NCAT Report 02-11

BULK SPECIFIC GRAVITY ROUND-ROBIN USING THE CORELOK VACUUM SEALING DEVICE

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November 2002

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16. Abstract

This project conducted an evaluation of the Corelok device for the determination of the bulk specific gravity of compacted hot mix asphalt samples. The project consisted of the bulk specific gravity determination for compacted HMA mixes utilizing the Corelok vacuum-sealing device and the SSD method (AASHTO T166). All samples were prepared (including compaction of samples) by the National Center for Asphalt Technology (NCAT) and were provided to each participating laboratory for testing. Participating laboratories conducted the bulk specific gravity testing utilizing both the Corelok device and SSD method. Test results were then returned to NCAT for statistical analysis and determination of repeatability and reproducibility parameters for both methods. A total of 21 laboratories participated in this study, 18 of which returned test results. Each laboratory was provided a Corelok vacuum-sealing device through the pooled-fund effort.

The repeatability and reproducibility of the Corelok method were shown to be similar to AASHTO T166. The analyses also compared mixes and Stone Matrix Asphalt, the measured bulk specific gravities diverged above a water absorption of 0.4 percent. For coarse graded mixes, this level of water absorption encompasses sample air voids typically found during mix design (4 percent). Therefore, the Corelok method was recommended for bulk specific gravity determination during both mix design and construction for coarse graded Superpave and Stone Matrix Asphalt. Further research was recommended to better define when the Corelok method should be used .

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INTRODUCTION

A major concern of the hot mix asphalt (HMA) industry is the proper measurement of the bulk specific gravity (G_{mb}) for compacted HMA samples. This issue has become a bigger problem with the increased use of coarse gradations. G_{mb} measurements are the basis for volumetric calculations used during HMA mix design, field control, and construction acceptance. During mix design, volumetric properties such as air voids, voids in mineral aggregates, voids filled with asphalt, and percent maximum density at a certain number of gyrations are used to evaluate the acceptability of mixes. All of these properties are based upon G_{mb}.

In most states, acceptance of constructed pavements is based upon percent compaction (density based upon G_{mb} and theoretical maximum specific gravity). Whether nuclear gages or cores are used as the basis of acceptance, G_{mb} measurements are equally important. When nuclear gages are utilized, each gage has to first be calibrated to the G_{mb} of cores. If the G_{mb} measurements of the cores are inaccurate in this calibration step, then the gage will provide inaccurate data. Additionally, pay factors for construction, whether reductions or bonuses, are generally applied to percent compaction. Thus, errors in G_{mb} measurements can potentially affect both the agency and producer.

Bulk Specific Gravity By The Saturated-Surface Dry Method

For many years, the measurement of G_{mb} has been accomplished by the water displacement concept, using saturated-surface dry (SSD) samples. This consists of first weighing a dry sample in air, then obtaining a submerged mass after the sample has been placed in a water bath for a specified time interval. Upon removal from the water bath, the SSD mass is determined after patting the sample dry using a damp towel. Procedures for this test method are outlined in AASHTO T166 and ASTM D2726.

The SSD method has proved adequate for conventionally designed mixes that utilized fine-graded aggregates. Historically, mixes have been designed to have gradations passing close to or above the maximum density line (fine-graded). However, since the adoption of the Superpave mix design system and the increased use of stone matrix asphalt (SMA), mixes are being designed with coarse-graded aggregate resulting in erroneous G_{mb} measurements. Many of the HMA mixes that were designed with the Superpave mix design system have been coarse-graded (gradation passing below the restricted zone and maximum density line). SMA mixes utilize a gap-graded gradation that is also coarse-graded.

The problem in measuring the G_{mb} of coarse-graded Superpave and SMA mixes using the SSD method comes from the internal air void structure within these mix types. These types of mixes tend to have larger internal air voids than the conventional mixes, though the volume of air voids is the same. Figure 1 illustrates this point. Mixes with the coarser gradations have a much higher percentage of large aggregate particles. At a certain overall air void volume, which is mix specific, the large internal air voids of the coarse mixes can become interconnected. During G_{mb} testing with the SSD method, water can quickly infiltrate into the sample. However, after removing the sample from the water bath to obtain the saturated-surface dry condition the water can also drain from the sample quickly. This draining of the water from the sample is what causes the errors with the water displacement method.

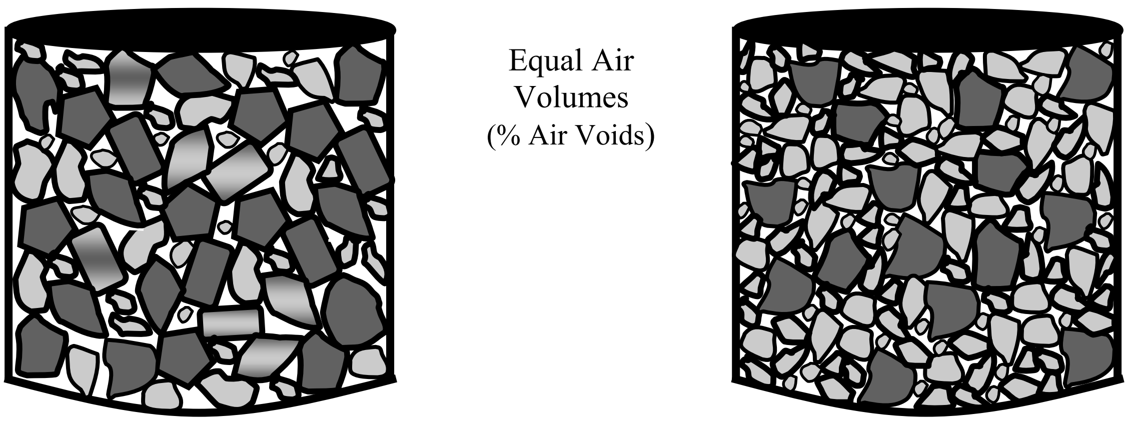

Figure 1. Differences in Internal Void Structure for Coarse- and Fine-Graded Mixes

To understand the cause of potential errors, one must first understand the principles of the water displacement method. The philosophy of the SSD method is based upon Archimedes' Principle. Archimedes' Principle states that a material immersed in fluid is buoyed up by a force equal to the mass of the displaced fluid. Take for instance the material submerged in water illustrated within Figure 2. The surface of the material that is in contact with water can be divided into two halves: the upper surface (face BCE) and lower surface (face BDE). Submerged in this manner, there are three forces acting on the material: 1) the weight of the material in a dry condition acting along BDE (W_M); 2) the force of the water within ABCEF on the material (F_{D2}); and 3) the force of the buoyant resistance acting upward (F_{U1}) which is equal to the weight of the water within ABDEF.

