tensile Strength Ratio

Lab#		1		**TSR**(3)	**0.96**
Gmm(1)		2.445	Spec. Molded@		Central
Cycles			MATERIAL		**W**
Spec.	Voids %	Hght. inch	Load lbs	TS(2) psi	Avg. TS psi
1D	6.9	1.98	2,112	166.4	163.1
2D	6.2	2.01	1,993	154.7	
3D	7.1	1.99	2,146	168.2	
4D	6.7	1.99	2,080	163.1	
5W	6.9	1.98	1,936	152.5	155.8
6W	6.1	1.97	2,161	171.1	
7W	7.1	1.99	1,929	151.2	
8W	6.7	1.98	1,885	148.5	

(1) Gmm = Measured Maximum Theor. Sp. Gr.
(2) TS = Tensile Strength
(3) TSR = Tensile Strength Ratio

Table A.8. Results for Test Tex 531-C for Laboratory 2 (Between-Laboratory Study)

Lab#		2		TSR[3]	0.79
Gmm[1]		2.474	Spec. Molded@		Lab 2
Cycles			MATERIAL		**B**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	6.3	1.99	1,515	118.8	113.4
2D	7.1	2.01	1,305	101.3	
3D	6.4	1.98	1,540	121.3	
4D	6.8	2.00	1,440	112.3	
5W	6.8	2.00	1,165	90.9	89.6
6W	6.4	1.99	1,125	88.2	
7W	6.8	1.99	1,185	92.9	
8W	7.0	1.99	1,105	86.6	

Lab#		2		TSR[3]	0.78
Gmm[1]		2.455	Spec. Molded@		Central
Cycles			MATERIAL		**B**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	6.5	1.97	1,470	116.4	108.5
2D	6.3	1.98	1,395	109.9	
3D	6.2	1.99	1,330	104.3	
4D	6.3	2.00	1,325	103.4	
5W	6.0	1.97	1,125	89.1	84.2
6W	6.5	1.98	1,035	81.5	
7W	6.1	1.96	1,050	83.6	
8W	6.6	1.98	1,050	82.7	

Lab#		2		TSR[3]	0.81
Gmm[1]		2.414	Spec. Molded@		Lab 2
Cycles			MATERIAL		**C**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	6.5	2.04	1,405	107.4	105.5
2D	6.9	2.05	1,465	111.5	
3D	6.4	2.05	1,360	103.5	
4D	7.1	2.06	1,315	99.6	
5W	7.4	2.07	1,115	84.0	85.2
6W	6.7	2.05	1,165	88.7	
7W	7.0	2.05	1,030	78.4	
8W	6.1	2.04	1,175	89.9	

Lab#		2		TSR[3]	0.74
Gmm[1]		2.414	Spec. Molded@		Central
Cycles			MATERIAL		**C**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	7.5	2.08	1,460	109.5	113.1
2D	7.1	2.05	1,560	118.7	
3D	7.4	2.07	1,585	119.4	
4D	8.0	2.10	1,410	104.7	
5W	7.3	2.04	1,120	85.6	83.9
6W	7.8	2.08	1,105	82.9	
7W	7.3	2.07	1,135	85.5	
8W	7.7	2.09	1,095	81.7	

Lab#		2		TSR[3]	0.87
Gmm[1]		2.453	Spec. Molded@		Lab 2
Cycles			MATERIAL		**W**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	7.7	2.06	2,290	173.4	169.3
2D	7.6	2.05	2,475	188.3	
3D	7.7	2.05	2,080	158.3	
4D	7.8	2.05	2,065	157.1	
5W	7.5	2.05	2,005	152.6	148.1
6W	8.0	2.05	2,025	154.1	
7W	7.9	2.05	1,895	144.2	
8W	7.3	2.04	1,850	141.5	

(1) Gmm = Measured Maximum Theor. Sp. Gr.
(2) TS = Tensile Strength
(3) TSR = Tensile Strength Ratio

Lab#		2		TSR[3]	0.88
Gmm[1]		2.453	Spec. Molded@		Central
Cycles			MATERIAL		**W**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	6.5	1.98	2,120	167.0	159.1
2D	6.7	1.96	2,090	166.3	
3D	6.7	1.98	2,015	158.8	
4D	7.0	2.00	1,850	144.3	
5W	6.0	1.96	1,835	146.1	139.4
6W	7.2	1.99	1,640	128.6	
7W	6.4	1.97	1,825	144.5	
8W	7.0	1.97	1,750	138.6	

(1) Gmm = Measured Maximum Theor. Sp. Gr.
(2) TS = Tensile Strength
(3) TSR = Tensile Strength Ratio

Table A.9. Results for Test Tex 531-C for Laboratory 3 (Between-Laboratory Study)

Lab#		3		TSR[3]	0.46
Gmm[1]		2.481	Spec. Molded@		Lab3
Cycles		8	MATERIAL		**B**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	8.6	2.03	1,350	103.7	112.3
2D	7.6	2.01	1,330	103.2	
3D	7.5	2.00	1,551	121.0	
4D	7.4	2.02	1,571	121.3	
5W	8.0	2.00	626	48.8	51.2
6W	7.3	2.00	636	49.6	
7W	7.8	1.99	666	52.2	
8W	7.7	1.98	686	54.0	

Lab#		3		TSR[3]	0.44
Gmm[1]		2.481	Spec. Molded@		Central
Cycles			MATERIAL		**B**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	5.9	1.95	1,440	115.2	121.6
2D	5.7	1.96	485*		
3D	5.5	1.94	1,461	117.5	
4D	6.0	1.95	1,652	132.2	
5W	5.5	1.95	686	54.9	53.8
6W	5.1	1.94	656	52.8	
7W	6.0	1.96	726	57.8	
8W	6.4	1.96	626	49.8	

* Value not considered in calculating the average stngth.

Lab#		3		TSR	0.61
Gmm[1]		2.414	Spec. Molded@		Lab 3
Cycles			MATERIAL		**C**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	7.2	2.00	1,465	114.3	115.6
2D	7.6	2.01	1,516	117.7	
3D	7.2	2.01	1,521	118.0	
4D	7.4	2.01	1,448	112.4	
5W	7.5	2.02	942	72.7	70.8
6W	7.9	2.02	899	69.4	
7W	7.7	2.03	796	61.2	
8W	6.2	1.98	1,016	80.0	

Lab#		3		TSR	0.80
Gmm[1]		2.414	Spec. Molded@		Central
Cycles			MATERIAL		**C**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	7.6	2.06	1,487	112.6	112.3
2D	8.1	2.07	1,448	109.1	
3D	7.9	2.07	1,497	112.8	
4D	7.9	2.07	1,521	114.6	
5W	7.7	2.05	1,206	91.8	89.6
6W	7.9	2.07	1,138	85.8	
7W	7.5	2.05	1,243	94.6	
8W	8.3	2.02	1,116	86.2	

Lab#		3		TSR[3]	0.62
Gmm[1]		2.428	Spec. Molded@		Lab 3
Cycles		8	MATERIAL		**W**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	8.1	2.02	1,119	86.4	110.2
2D	7.3	2.03	1,440	110.7	
3D	7.9	2.05	1,591	121.1	
4D	8.2	2.06	1,621	122.8	
5W	6.3	2.03	778	59.8	68.7
6W	8.4	2.08	908	68.1	
7W	7.7	2.05	918	69.9	
8W	7.3	2.04	1,008	77.1	

(1) Gmm = Measured Maximum Theor. Sp. Gr.
(2) TS = Tensile Strength
(3) TSR = Tensile Strength Ratio

Lab#		3		TSR[3]	0.59
Gmm[1]		2.433	Spec. Molded@		Central
Cycles			MATERIAL		**W**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	8.5	2.08	1,440	108.0	105.6
2D	8.6	2.10	1,129	83.9	
3D	8.7	2.08	1,601	120.1	
4D	9.5	2.06	1,461	110.6	
5W	8.6	2.10	718	53.3	62.8
6W	8.5	2.08	768	57.6	
7W	9.3	2.11	978	72.3	
8W	8.4	2.09	908	67.8	

(1) Gmm = Measured Maximum Theor. Sp. Gr.
(2) TS = Tensile Strength
(3) TSR = Tensile Strength Ratio

Table A.10. Results for Test Tex 531-C for Laboratory 4 (Between-Laboratory Study)

Lab#		4		**TSR**[3]	**0.64**
Gmm[1]		2.458	Spec. Molded@		Lab 4
Cycles		7	MATERIAL		**B**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	7.3	2.00	1,446	112.8	117.5
2D	6.9	2.00	1,496	116.7	
3D	7.1	2.00	1,536	119.8	
4D	7.0	2.00	1,546	120.6	
5W	6.5	1.99	974	76.4	75.8
6W	7.5	1.98	934	73.6	
7W	7.1	2.00	944	73.6	
8W	7.0	1.99	1,014	79.5	

Lab#		4		**TSR**[3]	**0.84**
Gmm[1]		2.490	Spec. Molded@		Central
Cycles			MATERIAL		**B**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	6.8	1.97	1,657	131.2	131.3
2D	6.1	1.96	1,667	132.7	
3D	7.0	1.95	1,647	131.8	
4D	6.1	1.96	1,627	129.5	
5W	6.7	1.97	1,466	116.1	110.6
6W	6.5	1.97	1,325	104.9	
7W	6.1	1.95	1,386	110.9	
8W	6.7	1.96	1,386	110.3	

Lab#		4		**TSR**[3]	**0.65**
Gmm[1]		2.412	Spec. Molded@		Lab 4
Cycles		7	MATERIAL		**C**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	7.2	2.06	1,728	130.9	130.0
2D	7.2	2.06	1,717	130.0	
3D	7.3	2.06	1,737	131.5	
4D	7.1	2.06	1,687	127.8	
5W	7.1	2.06	1,185	89.7	85.2
6W	7.1	2.04	1,094	83.7	
7W	7.7	2.05	1,094	83.3	
8W	7.1	2.05	1,104	84.0	

Lab#		4		**TSR**[3]	**0.83**
Gmm[1]		2.410	Spec. Molded@		Central
Cycles			MATERIAL		**C**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	7.3	2.05	1,536	116.9	117.2
2D	7.2	2.05	1,556	118.4	
3D	7.3	2.04	1,556	119.0	
4D	6.6	2.04	1,496	114.4	
5W	7.2	2.05	1,295	98.5	97.5
6W	7.1	2.06	1,175	89.0	
7W	7.1	2.06	1,335	101.1	
8W	7.1	2.04	1,325	101.3	

Lab#		4		**TSR**[3]	**0.91**
Gmm[1]		2.425	Spec. Molded@		Lab 4
Cycles		6	MATERIAL		**W**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	6.8	2.00	2,289	178.5	180.5
2D	6.6	2.00	2,400	187.2	
3D	6.6	2.00	2,259	176.2	
4D	6.7	2.00	2,309	180.1	
5W	6.8	2.00	2,008	156.6	165.0
6W	6.6	2.01	2,169	168.3	
7W	6.6	2.01	2,129	165.2	
8W	6.6	2.01	2,189	169.9	

(1) Gmm = Measured Maximum Theor. Sp. Gr.
(2) TS = Tensile Strength
(3) TSR = Tensile Strength Ratio

Lab#		4		**TSR**[3]	**0.83**
Gmm[1]		2.440	Spec. Molded@		Central
Cycles			MATERIAL		**W**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	7.1	2.01	1,968	152.7	155.7
2D	7.2	2.00	1,978	154.3	
3D	7.1	2.00	1,988	155.1	
4D	6.9	2.00	2,058	160.5	
5W	7.3	2.01	1,677	130.2	129.8
6W	7.0	2.00	1,657	129.2	
7W	7.4	1.99	1,506	118.1	
8W	6.6	1.99	1,807	141.7	

(1) Gmm = Measured Maximum Theor. Sp. Gr.
(2) TS = Tensile Strength
(3) TSR = Tensile Strength Ratio

Table A.11. Results for Test Tex 531-C for Laboratory 5 (Between Laboratory Study)

Lab#		5		TSR(3)	0.84
Gmm(1)		2.520	Spec. Molded@		Lab 5
Cycles		8	MATERIAL		B
Spec.	Voids %	Hght. inch	Load lbs	TS(2) psi	Avg. TS psi
1D	6.7	1.96	2,218	176.5	167.2
2D	7.2	1.96	2,022	160.9	
3D	6.9	1.96	2,036	162.0	
4D	7.2	1.96	2,127	169.3	
5W	7.2	1.96	1,670	132.9	141.2
6W	6.7	1.96	1,936	154.1	
7W	7.3	1.96	1,611	128.2	
8W	6.7	1.96	1,879	149.6	

Lab#		5		TSR(3)	0.79
Gmm(1)		2.506	Spec. Molded@		Central
Cycles			MATERIAL		B
Spec.	Voids %	Hght. inch	Load lbs	TS(2) psi	Avg. TS psi
1D	6.2	1.94	1,511	121.5	126.8
2D	6.1	1.94	1,548	124.5	
3D	6.8	1.95	1,588	127.0	
4D	6.8	1.95	1,677	134.2	
5W	6.4	1.96	1,183	94.2	100.7
6W	6.3	1.95	1,247	99.8	
7W	6.8	1.97	1,299	102.9	
8W	6.7	1.95	1,327	106.2	

Lab#		5		TSR	0.97
Gmm(1)		2.404	Spec. Molded@		Lab 5
Cycles			MATERIAL		C
Spec.	Voids %	Hght. inch	Load lbs	TS(2) psi	Avg. TS psi
1D	6.7	1.98	1,516	119.4	127.8
2D	6.9	1.99	1,550	121.5	
3D	5.9	1.96	1,741	138.6	
4D	6.0	2.03	1,712	131.6	
5W	6.2	2.00	1,570	122.5	124.3
6W	6.2	1.95	1,580	126.4	
7W	6.1	1.95	1,723	137.8	
8W	6.6	1.96	1,388	110.5	

Lab#		5		TSR	0.70
Gmm(1)		2.386	Spec. Molded@		Central
Cycles			MATERIAL		C
Spec.	Voids %	Hght. inch	Load lbs	TS(2) psi	Avg. TS psi
1D	8.0	2.09	1,273	95.0	105.8
2D	7.4	2.06	1,437	108.8	
3D	6.9	2.06	1,393	105.5	
4D	6.9	2.07	1,512	113.9	
5W	7.3	2.10	932	69.2	74.5
6W	7.3	2.07	*		
7W	7.4	2.09	*		
8W	7.1	2.06	1,054	79.8	

* Two specimens fell apart in 140F bath.

Lab#		5		TSR(3)	0.92
Gmm(1)		2.430	Spec. Molded@		Lab 5
Cycles		8	MATERIAL		W
Spec.	Voids %	Hght. inch	Load lbs	TS(2) psi	Avg. TS psi
1D	6.1	2.01	2,456	190.6	178.1
2D	6.3	2.02	2,215	171.1	
3D	6.7	2.02	2,127	164.3	
4D	6.0	2.02	2,412	186.3	
5W	6.8	2.02	2,045	157.9	164.0
6W	6.0	2.01	2,097	162.8	
7W	6.0	2.01	2,205	171.1	
8W	7.0	2.04	2,147	164.2	

(1) Gmm = Measured Maximum Theor. Sp. Gr.
(2) TS = Tensile Strength
(3) TSR = Tensile Strength Ratio

Lab#		5		TSR(3)	0.94
Gmm(1)		2.445	Spec. Molded@		Central
Cycles			MATERIAL		W
Spec.	Voids %	Hght. inch	Load lbs	TS(2) psi	Avg. TS psi
1D	6.7	1.98	1,815	143.0	135.3
2D	6.8	2.02	1,736	134.1	
3D	7.5	2.03	1,677	128.9	
4D	7.6	2.01	1,741	135.1	
5W	7.2	2.00	1,625	126.8	126.8
6W	7.2	1.99	1,790	140.3	
7W	7.1	2.03	1,533	117.8	
8W	7.1	2.02	1,582	122.2	

(1) Gmm = Measured Maximum Theor. Sp. Gr.
(2) TS = Tensile Strength
(3) TSR = Tensile Strength Ratio

Table A.12. Results for Test Tex 531-C for Laboratory 6 (Between-Laboratory Study)

Lab#		6		TSR[3]	0.79
Gmm[1]		2.475	Spec. Molded@		Lab 6
Cycles		8	MATERIAL		**B**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	7.4	2.01	1,690	131.2	136.4
2D	7.4	2.02	1,611	124.4	
3D	7.0	2.01	1,858	144.2	
4D	6.5	1.99	1,858	145.7	
5W	7.2	2.01	1,389	107.8	107.7
6W	7.1	2.01	1,426	110.7	
7W	7.0	2.01	1,378	106.9	
8W	7.0	2.01	1,358	105.4	

Lab#		6		TSR[3]	0.77
Gmm[1]		2.505	Spec. Molded@		Central
Cycles			MATERIAL		**B**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	6.3	1.96	1,620	128.9	129.4
2D	6.8	1.97	1,600	126.7	
3D	6.4	1.96	1,607	127.9	
4D	6.4	1.96	1,685	134.1	
5W	6.6	1.98	1,323	104.2	99.5
6W	6.0	1.95	1,221	97.7	
7W	6.4	1.96	1,223	97.3	
8W	7.0	1.98	1,251	98.6	

Lab#		6		TSR	0.64
Gmm[1]		2.404	Spec. Molded@		Lab 6
Cycles		7	MATERIAL		**C**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	7.2	2.06	1,685	127.6	119.0
2D	7.2	2.06	1,511	114.4	
3D	7.0	2.06	1,701	128.8	
4D	7.5	2.07	1,396	105.2	
5W	7.1	2.06	1,007	76.3	75.9
6W	7.3	2.07	959	72.3	
7W	7.2	2.07	994	74.9	
8W	6.8	2.06	1,058	80.1	

Lab#		6		TSR	0.80
Gmm[1]		2.386	Spec. Molded@		Central
Cycles			MATERIAL		**C**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	7.2	2.05	1,620	123.3	118.8
2D	7.4	2.06	1,484	112.4	
3D	6.7	2.06	1,773	134.3	
4D	6.9	2.06	1,390	105.3	
5W	7.2	2.06	1,215	92.0	94.5
6W	7.0	2.05	1,303	99.2	
7W	6.8	2.06	1,285	97.3	
8W	6.7	2.08	1,194	89.6	