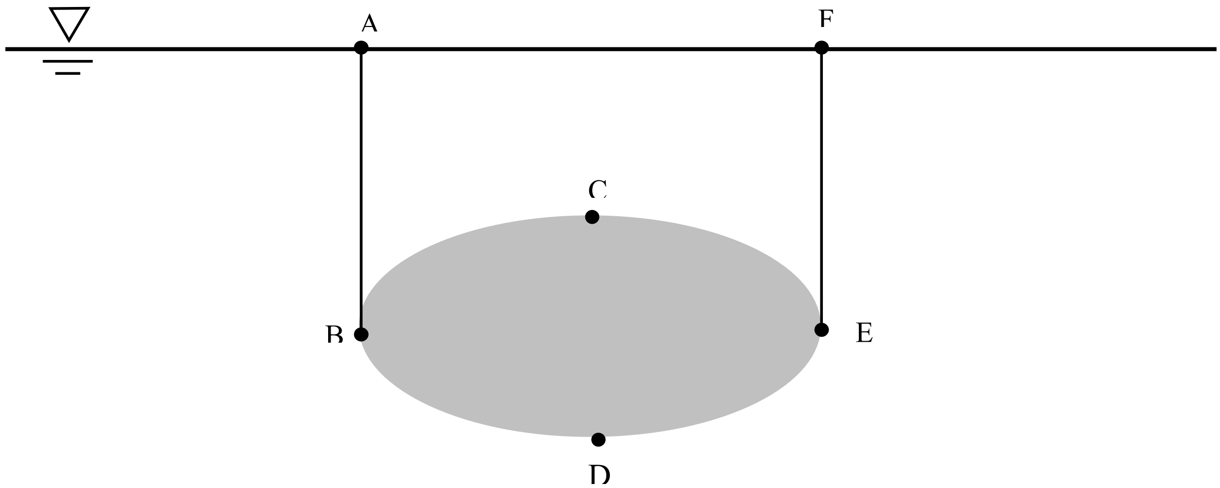

Figure 2. Hydrostatic Forces on a Submerged Material

Using these known forces acting on the material, a series of relationships can be identified:

Total force acting downward = $F_D = W_M + F_{D2}$ (1)

Total net force = $F_N = W_M + F_{D2} – F_{U1}$ (2)

The net force acting downward on the block (F_N) can be determined by measuring the weight of the block when it is submerged in water (W_{MW}). Therefore, the weight of the material submerged in water is equal to the right hand side of Equation 2. Further, the difference in the weight of the two water columns (F_{D2} and F_{U1}) is equal to the weight of fluid that is displaced when the material is submerged in water (W_W). Hence:

$W_{MW} = W_M - W_W$ (3)

Now, using the properties shown in Equations 1 through 3 and the definition of density and specific gravity, the equation for the water displacement method can be derived. The definition of density and specific gravity are as follows:

$\gamma_M = M_M / V_M$ (4)

$G_s = \gamma_M / \gamma_W$ (5)

Where:

γ = the density of an object (γ_M for material and γ_W for water);
M_M = the mass of a material;
V_M = the volume of the material; and
G_s = specific gravity of a material.

Since the volume of the material is equal to the volume of the water displaced by the material, substituting Equation 4 into Equation 5 yields the following:

$$G_s = M_M / M_W \tag{6}$$

The mass of a material is equal to the weight of that material divided by the acceleration caused by gravity; therefore, Equations 3 and 6 can be used to derive the equation used for determining the specific gravity of a material using the water displacement method:

$$G_s = M_M / (M_M - M_{MW}) \tag{7}$$

Equation 7 is the method of determining the specific gravity of a material using Archimedes' Principle. However, this equation defines a "dry" apparent specific gravity and not the bulk specific gravity. A brief discussion of the differences between the apparent and bulk specific gravities of compacted HMA is provided.

Figure 3 illustrates volumes and air voids that are associated with compacted HMA. Each of the diagrams within Figure 3 are divided into halves with each half representing the volumes and air voids of mixes with coarse and fine gradations. The dark black line in Figure 3a shows the volume that is associated with the specific gravity measurements using the dimensional procedure. Dimensions (height and diameter) of the sample are used to calculate the volume of the sample. Figure 3a illustrates the effect of using this volume in determining the air void content of HMA. The volume includes any surface irregularities on the outside of the sample and thus overestimates the internal air void content. Of the three cases illustrated in Figure 3, the gyratory volume is the highest, resulting in the lowest measured density.

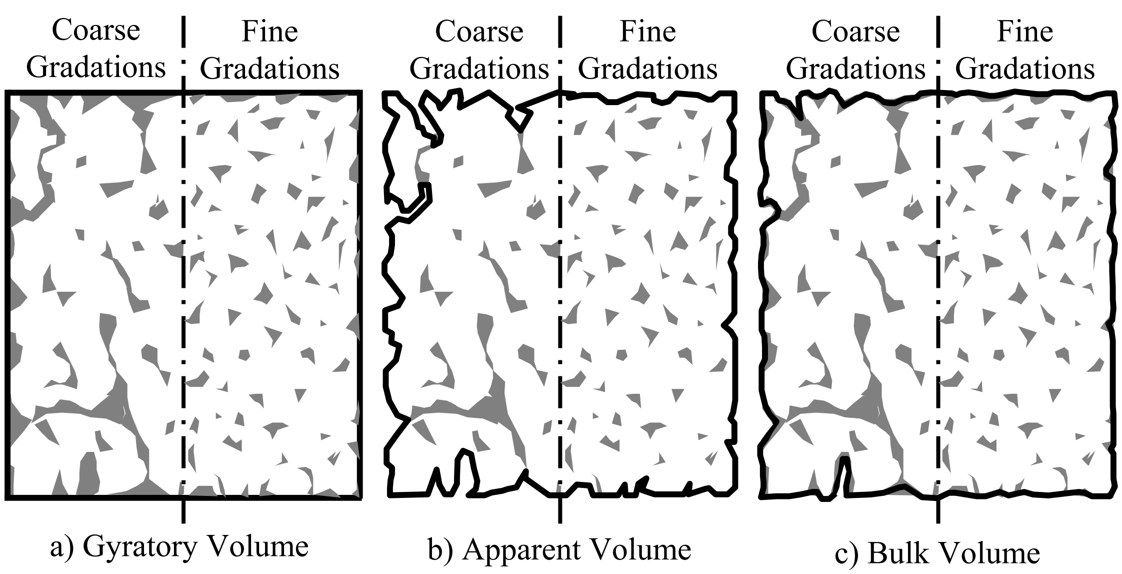

Figure 3. Volumes Associated with Compacted HMA

Figure 3b illustrates the apparent volume of compacted HMA samples. This volume is identical to the one derived from Equation 7 above. Because Equation 7 utilizes the dry mass in the volume determination (denominator of Equation 7), the calculated volume does not include any of the surface irregularities on the sample or the air voids that are interconnected to the surface. Water that infiltrates the sample through the interconnected surface voids are not considered a portion of the sample volume. Therefore, the apparent volume underestimates the sample's true internal voids. Figure 3b shows that this problem is more prevalent with mixes having coarser gradations, as there are more voids interconnected to the surface of the sample.

Figure 3c illustrates the bulk volume determined from the SSD method. The difference between the bulk and apparent volumes is that the bulk volume does not take into account the voids that are interconnected to the surface. This is accomplished by using the saturated-surface dry mass in the volume determination (replace M_M in the denominator of Equation 7 with the saturated-surface dry mass). The net result of using the saturated-surface dry mass is voids that are interconnected to the surface and do not lose their water within the saturated-surface dry condition are included as internal voids. Therefore, the bulk volume lies between the gyratory and apparent volumes.