Lab#		6		TSR[3]	0.92
Gmm[1]		2.442	Spec. Molded@		Lab 6
Cycles			MATERIAL		**W**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	6.6	2.04	2,243	171.5	171.3
2D	7.2	2.04	2,161	165.3	
3D	6.8	2.05	2,413	183.6	
4D	7.3	2.04	2,156	164.9	
5W	7.1	2.04	2,065	157.9	157.7
6W	6.9	2.04	2,102	160.7	
7W	7.1	2.04	2,022	154.6	
8W	6.9	2.05	2,072	157.7	

(1) Gmm = Measured Maximum Theor. Sp. Gr.
(2) TS = Tensile Strength
(3) TSR = Tensile Strength Ratio

Lab#		6		TSR[3]	0.86
Gmm[1]		2.440	Spec. Molded@		Central
Cycles			MATERIAL		**W**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	6.0	1.99	2,163	169.6	167.7
2D	6.1	1.98	2,145	169.0	
3D	6.6	2.02	2,076	160.3	
4D	6.2	2.00	2,205	172.0	
5W	6.5	1.99	1,728	135.7	143.8
6W	6.2	2.00	1,935	150.9	
7W	6.0	1.98	1,873	147.6	
8W	6.6	2.01	1,815	140.9	

(1) Gmm = Measured Maximum Theor. Sp. Gr.
(2) TS = Tensile Strength
(3) TSR = Tensile Strength Ratio

Table A.13. Results for Test Tex 531-C for Laboratory 7 (Between-Laboratory Study)

Lab#	7		TSR[3]	0.76	
Gmm[1]	2.472	Spec. Molded@		Lab 7	
Cycles	7	MATERIAL		**B**	
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	6.8	1.97	1,784	141.3	135.2
2D	6.9	1.98	1,636	128.9	
3D	6.7	1.97	1,717	136.0	
4D	7.1	1.98	1,708	134.6	
5W	6.6	1.97	1,173	92.9	102.7
6W	6.8	1.97	1,359	107.6	
7W	6.6	1.96	1,279	101.8	
8W	6.4	1.96	1,361	108.3	

Lab#	7		TSR[3]	0.88	
Gmm[1]	2.472	Spec. Molded@		Central	
Cycles		MATERIAL		**B**	
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	6.3	1.97	1,561	123.6	124.1
2D	6.5	1.97	1,588	125.8	
3D	6.3	1.97	1,579	125.0	
4D	6.6	1.98	1,547	121.9	
5W	6.4	1.97	1,404	111.2	108.9
6W	6.1	1.96	1,497	119.1	
7W	6.4	1.97	1,302	103.1	
8W	6.5	1.98	1,297	102.2	

Lab#	7		TSR	0.62	
Gmm[1]	2.415	Spec. Molded@		Lab 7	
Cycles	6	MATERIAL		**C**	
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	8.2	2.08	1,590	119.3	123.8
2D	7.6	2.07	1,662	125.3	
3D	8.0	2.10	1,663	123.5	
4D	7.2	2.06	1,678	127.1	
5W	7.5	2.07	1,038	78.2	76.2
6W	7.8	2.08	927	69.5	
7W	7.7	2.08	1,065	79.9	
8W	8.2	2.06	1,017	77.0	

Lab#	7		TSR	0.84	
Gmm[1]	2.415	Spec. Molded@		Central	
Cycles		MATERIAL		**C**	
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	7.0	2.05	2,048	155.8	150.4
2D	7.7	2.06	1,986	150.4	
3D	7.7	2.07	1,998	150.6	
4D	7.8	2.07	1,919	144.6	
5W	7.4	2.05	1,701	129.4	126.5
6W	8.0	2.07	1,771	133.5	
7W	7.6	2.06	1,558	118.0	
8W	7.3	2.06	1,653	125.2	

Lab#	7		TSR[3]	0.84	
Gmm[1]	2.433	Spec. Molded@		Lab 7	
Cycles	5	MATERIAL		**W**	
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	6.0	1.97	2,179	172.6	168.5
2D	6.8	1.99	2,146	168.2	
3D	6.4	2.01	2,194	170.3	
4D	6.1	1.99	2,078	162.9	
5W	6.9	1.99	1,739	136.3	142.1
6W	6.4	2.01	1,799	139.6	
7W	6.0	1.97	2,051	162.4	
8W	6.1	2.00	1,669	130.2	

(1) Gmm = Measured Maximum Theor. Sp. Gr.
(2) TS = Tensile Strength
(3) TSR = Tensile Strength Ratio

Lab#	7		TSR[3]	0.85	
Gmm[1]	2.433	Spec. Molded@		Central	
Cycles		MATERIAL		**W**	
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	7.5	2.04	1,836	140.4	129.9
2D	8.1	2.07	1,786	134.6	
3D	7.7	2.06	1,699	128.7	
4D	8.0	1.93	1,434	115.9	
5W	8.1	2.07	1,293	97.4	111.0
6W	7.2	2.04	1,569	120.0	
7W	7.6	2.05	1,461	111.2	
8W	7.9	2.07	1,530	115.3	

(1) Gmm = Measured Maximum Theor. Sp. Gr.
(2) TS = Tensile Strength
(3) TSR = Tensile Strength Ratio

Table A.14. Results for Test Tex 531-C for Laboratory 8 (Between-Laboratory Study)

Lab#		8		TSR[3]	0.70
Gmm[1]		2.451	Spec. Molded@		Lab 8
Cycles			MATERIAL		**B**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	N/A	1.98	1,641	129.3	128.2
2D	N/A	1.99	1,618	126.8	
3D	N/A	1.98	1,665	131.2	
4D	N/A	2.00	1,610	125.6	
5W	N/A	2.00	1,122	87.5	90.0
6W	N/A	1.99	1,101	86.3	
7W	N/A	1.99	1,191	93.4	
8W	N/A	1.99	1,183	92.7	

Lab#		8		TSR[3]	0.75
Gmm[1]		2.472	Spec. Molded@		Central
Cycles			MATERIAL		**B**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	N/A	1.96	1,874	149.2	148.8
2D	N/A	1.94	2,025	162.8	
3D	N/A	1.94	1,853	149.0	
4D	N/A	1.97	1,696	134.3	
5W	N/A	1.97	1,498	118.6	112.3
6W	N/A	1.96	1,341	106.7	
7W	N/A	1.97	1,382	109.4	
8W	N/A	1.96	1,437	114.4	

Lab#		8		TSR	0.69
Gmm[1]		2.405	Spec. Molded@		Lab 8
Cycles		6	MATERIAL		**C**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	N/A	2.06	1,541	116.7	114.5
2D	N/A	2.02	1,503	116.1	
3D	N/A	2.03	1,391	106.9	
4D	N/A	2.03	1,540	118.3	
5W	N/A	2.04	1,031	78.8	78.9
6W	N/A	2.04	1,033	79.0	
7W	N/A	2.02	1,047	80.9	
8W	N/A	2.01	991	76.9	

Lab#		8		TSR	0.83
Gmm[1]		2.405	Spec. Molded@		Central
Cycles			MATERIAL		**C**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	N/A	2.05	1,874	142.6	137.0
2D	N/A	2.06	1,853	140.3	
3D	N/A	2.05	1,773	134.9	
4D	N/A	2.06	1,718	130.1	
5W	N/A	2.06	1,520	115.1	113.9
6W	N/A	2.05	1,641	124.9	
7W	N/A	2.05	1,407	107.1	
8W	N/A	2.07	1,441	108.6	

Lab#		8		TSR[3]	0.89
Gmm[1]		2.437	Spec. Molded@		Lab 8
Cycles		5	MATERIAL		**W**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	N/A	2.01	2,138	165.9	170.7
2D	N/A	2.01	2,241	173.9	
3D	N/A	2.01	2,297	178.3	
4D	N/A	2.01	2,120	164.5	
5W	N/A	2.01	1,838	142.7	152.1
6W	N/A	1.98	1,884	148.4	
7W	N/A	2.00	2,116	165.0	
8W	N/A	2.03	1,979	152.1	

(1) Gmm = Measured Maximum Theor. Sp. Gr.
(2) TS = Tensile Strength
(3) TSR = Tensile Strength Ratio

Lab#		8		TSR[3]	0.85
Gmm[1]		2.433	Spec. Molded@		Central
Cycles			MATERIAL		**W**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	N/A	1.97	2,594	205.4	198.5
2D	N/A	1.97	2,534	200.7	
3D	N/A	1.98	2,435	191.8	
4D	N/A	1.98	2,491	196.3	
5W	N/A	1.97	1,940	153.6	169.1
6W	N/A	1.98	2,250	177.3	
7W	N/A	1.94	1,994	160.3	
8W	N/A	1.95	2,316	185.3	

(1) Gmm = Measured Maximum Theor. Sp. Gr.
(2) TS = Tensile Strength
(3) TSR = Tensile Strength Ratio

Table A.15. Results for Test Tex 531-C for Laboratory 9

Lab#		9		TSR[3]	0.58
Gmm[1]		2.460	Spec. Molded@		Lab 9
Cycles			MATERIAL		**B**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	6.9	2.01	1,543	119.8	122.5
2D	7.3	2.00	1,504	117.3	
3D	6.5	1.99	1,641	128.6	
4D	6.8	1.99	1,584	124.2	
5W	6.8	2.00	875	68.3	71.6
6W	7.0	1.99	933	73.1	
7W	6.8	2.02	922	71.2	
8W	7.1	2.02	956	73.8	

Lab#		9		TSR[3]	0.69
Gmm[1]		2.480	Spec. Molded@		Central
Cycles			MATERIAL		**B**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	6.0	1.92	2,078	168.8	175.3
2D	6.1	1.93	2,134	172.5	
3D	6.1	1.93	2,213	178.9	
4D	6.2	1.92	2,227	180.9	
5W	6.2	1.92	1,440	117.0	120.4
6W	6.1	1.92	1,454	118.1	
7W	6.0	1.92	1,559	126.7	
8W	6.2	1.92	1,472	119.6	

Lab#		9		TSR	0.53
Gmm[1]		2.425	Spec. Molded@		Lab 9
Cycles			MATERIAL		**C**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	6.0	1.96	1,810	144.1	130.3
2D	7.1	2.02	1,626	125.6	
3D	8.0	2.02	1,665	128.6	
4D	7.7	2.01	1,584	122.9	
5W	7.7	2.02	902	69.7	69.7
6W	8.0	2.04	857	65.5	
7W	6.5	2.00	988	77.1	
8W	7.3	2.04	869	66.5	

Lab#		9		TSR	0.62
Gmm[1]		2.415	Spec. Molded@		Central
Cycles			MATERIAL		**C**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	8.0	2.05	1,799	136.9	142.5
2D	7.9	2.05	1,925	146.5	
3D	7.9	2.05	1,846	140.5	
4D	8.0	2.04	1,913	146.3	
5W	8.0	2.02	1,153	89.0	88.9
6W	8.0	2.01	1,226	95.2	
7W	7.9	2.03	1,210	93.0	
8W	8.0	2.04	1,026	78.5	

Lab#		9		TSR[3]	0.81
Gmm[1]		2.422	Spec. Molded@		Lab 9
Cycles			MATERIAL		**W**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	7.4	2.00	2,213	172.6	170.9
2D	6.5	1.99	2,197	172.2	
3D	6.1	2.00	2,216	172.8	
4D	6.6	1.99	2,114	165.7	
5W	6.6	1.99	1,745	136.8	138.1
6W	6.5	1.98	1,763	138.9	
7W	6.5	1.99	1,773	139.0	
8W	6.2	2.00	1,764	137.6	

(1) Gmm = Measured Maximum Theor. Sp. Gr.
(2) TS = Tensile Strength
(3) TSR = Tensile Strength Ratio

Lab#		9		TSR[3]	0.79
Gmm[1]		2.433	Spec. Molded@		Central
Cycles			MATERIAL		**W**
Spec.	Voids %	Hght. inch	Load lbs	TS[2] psi	Avg. TS psi
1D	6.0	1.95	2,487	199.0	191.0
2D	6.7	1.97	2,407	190.6	
3D	6.0	1.94	2,249	180.8	
4D	6.3	1.95	2,421	193.7	
5W	6.0	1.94	1,880	151.2	151.4
6W	6.0	1.95	1,956	156.5	
7W	6.2	1.94	1,895	152.4	
8W	6.3	1.95	1,819	145.5	

(1) Gmm = Measured Maximum Theor. Sp. Gr.
(2) TS = Tensile Strength
(3) TSR = Tensile Strength Ratio

Table A.16. Summary of Results from Indirect Tensile Test for Material B

(Between-Laboratory Study, Specimens compacted at the testing laboratory)

Lab	1		2		3		4		5		6		7		8		9	
Spec.	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi
1D	8.1	106.4	6.3	118.8	8.6	103.7	7.3	112.8	6.7	176.5	7.4	131.2	6.8	141.3	N/A	129.3	6.9	119.8
2D	7.9	104.4	7.1	101.3	7.6	103.2	6.9	116.7	7.2	160.9	7.4	124.4	6.9	128.9	N/A	126.8	7.3	117.3
3D	8.3	106.2	6.4	121.3	7.5	121.0	7.1	119.8	6.9	162.0	7.0	144.2	6.7	136.0	N/A	131.2	6.5	128.6
4D	8.1	110.9	6.8	112.3	7.4	121.3	7.0	120.6	7.2	169.3	6.5	145.7	7.1	134.6	N/A	125.6	6.8	124.2
Avg.	**8.1**	**107.0**	**6.7**	**113.4**	**7.8**	**112.3**	**7.1**	**117.5**	**7.0**	**167.2**	**7.1**	**136.4**	**6.9**	**135.2**	**N/A**	**128.2**	**6.9**	**122.5**
5W	8.0	61.6	6.8	90.9	8.0	48.8	6.5	76.4	7.2	132.9	7.2	107.8	6.6	92.9	N/A	87.5	6.8	68.3
6W	8.3	61.6	6.4	88.2	7.3	49.6	7.5	73.6	6.7	154.1	7.1	110.7	6.8	107.6	N/A	86.3	7.0	73.1
7W	8.2	59.3	6.8	92.9	7.8	52.2	7.1	73.6	7.3	128.2	7.0	106.9	6.6	101.8	N/A	93.4	6.8	71.2
8W	7.5	65.0	7.0	86.6	7.7	54.0	7.0	79.5	6.7	149.6	7.0	105.4	6.4	108.3	N/A	92.7	7.1	73.8
Avg.	**8.0**	**61.8**	**6.8**	**89.6**	**7.7**	**51.2**	**7.0**	**75.8**	**7.0**	**141.2**	**7.1**	**107.7**	**6.6**	**102.7**	**N/A**	**90.0**	**6.9**	**71.6**
TSR		**0.58**		**0.79**		**0.46**		**0.64**		**0.84**		**0.79**		**0.76**		**0.70**		**0.58**

Table A.17. Summary of Results from Indirect Tensile Test for Material C

(Between-Laboratory Study, Specimens compacted at the testing laboratory).

Lab	1		2		3		4		5		6		7		8		9	
Spec.	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi
1D	7.2	114.3	6.5	107.4	7.2	114.3	7.2	130.9	6.7	119.4	7.4	131.2	8.2	119.3	N/A	116.7	6.0	144.1
2D	7.6	117.7	6.9	111.5	7.6	117.7	7.2	130.0	6.9	121.5	7.4	124.4	7.6	125.3	N/A	116.1	7.1	125.6
3D	7.2	118.0	6.4	103.5	7.2	118.0	7.3	131.5	5.9	138.6	7.0	144.2	8.0	123.5	N/A	106.9	8.0	128.6
4D	7.4	112.4	7.1	99.6	7.4	112.4	7.1	127.8	6.0	131.6	6.5	145.7	7.2	127.1	N/A	118.3	7.7	122.9
Avg.	**7.4**	**115.6**	**6.7**	**105.5**	**7.4**	**115.6**	**7.2**	**130**	**6.4**	**128**	**7.1**	**136**	**7.8**	**124**	**N/A**	**115**	**7.2**	**130**
5W	7.5	72.7	7.4	84.0	7.5	72.7	7.1	89.7	6.2	122.5	7.2	107.8	7.5	78.2	N/A	78.8	7.7	69.7
6W	7.9	69.4	6.7	88.7	7.9	69.4	7.1	83.7	6.2	126.4	7.1	110.7	7.8	69.5	N/A	79.0	8.0	65.5
7W	7.7	61.2	7.0	78.4	7.7	61.2	7.7	83.3	6.1	137.8	7.0	106.9	7.7	79.9	N/A	80.9	6.5	77.1
8W	6.2	80.0	6.1	89.9	6.2	80.0	7.1	84.0	6.6	110.5	7.0	105.4	8.2	77.0	N/A	76.9	7.3	66.5
Avg.	**7.3**	**70.8**	**6.8**	**85.2**	**7.3**	**70.8**	**7.3**	**85.2**	**6.3**	**124**	**7.1**	**107.7**	**7.8**	**76.2**	**N/A**	**78.9**	**7.4**	**69.7**
TSR		**0.61**		**0.81**		**0.61**		**0.65**		**0.97**		**0.79**		**0.62**		**0.69**		**0.53**

Table A.18. Summary of Results from Indirect Tensile Test for Material W

(Between-Laboratory Study, Specimens compacted at the testing laboratory).

Lab	1		2		3		4		5		6		7		8		9	
Spec.	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi
1D	6.5	186.8	7.7	173.4	8.1	86.4	6.8	178.5	6.1	190.6	6.6	171.5	6.0	172.6	N/A	165.9	7.4	172.6
2D	6.2	168.4	7.6	188.3	7.3	110.7	6.6	187.2	6.3	171.1	7.2	165.3	6.8	168.2	N/A	173.9	6.5	172.2
3D	6.6	167.8	7.7	158.3	7.9	121.1	6.6	176.2	6.7	164.3	6.8	183.6	6.4	170.3	N/A	178.3	6.1	172.8
4D	6.9	187.6	7.8	157.1	8.2	122.8	6.7	180.1	6.0	186.3	7.3	164.9	6.1	162.9	N/A	164.5	6.6	165.7
Avg.	**6.6**	**177.7**	**7.7**	**169.3**	**7.9**	**110.2**	**6.7**	**181**	**6.3**	**178**	**7.0**	**171**	**6.3**	**168**	**N/A**	**171**	**6.7**	**171**
5W	6.5	150.0	7.5	152.6	6.3	59.8	6.8	156.6	6.8	157.9	7.1	157.9	6.9	136.3	N/A	142.7	6.6	136.8
6W	7.0	154.3	8.0	154.1	8.4	68.1	6.6	168.3	6.0	162.8	6.9	160.7	6.4	139.6	N/A	148.4	6.5	138.9
7W	6.7	174.3	7.9	144.2	7.7	69.9	6.6	165.2	6.0	171.1	7.1	154.6	6.0	162.4	N/A	165.0	6.5	139.0
8W	6.1	165.9	7.3	141.5	7.3	77.1	6.6	169.9	7.0	164.2	6.9	157.7	6.1	130.2	N/A	152.1	6.2	137.6
Avg.	**6.6**	**161.1**	**7.7**	**148.1**	**7.4**	**68.7**	**6.7**	**165.0**	**6.5**	**164**	**7.0**	**157.7**	**6.4**	**142.1**	**N/A**	**152.1**	**6.5**	**138.1**
TSR		**0.91**		**0.87**		**0.62**		**0.91**		**0.92**		**0.92**		**0.84**		**0.89**		**0.81**