This exercise of deriving the equation for measuring specific gravity using Archimedes' Principle and the discussion of the different volumes associated with compacted HMA was necessary to show the potential deficiency of the SSD method for determining bulk specific gravity of coarse-graded mixes. If bulk volume is the desired property, which it is for HMA, then mixes with coarser gradations have a high potential for error, as seen in Figure 3c. If a sample is submerged in water for a given time period (per standard procedure), a certain volume of water is absorbed into the sample through voids interconnected to the surface. For the coarse gradations shown in Figure 3c, this volume of interconnected voids is higher than for the fine gradations (assuming both the coarse and fine gradation mixes have the same total volume of air voids). Upon removal of the sample from the water bath, any water draining from the large interconnected voids within the coarse gradation mix leads to a lower saturated-surface dry mass. This, in effect, decreases the volume of the sample (denominator of Equation 7 with M_M replaced with saturated-surface dry mass) and, thus, underestimates the air void content of the sample. This is the potential drawback of the SSD method for determining the bulk specific gravity of mixes having coarse gradations.

The literature on the subject suggests a number of alternatives to alleviate the problem. Researchers have tried substances that would impede the water from penetrating the surface connected voids like parafilm, paraffin wax, rubber membranes, and masking tape (*1,2*). Others have also investigated compounds like zinc stearate that are hydrophobic which would prevent water from penetrating into the sample (*1*). However, these methods have not been adopted due to increased variability in bulk specific gravity measurements and/or damaging the sample such that additional testing could not be performed.

Bulk Specific Gravity By The Corelok Method

Results from a recent evaluation of the Corelok vacuum-sealing device indicated that the device could be used to determine the G_{mb} of compacted HMA samples with greater accuracy than conventional methods, such as water displacement, parafilm, and dimensional analysis (*3*). This vacuum-sealing device utilizes an automatic vacuum chamber (shown in Figure 4a) with a specially designed, puncture resistant, resilient plastic bag, which tightly conforms to the sides of the sample (shown in Figure 4b) and prevents water from infiltrating into the sample. This process has the potential for increasing the accuracy of G_{mb} measurements.

Figure 4a. Corelok Device

Figure 4b. Sealed Sample

The steps involved in sealing and analyzing compacted HMA samples are as follows (4):

Step 1: Determine the density of the plastic bag (generally manufacturer provided).
Step 2: Place the compacted HMA sample into the bag.
Step 3: Place the bag containing the HMA sample inside the vacuum chamber.
Step 4: Close the vacuum chamber door. The vacuum pump will start automatically and evacuate the chamber to 760 mm (30 in) Hg.
Step 5: In approximately two minutes, the chamber door will automatically open with the sample completely sealed within the plastic bag and ready for water displacement testing.
Step 6: Perform water displacement method. Correct the results for the bag density and the displaced bag volume.

Research by Buchanan (3) has indicated that the Corelok vacuum-sealing device provides a better measure of internal air void contents of coarse graded mixes than other conventional methods. Hall et al. (5) have also indicated that the Corelok method is a viable option for determining the G_{mb} of compacted HMA. Hall et al. indicated that the within-lab (operator) variability for the Corelok method was less than the water displacement method. However, before the Corelok device can be specified by agencies, the repeatability and reproducibility of the procedure needs to be evaluated.

OBJECTIVE

The objective of this round robin study was to further evaluate the Corelok vacuum-sealing device for the determination of the G_{mb} of compacted HMA samples and to determine the repeatability and reproducibility of the test procedure.

SCOPE

The project consisted of the G_{mb} determination for compacted HMA mixes utilizing the Corelok vacuum-sealing device and the SSD method. All samples were prepared (including compaction of samples) by the National Center for Asphalt Technology (NCAT) and were provided to each participating laboratory for testing. Participating laboratories conducted the G_{mb} testing utilizing both the Corelok device and SSD method. Test results were then returned to NCAT for statistical analysis and determination of repeatability and reproducibility parameters for both methods. A total of 21 laboratories participated in this study, 18 of which returned test results. Each laboratory was provided a Corelok vacuum-sealing device through the pooled-fund effort.

MATERIALS AND TEST METHODS

Within this section, the materials and test methods used for the study are discussed. During the course of any interlaboratory study, it is always desirable to utilize different materials. ASTM E691 indicates that a material is "… anything with a property that can be measured." Different materials need to be included to provide a wide range of levels for the property being measured (G_{mb} in this case).

A single aggregate type and source was used to fabricate the HMA mixes used in this study. This aggregate was quarried granite with water absorption of 0.6 percent. A single aggregate was utilized so that changes in bulk specific gravity of compacted samples would be direct changes in air void contents.

Each laboratory determined the G_{mb} of HMA specimens comprised of three mix types: stone matrix asphalt (SMA), coarse-, and fine-graded Superpave. To provide a range of air void contents, three compaction levels were included for each mix type: low (15 gyrations), medium (50 gyrations), and high (100 gyrations). Therefore, a total of nine "materials" were used within the study. Each mix type-gyration level was considered a different material because each would provide a different level of G_{mb}. Figure 5 illustrates the fine-graded, coarse-graded, and SMA gradations utilized. Triplicate samples of each material combination were prepared for each participating laboratory. Each laboratory was provided 27 samples [9 fine-graded (3 replicates * 3 compaction levels), 9 coarse-graded (3 replicates * 3 compaction levels), and 9 SMA (3 replicates * 3 compaction levels)].