Table A.19. Final Summary of Results

Mat'l **B** (Lab Compacted Specimens)

Lab #	Air Void Dry	Air Void Wet	TS psi Dry	TS psi Wet	TSR
1	8.1	8.0	107.0	61.8	0.58
2	6.7	6.8	113.4	89.6	0.79
3	7.8	7.7	112.3	51.2	0.46
4	7.1	7.0	117.5	75.8	0.64
5	7.0	7.0	167.2	141.2	0.84
6	7.1	7.1	136.4	107.7	0.79
7	6.9	6.6	135.2	102.7	0.76
8	N/A	N/A	128.2	90.0	0.70
9	6.9	6.9	122.5	71.6	0.58
Min.	6.7	6.6	107.0	51.2	**0.46**
Max.	8.1	8.0	136.4	107.7	**0.79**
Avg.	7.2	7.2	121.5	81.3	**0.66**
Std.	0.53	0.51	10.9	19.7	**0.12**
COV,%	7.4	7.1	9.0	24.2	**18.0**
Sr	0.23	0.26	14.65	10.82	**0.06**
SR	0.57	0.57	17.66	22.19	**0.13**
r	0.64	0.72	41.03	30.31	**0.16**
R	1.60	1.58	49.46	62.14	**0.37**

Result from Lab 5 being an outlier is excluded in Calculating the Statistical Parameters

Table A.20. Final Summary of Results

Mat'l **C** (Lab Compacted Specimens)

Lab #	Air Void Dry	Air Void Wet	TS psi Dry	TS psi Wet	TSR
1	7.4	7.3	115.6	70.8	0.61
2	6.7	6.8	105.5	85.2	0.81
3	7.4	7.3	115.6	70.8	0.61
4	7.2	7.3	130.0	85.2	0.65
5	6.4	6.3	127.8	124.3	0.97
6	7.1	7.1	136.4	107.7	0.79
7	7.8	7.8	123.8	76.2	0.62
8	N/A	N/A	114.5	78.9	0.69
9	7.2	7.4	130.3	69.7	0.53
Min.	6.7	6.8	105.5	69.7	**0.53**
Max.	7.8	7.8	136.4	107.7	**0.81**
Avg.	7.2	7.3	121.5	80.6	**0.66**
Std.	0.31	0.30	10.4	12.6	**0.09**
COV,%	4.3	4.2	8.5	15.6	**14.1**
Sr	0.24	0.31	17.08	13.00	**0.07**
SR	0.39	0.42	19.23	17.62	**0.12**
r	0.68	0.86	47.81	36.39	**0.20**
R	1.08	1.18	53.84	49.34	**0.33**

Table A.21. Final Summary of Results

Mat'l **W** (Lab Compacted Specimens)

Lab #	Air Void Dry	Air Void Wet	TS psi Dry	TS psi Wet	TSR
1	6.6	6.6	177.7	161.1	0.91
2	7.7	7.7	169.3	148.1	0.87
3*	7.9	7.4	110.2	68.7	0.62
4	6.7	6.7	180.5	165.0	0.91
5	6.3	6.5	178.1	164.0	0.92
6	7.0	7.0	171.3	157.7	0.92
7	6.3	6.4	168.5	142.1	0.84
8	N/A	N/A	170.7	152.1	0.89
9	6.7	6.5	170.9	138.1	0.81
Min.	6.3	6.4	110.2	68.7	**0.62**
Max.	7.9	7.7	180.5	165.0	**0.92**
Avg.	6.7	6.7	173.4	153.5	**0.89**
Std.	0.5	0.5	4.6	10.1	**0.04**
COV,%	7.2	6.9	2.7	6.6	**4.6**
Sr	0.33	0.21	12.96	12.44	**0.05**
SR	0.58	0.51	13.14	15.55	**0.06**
r	0.92	0.58	36.29	34.83	**0.14**
R	1.62	1.41	36.78	43.54	**0.17**

* The TSR result of 0.62 was indicated as an outlier and therefore not considered in the analysis

Table A.22. Summary of Results from Indirect Tensile Test for Material B

(Between-Laboratory Study, Specimens compacted at the central laboratory).

Lab	1		2		3		4		5		6		7		8		9	
Spec.	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi
1D	5.9	132.8	6.5	116.4	5.9	115.2	6.8	131.2	6.2	121.5	6.3	128.9	6.3	123.6	N/A	149.2	6.0	168.8
2D	6.1	135.6	6.3	109.9	5.7		6.1	132.7	6.1	124.5	6.8	126.7	6.5	125.8	N/A	162.8	6.1	172.5
3D	6.0	140.1	6.2	104.3	5.5	117.5	7.0	131.8	6.8	127.0	6.4	127.9	6.3	125.0	N/A	149.0	6.1	178.9
4D	6.1	142.9	6.3	103.4	6.0	132.2	6.1	129.5	6.8	134.2	6.4	134.1	6.6	121.9	N/A	134.3	6.2	180.9
Avg.	**6.0**	**137.8**	**6.3**	**108.5**	**5.8**	**121.6**	**6.5**	**131.3**	**6.5**	**126.8**	**6.5**	**129.4**	**6.4**	**124.1**	**N/A**	**148.8**	**6.1**	**175.3**
5W	5.9	109.2	6.0	89.1	5.5	54.9	6.7	116.1	6.4	94.2	6.6	104.2	6.4	111.2	N/A	118.6	6.2	117.0
6W	6.0	108.5	6.5	81.5	5.1	52.8	6.5	104.9	6.3	99.8	6.0	97.7	6.1	119.1	N/A	106.7	6.1	118.1
7W	6.1	106.1	6.1	83.6	6.0	57.8	6.1	110.9	6.8	102.9	6.4	97.3	6.4	103.1	N/A	109.4	6.0	126.7
8W	6.0	114.7	6.6	82.7	6.4	49.8	6.7	110.3	6.7	106.2	7.0	98.6	6.5	102.2	N/A	114.4	6.2	119.6
Avg.	**6.0**	**109.6**	**6.3**	**84.2**	**5.8**	**53.8**	**6.5**	**110.6**	**6.6**	**100.7**	**6.5**	**99.5**	**6.4**	**108.9**	**N/A**	**112.3**	**6.1**	**120.4**
TSR		**0.80**		**0.78**		**0.44**		**0.84**		**0.79**		**0.77**		**0.88**		**0.75**		**0.69**

Table A.23. Summary of Results from Indirect Tensile Test for Material C

(Between-Laboratory Study, Specimens compacted at the central laboratory).

Lab	1		2		3		4		5		6		7		8		9	
Spec.	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi
1D	7.6	112.6	7.5	109.5	7.6	112.6	7.3	116.9	8.0	95.0	7.2	123.3	7.0	155.8	N/A	142.6	8.0	136.9
2D	8.1	109.1	7.1	118.7	8.1	109.1	7.2	118.4	7.4	108.8	7.4	112.4	7.7	150.4	N/A	140.3	7.9	146.5
3D	7.9	112.8	7.4	119.4	7.9	112.8	7.3	119.0	6.9	105.5	6.7	134.3	7.7	150.6	N/A	134.9	7.9	140.5
4D	7.9	114.6	8.0	104.7	7.9	114.6	6.6	114.4	6.9	113.9	6.9	105.3	7.8	144.6	N/A	130.1	8.0	146.3
Avg.	**7.9**	**112.3**	**7.5**	**113.1**	**7.9**	**112.3**	**7.1**	**117.2**	**7.3**	**105.8**	**7.1**	**118.8**	**7.6**	**150.4**	**N/A**	**137.0**	**8.0**	**142.5**
5W	7.7	91.8	7.3	85.6	7.7	91.8	7.2	98.5	7.3	69.2	7.2	92.0	7.4	129.4	N/A	115.1	8.0	89.0
6W	7.9	85.8	7.8	82.9	7.9	85.8	7.1	89.0	7.3		7.0	99.2	8.0	133.5	N/A	124.9	8.0	95.2
7W	7.5	94.6	7.3	85.5	7.5	94.6	7.1	101.1	7.4		6.8	97.3	7.6	118.0	N/A	107.1	7.9	93.0
8W	8.3	86.2	7.7	81.7	8.3	86.2	7.1	101.3	7.1	79.8	6.7	89.6	7.3	125.2	N/A	108.6	8.0	78.5
Avg.	**7.9**	**89.6**	**7.5**	**83.9**	**7.9**	**89.6**	**7.1**	**97.5**	**7.3**	**75**	**6.9**	**94.5**	**7.6**	**126.5**	**N/A**	**113.9**	**8.0**	**88.9**
TSR		**0.80**		**0.74**		**0.80**		**0.83**		**0.70**		**0.80**		**0.84**		**0.83**		**0.62**

Table A.24. Summary of Results from Indirect Tensile Test for Material W

(Between-Laboratory Study, Specimens compacted at the central laboratory).