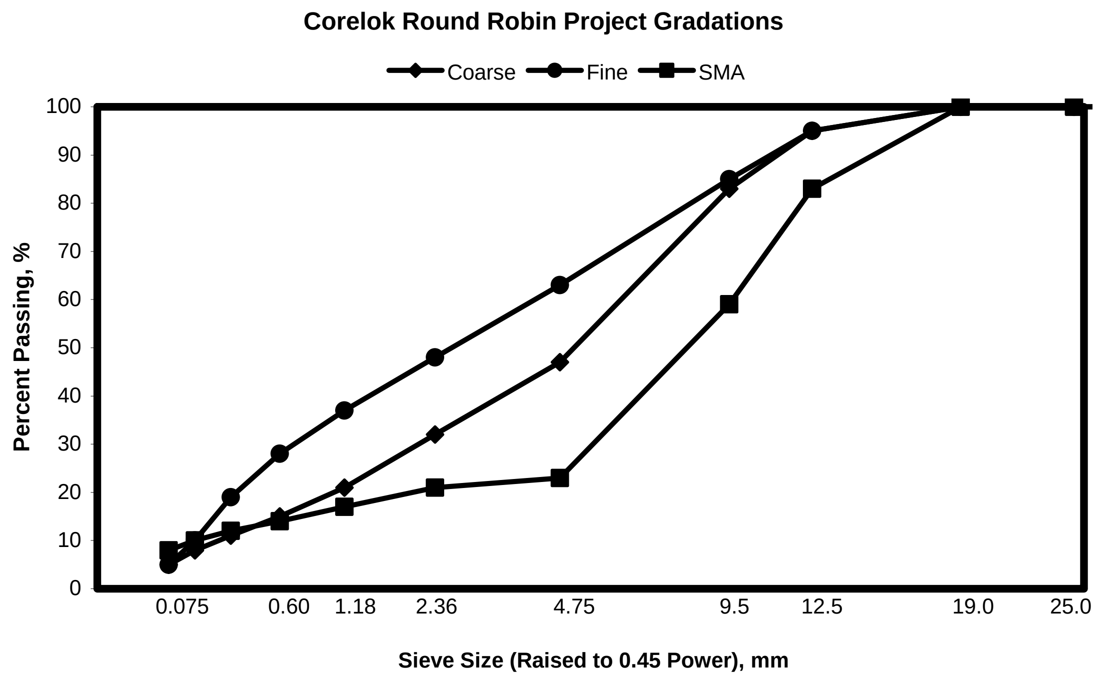

Figure 5. Project Gradations

The SMA mixes were prepared with 6.0 percent asphalt binder while the coarse and fine-graded Superpave mixes were prepared with 4.5 percent asphalt binder. A PG 76-22 asphalt binder was used for all of the samples. This stiff binder was chosen in an effort to reduce sample damage during transit to the participating laboratories. All samples were 150 mm diameter. Sample heights depended upon the gyration level a particular sample was compacted. The overall laboratory test plan is shown in Table 1.

Each laboratory determined the G_{mb} using both the Corelok test method (Appendix A) and SSD (AASHTO T166) method. The Corelok testing was conducted first. Because of the plastic bag coating samples during the Corelok procedure, the samples would remain dry so that AASHTO T166 procedure could be conducted after Corelok testing. If by chance the plastic bag punctured during the test, the participants were instructed to dry the sample in accordance with Note 1 in AASHTO T166.

Table 1. Test Plan

Aggregate Type	Compaction Level	Mix Type		
		Coarse-Graded Superpave	Fine-Graded Superpave	Stone Matrix Asphalt
Granite	Low (15 gyrations)	x	x	x
	Medium (50 gyrations)	x	x	x
	High (100 gyrations)	x	x	x

Note: "x" indicates cell to be evaluated. Three replicates were tested per cell.

Randomization of samples is important in any interlaboratory round robin to distribute any possible bias throughout the sample population. All samples of each mix type-gyration level combination were randomized among all the labs prior to sending the samples. To further eliminate any potential bias due to familiarity of test methods, the sequence in which each laboratory's 27 samples were tested was also randomized. This randomization was conducted initially for the Corelok testing, and then the testing sequence was re-randomized for the SSD testing.

For a given laboratory, all samples were arranged by mix type, starting with the fine-graded Superpave designed mixes compacted with 15 gyrations through the stone matrix asphalt mixes compacted with 100 gyrations. Then a random number generator was used to assign random numbers to each of the 27 samples. The first sample to be tested was the sample with the lowest random number while the last sample tested was the sample with the highest random number. Once the testing was complete, each laboratory provided NCAT with their results for analysis.

TEST RESULTS AND ANALYSIS

Within this section, analyses were conducted to accomplish the two primary objectives of this study: 1) evaluate the repeatability and reproducibility of test results from both the Corelok and water displacement methods and 2) further evaluate the ability of the Corelok device to accurately determine the G_{mb} of compacted HMA. To evaluate the repeatability and reproducibility of the two test methods, G_{mb} results from the different laboratories were analyzed per ASTM methods to develop precision statements. Analyses to further evaluate the Corelok test method included comparisons in G_{mb} measurements between the Corelok and SSD methods. Also, if the Corelok method was shown to be a viable option for measuring the G_{mb} of compacted HMA, the data were to be analyzed to determine when the Corelok should be utilized.

Analysis of Interlaboratory Test Results

Test results of the round robin study were analyzed for precision in accordance with ASTM C 802 and ASTM E 691 *(6)*. These standards are recommended practices to determine the between- and the within-laboratory estimates of a test method. The within-laboratory precision, or repeatability, provides an expectation of the difference in test results between replicate measurements on the same material in the same laboratory by one operator using the same equipment. The between-laboratory precision, or reproducibility, provides an expectation of the difference in test results between measurements made on the same material in two different laboratories. Analyses were performed on G_{mb} by mix type and gyration level.

Data Consistency

ASTM E 691 *(6)* uses two statistics to analyze the data for consistency: *h* and *k*. The *h* statistic is an indicator of how one laboratory's average for a material compares with the average of other laboratories. The *h* statistic is based on a two-tailed Student's *t* test. The average of the replicates for a given material and laboratory is referred to as a cell average. The cell average for a given laboratory is compared to the average of that same material when combining results from the remaining laboratories. A negative *h* statistic indicates a given laboratory's cell value that is less than the combined average for all of the other laboratories, whereas a positive *h* statistic indicates a given laboratory's cell average is greater than the combined average of the other laboratories.

The *k* statistic is an indicator of how one laboratory's variability for a given cell compares to the pooled variability of the remaining laboratories. The *k* statistic is based on the *F*-ratio from a one-way analysis of variance. Values of *k* larger than 1 indicate greater within-lab variability for a given laboratory than the average, or pooled, variability of the other laboratories. The *h* and *k* statistic were calculated using the ASTM E691 software (7

For a round-robin consisting of 18 laboratories and three replicates, critical values of *h* and *k* were found to be 2.53 and 2.20, respectively, at the 0.5 percent (α=0.005 or 99.5 percent confidence) significance level *(6)*. ASTM E 691 recommends the 0.5 percent significance level because experience has shown that 1.0 percent significance values were too sensitive and that the 0.1 percent significance values were insensitive to outliers.

In order to best utilize the *h*- and *k*- consistency statistics, the data is plotted both by material and laboratory. This aids in the identification of particular laboratories that produced consistently different results, potential errors in the production of test samples, and erroneous data. Problematic patterns in the data include: *h* values for one laboratory opposite all of the other laboratories, *h* values for all of the laboratories switching signs with changes in the measured property, and one laboratory having large *k* values for almost all of the materials.

Figure 6 shows the *h*-consistency statistics by laboratory for the AASHTO T166 results. The complete data is provided in Appendix B. The distribution of *h* values between labs does not indicate any cause for concern, though all of laboratory 16's results are negative. This would indicate that laboratory 16 consistently had lower G_{mb} values than the average for the remaining laboratories. Two samples, one each from labs 16 and 21 exceed the critical *h*- value on the low side. An additional sample from laboratory 16 is close with an *h* statistic = 2.52 (*h* critical =

2.53). Figure 7 shows the *h*-values by material from the AASHTO T166 results. Again, there does not appear to be a particular pattern that indicates the mix type or void level (compaction level) causes any significant affect in the measured results.

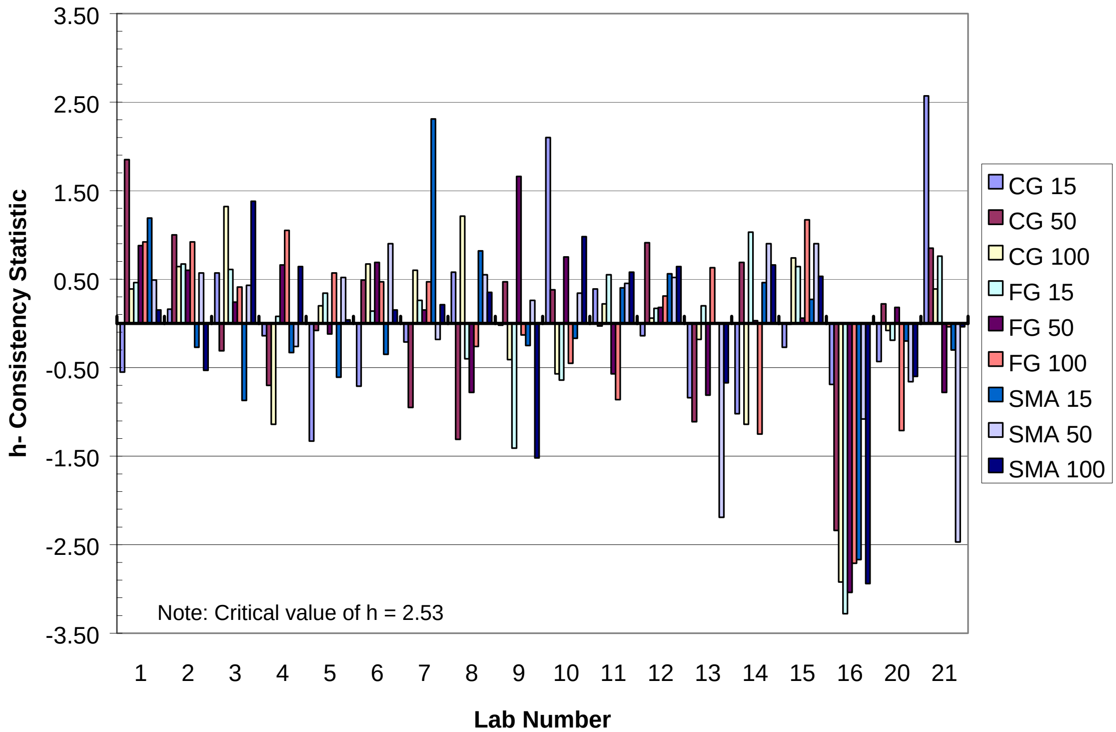

Figure 6. AASHTO T166 *h*-Consistency (Average) Factors by Laboratory

Figure 8 shows the *k*-consistency statistics by laboratory for the AASHTO T166 results. Four samples, one each from labs 9, 10, 14 and 21 exceed the critical *k*-value. Figure 9 shows the *k*-consistency statistics, by material, for the AASHTO T166 results. Figures 8 and 9 indicate no patterns that causes concern for the data. The supporting data for the four samples that exceeded the critical *k*-value was carefully examined and is presented later in the paper.