Lab	1		2		3		4		5		6		7		8		9	
Spec.	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi
1D	6.9	166.4	6.5	167.0	8.5	108.0	7.1	152.7	6.7	143.0	6.0	171.5	7.5	140.4	N/A	205.4	6.0	199.0
2D	6.2	154.7	6.7	166.3	8.6	83.9	7.2	154.3	6.8	134.1	6.1	165.3	8.1	134.6	N/A	200.7	6.7	190.6
3D	7.1	168.2	6.7	158.8	8.7	120.1	7.1	155.1	7.5	128.9	6.6	183.6	7.7	128.7	N/A	191.8	6.0	180.8
4D	6.7	163.1	7.0	144.3	9.5	110.6	6.9	160.5	7.6	135.1	6.2	164.9	8.0	115.9	N/A	196.3	6.3	193.7
Avg.	**6.7**	**163.1**	**6.7**	**159.1**	**8.8**	**105.6**	**7.1**	**155.7**	**7.2**	**135.3**	**6.2**	**171.3**	**7.8**	**129.9**	**N/A**	**198.5**	**6.3**	**191.0**
5W	6.9	152.5	6.0	146.1	8.6	53.3	7.3	130.2	7.2	126.8	6.5	157.9	8.1	97.4	N/A	153.6	6.0	151.2
6W	6.1	171.1	7.2	128.6	8.5	57.6	7.0	129.2	7.2	140.3	6.2	160.7	7.2	120.0	N/A	177.3	6.0	156.5
7W	7.1	151.2	6.4	144.5	9.3	72.3	7.4	118.1	7.1	117.8	6.0	154.6	7.6	111.2	N/A	160.3	6.2	152.4
8W	6.7	148.5	7.0	138.6	8.4	67.8	6.6	141.7	7.1	122.2	6.6	157.7	7.9	115.3	N/A	185.3	6.3	145.5
Avg.	**6.7**	**155.8**	**6.7**	**139.4**	**8.7**	**62.8**	**7.1**	**129.8**	**7.2**	**127**	**6.3**	**157.7**	**7.7**	**111.0**	**N/A**	**169.1**	**6.1**	**151.4**
TSR		**0.96**		**0.88**		**0.59**		**0.83**		**0.94**		**0.92**		**0.85**		**0.85**		**0.79**

Table A.25. Final Summary of Results

Mat'l **B** (UT Compacted Specimens)					
Lab #	Air Void Dry	Air Void Wet	TS psi Dry	TS psi Wet	TSR
1	6.0	6.0	137.8	109.6	0.80
2	6.3	6.3	108.5	84.2	0.78
3*	5.8	5.8	121.6	53.8	0.44
4	6.5	6.5	131.3	110.6	0.84
5	6.5	6.6	126.8	100.7	0.79
6	6.5	6.5	129.4	99.5	0.77
7	6.4	6.4	124.1	108.9	0.88
8	N/A	N/A	148.8	112.3	0.75
9	6.1	6.1	175.3	120.4	0.69
Min.	5.8	5.8	108.5	53.8	**0.44**
Max.	6.5	6.6	175.3	120.4	**0.88**
Avg.	6.3	6.3	133.7	100.0	**0.79**
Std.	0.3	0.3	19.1	20.1	**0.06**
COV,%	4.3	4.5	14.3	20.1	**7.3**
Sr	0.23	0.26	14.65	10.82	**0.06**
SR	0.34	0.37	23.63	22.57	**0.08**
r	0.64	0.72	41.03	30.31	**0.16**
R	0.96	1.05	66.17	63.19	**0.22**

* The TSR result of 0.44 was indicated as an outlier and therefore not considered in the analysis

Table A.26. Final Summary of Results

Mat'l **C** (UT Compacted Specimens)					
Lab #	Air Void Dry	Air Void Wet	TS psi Dry	TS psi Wet	TSR
1	7.9	7.9	112.3	89.6	0.80
2	7.5	7.5	113.1	83.9	0.74
3	7.9	7.9	112.3	89.6	0.80
4	7.1	7.1	117.2	97.5	0.83
5	7.3	7.3	105.8	74.5	0.70
6	7.1	6.9	118.8	94.5	0.80
7	7.6	7.6	150.4	126.5	0.84
8	N/A	N/A	137.0	113.9	0.83
9	8.0	8.0	142.5	88.9	0.62
Min.	7.1	6.9	105.8	74.5	**0.62**
Max.	8.0	8.0	150.4	126.5	**0.84**
Avg.	7.5	7.5	123.3	95.4	**0.77**
Std.	0.4	0.4	15.8	15.8	**0.07**
COV,%	4.7	5.0	12.8	16.5	**9.3**
Sr	0.24	0.31	17.08	13.00	**0.07**
SR	0.42	0.48	22.64	20.03	**0.10**
r	0.68	0.86	47.81	36.39	**0.20**
R	1.19	1.33	63.38	56.08	**0.28**

Table A.27. Final Summary of Results

Mat'l **W** (UT Compacted Specimens)					
Lab #	Air Void Dry	Air Void Wet	TS psi Dry	TS psi Wet	TSR
1	6.7	6.7	163.1	155.8	0.96
2	6.7	6.7	159.1	139.4	0.88
3*	8.8	8.7	105.6	62.8	0.59
4	7.1	7.1	155.7	129.8	0.83
5	7.2	7.2	135.3	126.8	0.94
6	6.2	6.3	171.3	157.7	0.92
7	7.8	7.7	129.9	111.0	0.85
8	N/A	N/A	198.5	169.1	0.85
9	6.3	6.1	191.0	151.4	0.79
Min.	6.2	6.1	105.6	62.8	**0.59**
Max.	8.8	8.7	198.5	169.1	**0.96**
Avg.	7.1	7.1	156.6	133.8	**0.88**
Std.	0.9	0.8	29.5	32.2	**0.06**
COV,%	12.2	11.8	18.9	24.1	**6.4**
Sr	0.33	0.21	12.96	12.44	**0.05**
SR	0.92	0.85	31.99	34.27	**0.07**
r	0.92	0.58	36.29	34.83	**0.14**
R	2.58	2.39	89.56	95.96	**0.20**

* The TSR result of 0.59 was indicated as an outlier and therefore not considered in the analysis

Table A.28. Summary of Results from Indirect Tensile Test for Material B

(Within-Laboratory Study)

Lab	Central		Central		Central		Central		Central		Central		Central		Central		Central		UT	
Spec.	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi
1D	6.8	141.4	6.9	136.7	6.3	123.9	6.8	128.2	6.7	156.5	7.2	115.3	6.4	176.2	7.2	139.9	7.0	125.8	7.0	116.8
2D	6.9	129.0	7.0	149.8	6.3	125.1	6.8	122.2	6.7	153.7	7.4	124.0	6.5	142.7	6.6	149.8	6.6	144.8	7.0	120.1
3D	6.7	135.8	6.8	155.5	6.5	125.7	6.9	116.9	7.1	151.9	7.0	123.1	6.7	149.6	7.5	148.7	6.7	141.3	6.9	122.5
4D	7.1	134.3	6.7	142.5	6.6	121.9	6.6	111.6	6.3	153.5	7.0	130.3	6.3	159.9	7.0	153.9	6.6	131.7	6.9	110.0
Avg.	**6.9**	**135.1**	**6.8**	**146.1**	**6.4**	**124.1**	**6.8**	**119.7**	**6.7**	**153.9**	**7.1**	**123.2**	**6.5**	**157.1**	**7.1**	**148.1**	**6.7**	**135.9**	**7.0**	**117.3**
5W	6.6	93.0	6.8	118.4	6.4	111.0	7.0	100.5	6.8	124.1	7.6	94.2	6.8	127.0	7.4	107.1	6.6	88.2	6.8	92.8
6W	6.8	107.4	7.0	118.7	6.1	119.1	6.9	93.1	6.6	108.6	6.7	102.6	6.8	109.2	6.8	114.9	6.6	93.3	6.8	98.8
7W	6.6	101.8	6.7	118.7	6.4	103.0	6.9	92.0	6.6	116.5	6.9	99.4	6.8	121.5	7.9	104.4	6.8	94.1	6.9	91.1
8W	6.4	108.1	6.3	126.1	6.5	102.3	6.6	97.0	6.6	107.8	7.0	105.2	6.4	123.9	7.3	115.0	6.7	84.4	6.8	94.6
Avg.	**6.6**	**102.6**	**6.7**	**120.5**	**6.4**	**108.9**	**6.8**	**95.6**	**6.7**	**114.2**	**7.0**	**100.3**	**6.7**	**120.4**	**7.3**	**110.3**	**6.7**	**90.0**	**6.8**	**94.3**
TSR		**0.76**		**0.82**		**0.88**		**0.80**		**0.74**		**0.81**		**0.77**		**0.75**		**0.66**		**0.80**

Table A.29. Summary of Results from Indirect Tensile Test for Material C

(Within-Laboratory Study)