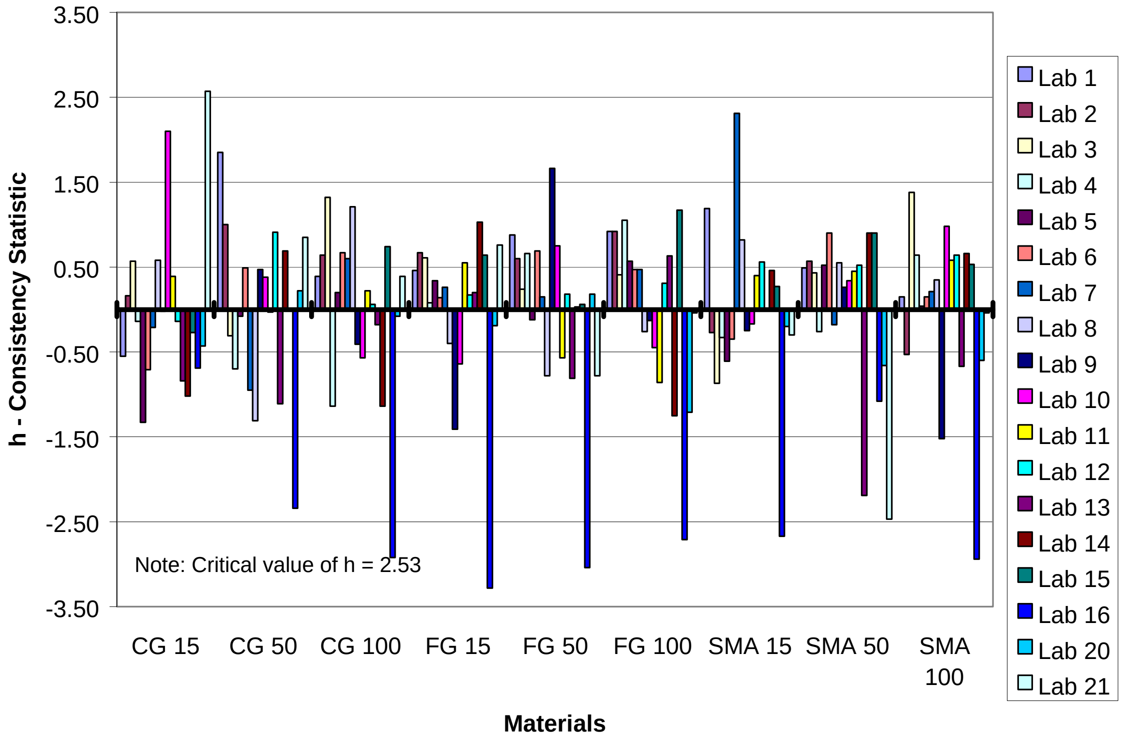

Figure 7. AASHTO T166 *h*-Consistency (Average) Factors by Material

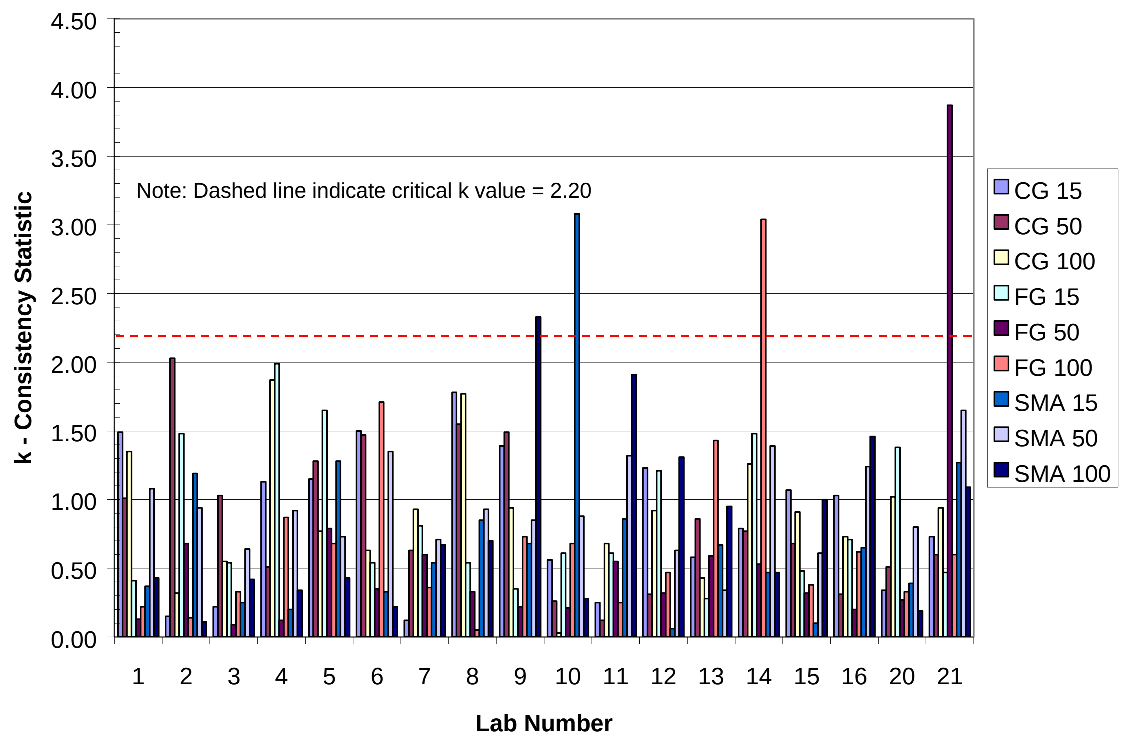

Figure 8. AASHTO T166 *k*-Consistency (Variability) Factors by Laboratory

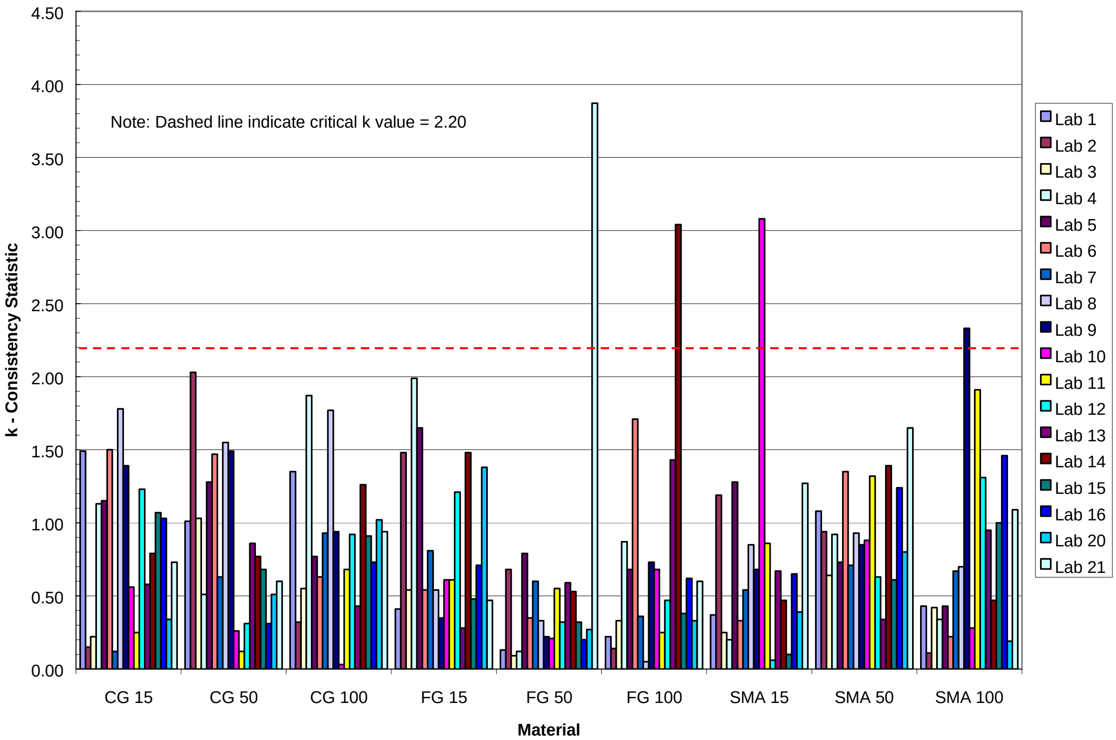

Figure 9. AASHTO T166 *k*-Consistency (Variability) Factors by Material

Figure 10 shows the *h*-consistency statistics by laboratory for the Corelok results. The distribution of *h*-values between labs indicates that the G_{mb} values measured by laboratory 16 are always lower than the material average. Also, six of nine cells tested by laboratory 16 exceeded the critical *h*-value. Laboratory 16's AASHTO T166 results, shown in Figure 6, were also consistently less than the other labs results. An additional cell tested by laboratory 21, CG 15, exceeds the critical *h*-value on the positive side. This same cell exceeded the critical *k*-values for the AASHTO T166 results. Figure 11 shows the *h*-values by material from the Corelok results. There does not appear to be a particular pattern that indicates the mix type or void level (compaction level) causes any significant affect on the measured results.

Figure 12 shows the *k*-consistency statistics by laboratory for the Corelok results. The complete results are provided in tabular form within Appendix C. Five sample sets, one each from labs 7, 11, 13, 14 and 21 exceed the critical *k*-value. Figure 13 shows the *k*-consistency statistics by material for the Corelok results. Figures 12 and 13 indicates no pattern that causes concern for the data. The supporting data for the four samples that exceeded the critical *k*-value were carefully examined. The compacted gyratory height of the fine-graded-100-gyration (FG-100) sample number 2 tested by laboratory 14 was 3-mm higher than the average height of the other FG-100 samples. Volumetric calculations indicate that a difference in height of 3-mm equates to approximately 2.4 percent air voids. Therefore, that sample was removed from the data set. No specific error could be confirmed for the remaining three samples that exceeded the critical *k*-value. Therefore, these samples remained in the data set. The *k*-consistency statistics for the cells tested by laboratory 16 were not unusual as compared to the other labs (Figure 12). This indicates that laboratory 16 made a consistent systematic error in their testing as compared