Lab	Central		Central		Central		Central		Central		Central		Central		Central		Central		Central	
Spec.	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi
1D	7.0	156.0	7.6	134.6	7.4	164.7	8.3	140.6	7.4	147.5	8.4	120.3	7.1	109.8	7.9	124.2	8.0	112.7	7.8	139.0
2D	7.7	150.3	7.3	134.2	7.7	159.7	7.5	143.0	7.3	145.8	8.5	114.7	8.1	113.0	7.9	130.1	7.7	120.7	7.6	127.6
3D	7.7	150.8	8.0	135.2	7.4	162.5	7.7	133.1	8.2	140.6	8.2	119.4	7.7	121.7	7.9	121.2	8.1	99.8	8.0	143.4
4D	7.8	144.8	7.3	139.1	7.6	178.5	7.2	145.9	7.8	127.0	8.2	124.6	8.0	114.1	7.9	128.6	7.9	107.2	7.9	137.1
Avg.	**7.5**	**150.5**	**7.6**	**135.8**	**7.5**	**166.4**	**7.7**	**140.6**	**7.7**	**140.2**	**8.3**	**120**	**7.7**	**114.7**	**7.9**	**126.0**	**7.9**	**110.1**	**7.8**	**136.8**
5W	7.4	129.4	8.9	102.8	7.2	-	8.1	106.1	7.3	114.1	8.8	96.6	7.8	85.6	8.0	98.7	7.7	97.0	8.0	94.8
6W	8.0	133.3	7.8	105.2	7.5	-	7.4	100.4	7.6	114.4	8.2	107.0	8.3	85.4	8.0	91.2	8.0	108.1	7.8	93.9
7W	7.6	118.0	8.1	110.5	7.3	108.4	7.8	105.5	7.7	125.2	8.2	99.4	7.6	84.3	7.9	91.8	7.8	94.7	7.7	87.8
8W	7.3	125.3	7.5	106.3	7.6	119.5	7.4	91.3	8.3	116.4	8.7	106.8	7.9	81.7	7.9	97.0	7.9	79.5	7.9	88.7
Avg.	**7.6**	**126.5**	**8.1**	**106.2**	**7.4**	**113.9**	**7.7**	**100.8**	**7.7**	**118**	**8.5**	**102.5**	**7.9**	**84.2**	**7.9**	**94.7**	**7.8**	**94.9**	**7.8**	**91.3**
TSR		**0.84**		**0.78**		**0.68**		**0.72**		**0.84**		**0.86**		**0.73**		**0.75**		**0.86**		**0.67**

Table A.30. Summary of Results from Indirect Tensile Test for Material W

(Within-Laboratory Study)

Lab	Central		Central		Central		Central		Central		Central		Central		Central		Central		Central	
Spec.	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi	Voids %	TS psi
1D	7.5	140.1	6.3	182.6	7.1	136.5	6.3	174.4	6.3	175.4	6.6	183.2	6.7	179.6	7.2	180.8	6.3	173.7	6.8	183.7
2D	8.3	134.8	6.5	150.5	6.8	149.8	6.8	163.1	6.5	176.8	6.1	182.4	7.4	186.2	7.3	177.8	7.1	172.2	7.4	168.1
3D	7.7	128.4	6.2	161.4	7.3	152.1	6.7	160.2	6.2	171.9	6.3	179.0	6.8	175.2	6.3	190.9	6.7	178.8	7.2	195.3
4D	8.7	115.9	6.0	173.6	7.0	145.3	6.5	151.8	7.0	174.2	6.1	197.7	6.7	190.1	7.3	172.0	7.1	170.9	6.5	213.2
Avg.	**8.0**	**129.8**	**6.3**	**167.0**	**7.1**	**145.9**	**6.6**	**162.4**	**6.5**	**174.6**	**6.3**	**185.6**	**6.9**	**182.8**	**7.0**	**180.4**	**6.8**	**173.9**	**6.9**	**190.1**
5W	8.3	97.3	6.0	158.9	6.1	130.9	6.6	149.5	6.2	132.5	7.2	161.2	6.9	155.3	6.4	159.8	6.3	122.3	6.8	99.1
6W	7.2	120.0	6.6	151.9	6.5	134.7	5.7	157.5	6.7	125.6	6.7	166.4	7.1	156.2	7.1	155.8	6.9	138.1	7.3	113.0
7W	7.6	111.1	7.0	153.3	7.3	125.6	6.8	146.6	6.4	140.2	6.8	166.8	6.1	157.2	6.9	153.7	6.6	163.4	6.8	130.8
8W	7.9	115.1	6.4	155.6	6.7	120.7	6.0	151.8	6.2	147.5	6.5	173.2	7.3	159.6	6.5	156.8	5.9	163.8	7.1	152.3
Avg.	**7.7**	**110.9**	**6.5**	**154.9**	**6.6**	**128.0**	**6.3**	**151.3**	**6.4**	**136**	**6.8**	**166.9**	**6.9**	**157.1**	**6.7**	**156.5**	**6.4**	**146.9**	**7.0**	**123.8**
TSR		**0.85**		**0.93**		**0.88**		**0.93**		**0.78**		**0.90**		**0.86**		**0.87**		**0.84**		**0.65**

Table A.31. Final Summary of Results

Mat'l **B** (within lab. Study))

Lab #	Air Void Dry	Air Void Wet	TS psi Dry	TS psi Wet	TSR
Cent.	6.9	6.6	135.1	102.6	0.76
Cent.	6.8	6.7	146.1	120.5	0.82
Cent.	6.4	6.4	124.1	108.9	0.88
Cent.	6.8	6.8	119.7	95.6	0.80
Cent.	6.7	6.7	153.9	114.2	0.74
Cent.	7.1	7.0	123.2	100.3	0.81
Cent.	6.5	6.7	157.1	120.4	0.77
Cent.	7.1	7.3	148.1	110.3	0.75
Cent.	6.7	6.7	135.9	90.0	0.66
Cent.	7.0	6.8	117.3	94.3	0.80
Min.	6.4	6.4	117.3	90.0	**0.66**
Max.	7.1	7.3	157.1	120.5	**0.88**
Avg.	6.8	6.8	136.1	105.7	**0.78**
Std.	0.23	0.26	14.7	10.8	**0.06**
COV,%	3.4	3.8	10.8	10.2	**7.5**

Table A.32. Final Summary of Results

Mat'l **C** (within lab. Study))

Lab #	Air Void Dry	Air Void Wet	TS psi Dry	TS psi Wet	TSR
Cent.	7.5	7.6	150.5	126.5	0.84
Cent.	7.6	8.1	135.8	106.2	0.78
Cent.	7.5	7.4	166.4	113.9	0.68
Cent.	7.7	7.7	140.6	100.8	0.72
Cent.	7.7	7.7	140.2	117.5	0.84
Cent.	8.3	8.5	119.7	102.5	0.86
Cent.	7.7	7.9	114.7	84.2	0.73
Cent.	7.9	7.9	126.0	94.7	0.75
Cent.	7.9	7.8	110.1	94.9	0.86
Cent.	7.8	7.8	136.8	91.3	0.67
Min.	7.5	7.4	110.1	84.2	**0.67**
Max.	8.3	8.5	166.4	126.5	**0.86**
Avg.	7.8	7.8	134.1	103.3	**0.77**
Std.	0.24	0.31	17.1	13.0	**0.07**
COV	3.1	3.9	12.7	12.6	**9.4**

Table A.33. Final Summary of Results

Mat'l **W** (within lab. Study))

Lab #	Air Void Dry	Air Void Wet	TS psi Dry	TS psi Wet	TSR
Cent.	8.0	7.7	129.8	110.9	0.85
Cent.	6.3	6.5	167.0	154.9	0.93
Cent.	7.1	6.6	145.9	128.0	0.88
Cent.	6.6	6.3	162.4	151.3	0.93
Cent.	6.5	6.4	174.6	136.5	0.78
Cent.	6.3	6.8	185.6	166.9	0.90
Cent.	6.9	6.9	182.8	157.1	0.86
Cent.	7.0	6.7	180.4	156.5	0.87
Cent.	6.8	6.4	173.9	146.9	0.84
Cent.	6.9	7.0	190.1	123.8	0.65
Min.	6.3	6.3	129.8	110.9	0.65
Max.	8.0	7.7	190.1	166.9	0.93
Avg.	6.7	6.6	171.6	149.8	**0.87**
Std.	0.33	0.21	13.0	12.4	**0.05**
COV	4.9	3.2	7.6	8.3	5.6

Results from the first set of tests (line 1 in Table A.6) and the last set of tests are not included in calculating the statistics.

Table A.34. Precision Statistics for TSR based on the results for the materials tested in this study

Specimens compacted at the participating laboratories

Material	X	Std	COV, %	Sr	S_R	r	R
B	0.66	0.12	18.0	0.06	0.13	0.16	0.37
C	0.66	0.09	14.1	0.07	0.12	0.20	0.33
W	0.89	0.04	4.6	0.05	0.06	0.14	0.17
AVERAGE			**12.2**	**0.06**	**0.10**	**0.17**	**0.29**

Table A.35. Precision Statistics for TSR based on the results for the materials tested in this study

Specimens compacted at the central laboratory

Material	X	Std	COV, %	S_r	S_R	r	R
B	0.79	0.06	7.3	0.06	0.08	0.16	0.22
C	0.77	0.07	9.3	0.07	0.10	0.20	0.28
W	0.88	0.06	6.4	0.05	0.07	0.14	0.20
AVERAGE			**7.6**	**0.06**	**0.08**	**0.17**	**0.23**

Definitions

X	Average TSR for all laboratories
Std	Standard Deviation for TSR values from all laboratories
COV	Coefficient of Variation
S_r	Repeatability Standard Deviation
S_R	Reproducibilty Standard Deviation
r	95% repeatability limit
R	95% reproducibility limit

APPENDIX B

Table B.1. Gradation for Material B.

Sieves			Materials (% Passing)					%Pass		
US Units	SI,mm Units	SI^.45	TXI Briprt Typ D	`XI Bripı Srng	TXI Sand	Damron Sand	None None	Combnd	Low Limit	Upper Limit
1	25	4.26	100.0	100.0	100.0	100.0	100.0	**100.0**	**100.0**	**100.0**
7/8	22.4	4.05	100.0	100.0	100.0	100.0	100.0	**100.0**	**100.0**	**100.0**
5/8	16	3.48	100.0	100.0	100.0	100.0	100.0	**100.0**	**100.0**	**100.0**
1/2	12.5	3.12	100.0	100.0	100.0	100.0	100.0	**100.0**	**98.0**	**100.0**
3/8	9.5	2.75	98.0	100.0	100.0	100.0	98.6	**98.8**	**85.0**	**100.0**
#4	4.75	2.02	38.0	99.6	100.0	100.0	75.3	**62.7**	**50.0**	**70.0**
#10	2.0	1.37	5.0	79.5	99.6	100.0	55.1	**36.0**	**32.0**	**42.0**
#40	0.425	0.68	2.0	28.9	96.7	98.1	42.9	**16.8**	**11.0**	**26.0**
#80	0.18	0.46	1.0	14.2	44.7	68.4	34.1	**8.1**	**4.0**	**14.0**
#200	0.075	0.31	0.6	6.9	6.2	4.3	16.5	**3.1**	**1.0**	**6.0**
pan	0	0.00	0.0	0.0	0.0	0.0	0.0	**0.0**	**0.0**	**0.0**
Combined Gradation(%)			**60**	**34**	**6**	**0**	**0**	**100**		

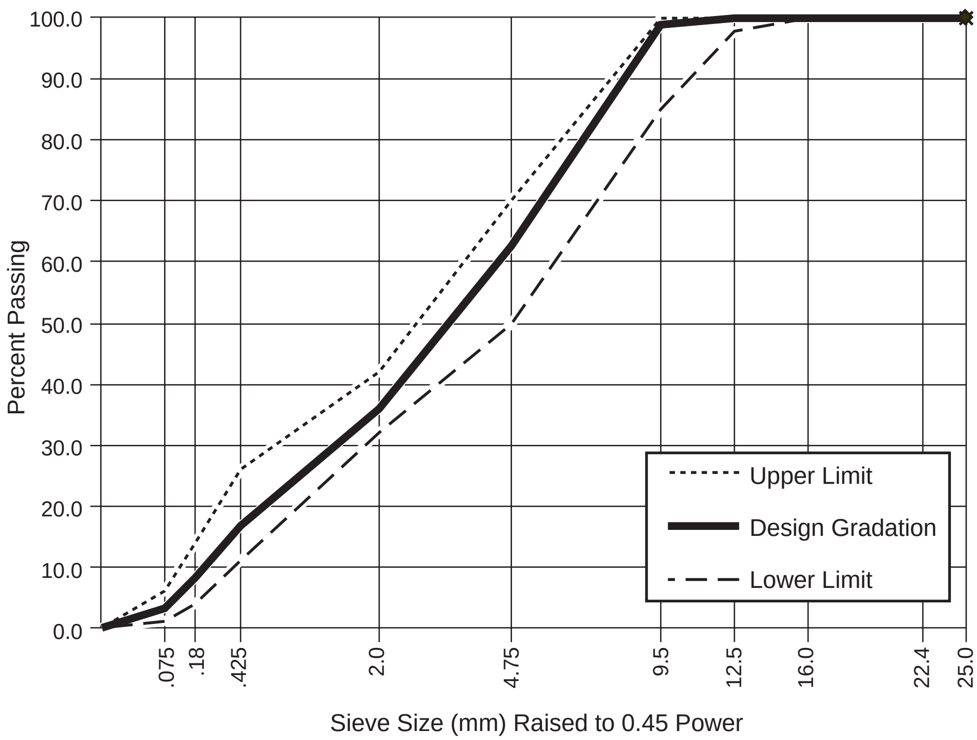

Table B.2. Gradation for Material C,
Superpave 12.5-mm Max. Nominal Size Gradation

Sieves			Materials (% Passing)					%Pass
US Units	SI,mm Units	SI^.45	Col. TP C	Col. TP D	Col. TP F	Manf. Sand	Nat. Sand	**Combnd**
3/4	19	3.76	100.0	100.0	100.0	100.0	100.0	**100.0**
1/2	12.5	3.12	49.3	97.4	100.0	100.0	100.0	**91.6**
3/8	9.5	2.75	4.5	70.0	100.0	100.0	100.0	**76.7**
#4	4.75	2.02	1.8	7.4	68.4	99.1	100.0	**50.9**
#8	2.36	1.47	1.8	3.8	17.0	84.3	100.0	**35.9**
#16	1.18	1.08	1.7	3.3	6.4	53.1	71.0	**22.9**
#30	0.6	0.79	1.6	3.0	4.0	31.7	27.8	**12.6**
#50	0.3	0.58	1.6	2.9	2.8	17.2	2.2	**6.2**
#100	0.15	0.43	1.5	2.7	2.4	10.7	1.0	**4.3**
#200	0.075	0.31	1.4	2.0	2.1	8.6	0.9	**3.5**
pan	0	0.00	0.0	0.0	0.0	0.0	0.0	**0.0**
Combined Gradation(%)			**15**	**30**	**20**	**25**	**10**	**100**

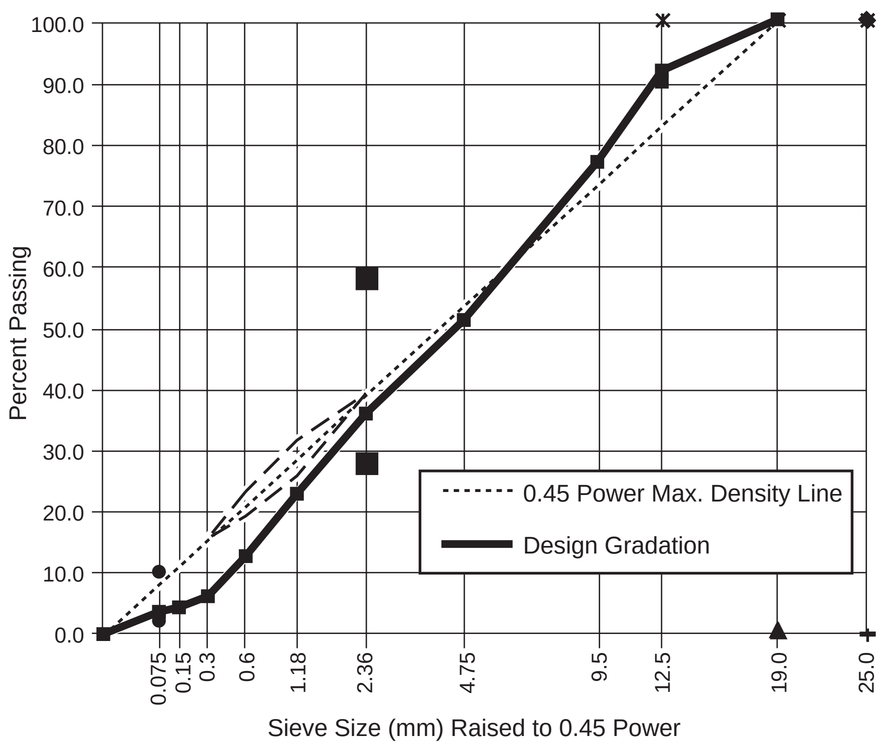

Table B.3. Gradation for Material W.

Sieves			Materials (% Passing)					%Pass		
US Units	SI,mm Units	SI^.45	Wright 5/8"	Wright 7/16"	Redland Scrn	Wright Sand	None None	Combnd	Low Limit	Upper Limit
1	25	4.26	100.0	100.0	100.0	100.0	100.0	**100.0**	**100.0**	**100.0**
7/8	22.4	4.05	100.0	100.0	100.0	100.0	100.0	**100.0**	**98.0**	**100.0**
5/8	16	3.48	90.0	100.0	100.0	100.0	100.0	**98.0**	**95.0**	**100.0**
1/2	12.5	3.12	50.0	98.0	100.0	100.0	100.0	**89.2**	**84.0**	**92.0**
3/8	9.5	2.75	8.6	92.5	100.0	100.0	98.6	**78.7**	**70.0**	**85.0**
#4	4.75	2.02	5.7	45.2	100.0	95.2	75.3	**58.7**	**43.0**	**63.0**
#10	2.0	1.37	3.8	9.8	75.2	77.2	55.1	**35.0**	**30.0**	**40.0**
#40	0.425	0.68	2.6	0.9	27.8	27.3	42.9	**12.0**	**10.0**	**25.0**
#80	0.18	0.46	1.7	0.6	14.5	2.1	34.1	**5.1**	**3.0**	**13.0**
#200	0.075	0.31	0.9	0.4	10.2	0.3	16.5	**3.4**	**1.0**	**6.0**
pan	0	0.00	0.0	0.0	0.0	0.0	0.0	**0.0**	**0.0**	**0.0**
Combined Gradation(%)			**20**	**40**	**30**	**10**	**0**	**100**