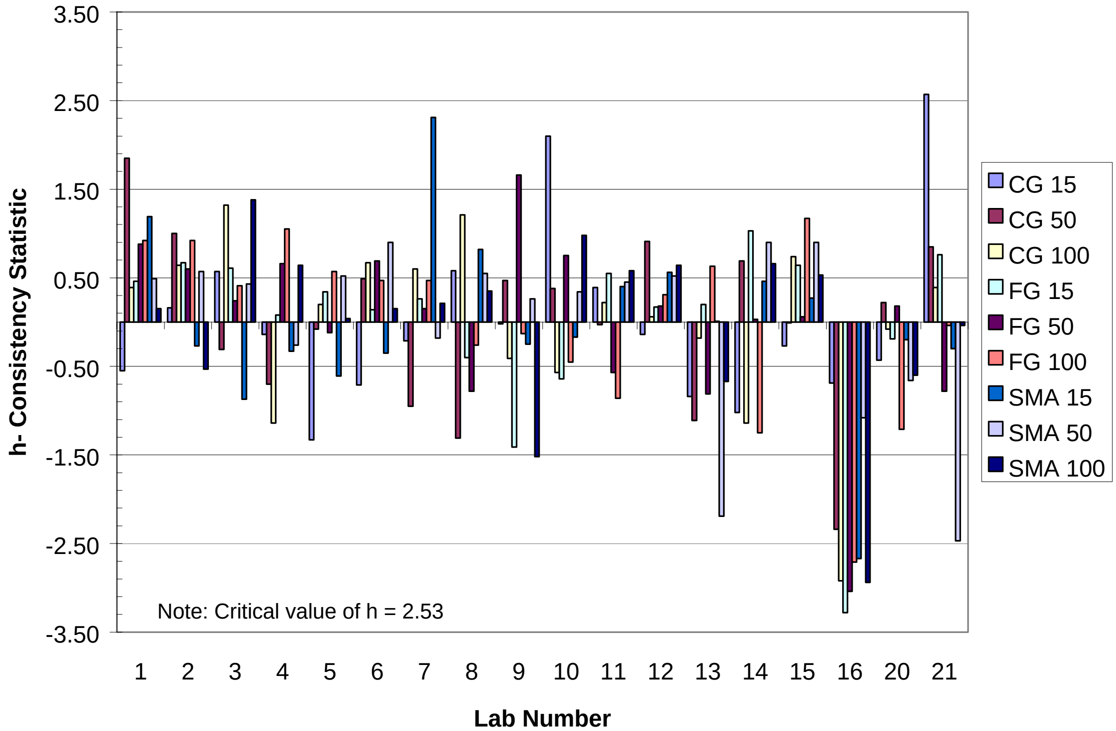

Figure 10. Corelok *h*-Consistency (Average) Factors by Laboratory

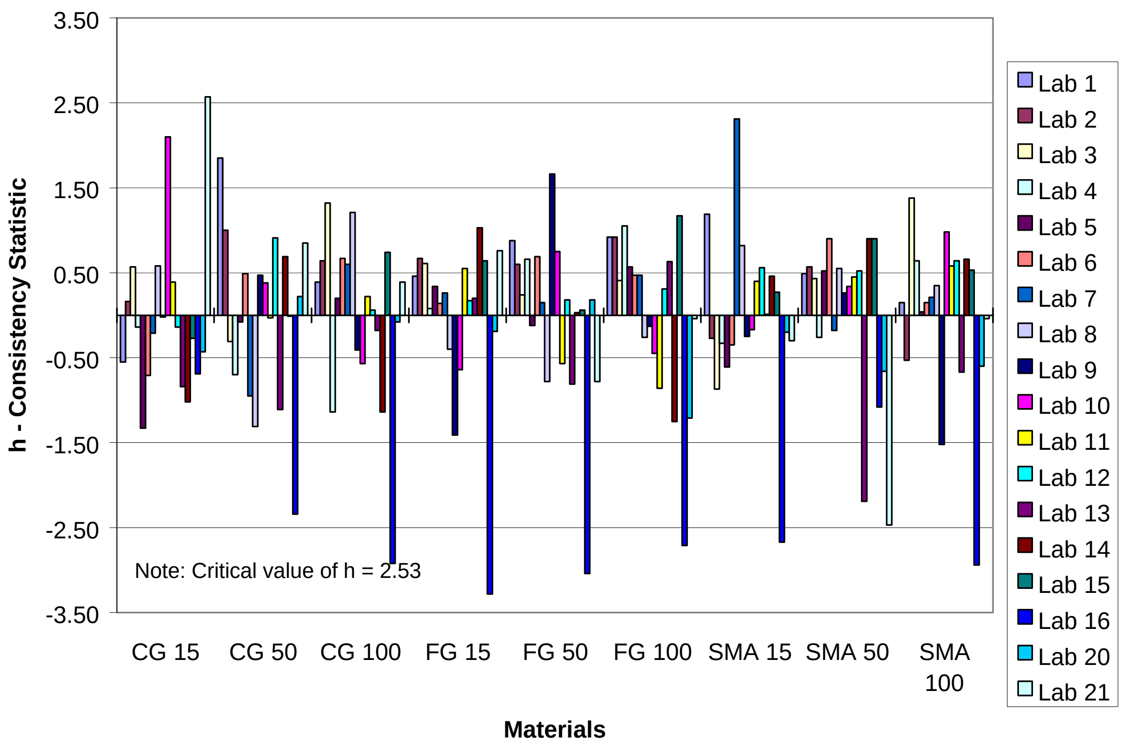

Figure 11. Corelok *h*-Consistency (Average) Factors by Material

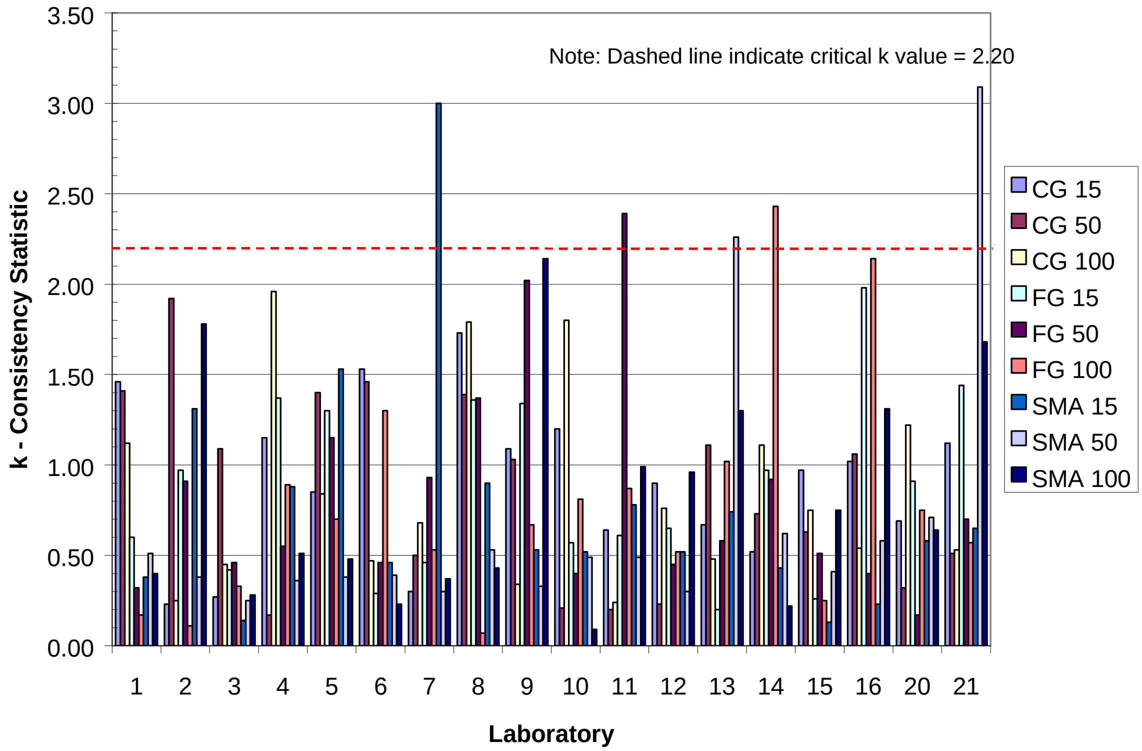

Figure 12. Corelok *k*-Consistency (Variability) Factors by Laboratory

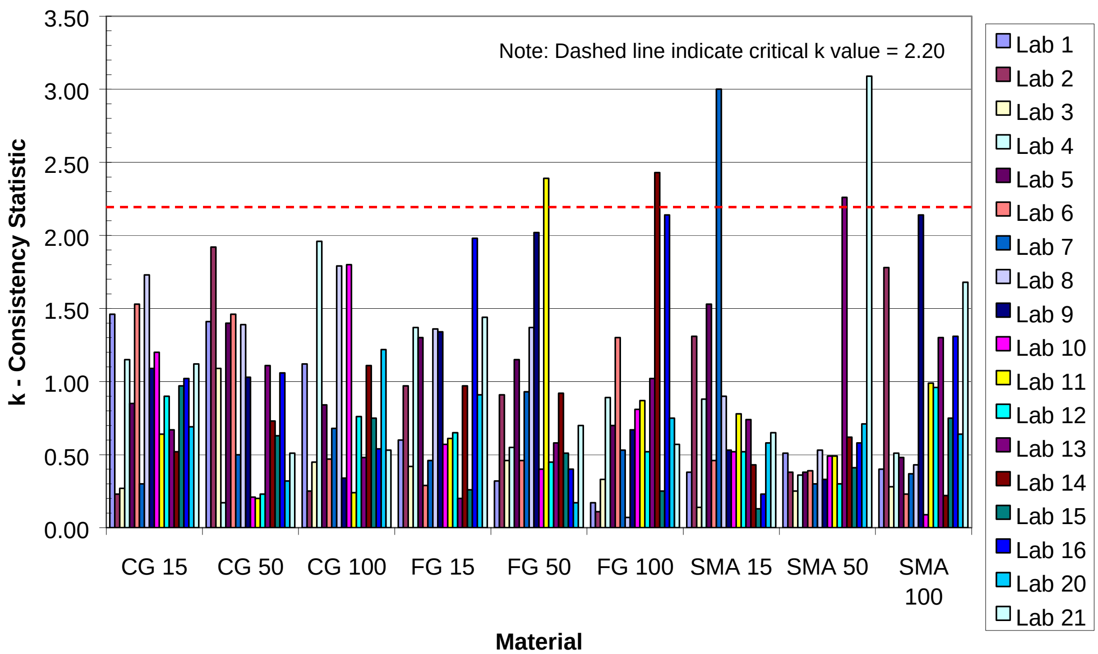

Figure 13. Corelok *k*-Consistency (Variability) Factors by Material

to the other labs shown in Figure 10. Therefore, laboratory 16's results were removed from the data set and excluded from the calculations to determine the precision statement.

Table 2 presents the results of the investigations of samples that exceeded the critical *k*-value for either the AASHTO T166 and Corelok results. As stated previously, the compacted gyratory height of the FG-100 sample number 2 tested by laboratory 14 was 3-mm higher than the average height of the other fine-graded 100 gyration samples. This indicates an error in the compaction of the sample, which would result in lower density. Therefore, this sample was removed from both the T166 and Corelok data sets. No specific error could be confirmed for the remaining three samples that exceeded the critical *k*-value. Therefore, these samples remained in the data set.

Table 2. Investigation of Samples with *k*-Consistency Statistics Greater than the Critical Value (Outliers)

Gradation	No. of Gyrations	Sample No.	Lab No.	Measured Value	Material Average	Potential Reason for Outlier
T166						
Fine	50	7	21	2.234	2.355	Submerged mass appears low
Fine	100	2	14	2.333	2.390	Sample height more than 3 mm higher than material average
SMA	15	46	10	2.389	2.276	Submerged mass appears high
SMA	100	23	9	2.380	2.419	Submerged mass appears low
Corelok						
Fine	50	37	11	2.319	2.358	Sample picked up 1.5 g of water during test
Fine	100	2	14	2.343	2.394	Sample height more than 3 mm higher than material average
SMA	15	18	7	2.357	2.231	Submerged mass appears high
SMA	50	3	13	2.169	2.350	Submerged mass appears low
SMA	50	35	21	2.117	2.350	Submerged mass appears low

Repeatability and Reproducibility

Round-robin testing is conducted to estimate the one-sigma limit (1s), or standard deviation of the population of measurements, characteristic to a given test method. The one-sigma limit is estimated for two separate conditions, single operator, or within-lab, and multi-laboratory, or between-lab. The single operator standard deviation represents an estimate of the variability of a large number of test results that were made on the same material by a single operator using the same equipment in the same laboratory over a relatively short period of time. The single operator standard deviation is also termed the repeatability of a test method. The multi-laboratory standard deviation represents an estimate of the variability of a large number of measurements made on materials which are as close to identical as possible when each test is made in a different laboratory. The multi-laboratory standard deviation is also termed the reproducibility of the test method. Typically, the multi-laboratory standard deviation is larger than the single-operator standard deviation due to variability induced by differing equipment, operators, and laboratory environments (6). Using the single-operator or multi-laboratory standard deviations, the acceptable difference between two test results can be calculated.

Based on the analysis of the *h*- and *k*-statistics to identify outliers, all results from laboratory 16 and the result for one replicate of laboratory 14 for the FG-100 were removed from the AASHTO T166 and Corelok data sets. Once outliers were removed from the data set, the next step in the analysis was to determine the average, within-lab and between-lab components of variance for each of the nine materials, and the pooled within-lab and between-lab variances. These were determined according to ASTM C 802 (6). The within-lab variance equals the within-lab component of variance. Between-lab variance equals the sum of the within-lab and between-lab components of variance. Average material values, components of variance, and variances are shown in Table 3 for both the Corelok and AASHTO T166 test results.

Typically, it is suggested that the data be presented in order of increasing average test value (G_{mb} in this case). This is done to allow observation of the effects of the test value on variability. However, for G_{mb} this is confounded by the effect of gradation. In practice, the bulk specific gravity of the aggregate will also affect the measured G_{mb}. However, in this study all of the mixes were prepared from the same aggregate source such that changes in G_{mb} were directly related to changes in air voids. The results are presented by gradation in order of increasing compaction level, which should correspond to increasing G_{mb} within a given gradation (mix type). Averages in Table 3 indicate that gradation plays a significant role in the difference between the average test values for the AASHTO T166 and Corelok measurements. For the coarser mixes, coarse-graded Superpave (CG) and SMA, measured G_{mb} values by the Corelok device are less than the AASHTO T166 values. However, results for the fine-graded Superpave mixes are almost identical. A comparison of the density results from the two methods will be discussed later in the paper. It should also be noted that the between-lab component of variance is smaller than the within-lab component of variance. In six cases the between-lab component of variance is zero. This indicates that for this data set, the within-lab variability was greater than the variability introduced by conducting tests in different laboratories. Further, this trend holds true for both test methods.

Table 4 presents the average material values, standard deviations and coefficients of variation for all of the materials. The values were calculated according to ASTM C 802 (6). Within-lab standard deviations (1s) shown in Table 4 are simply the square root of the variances shown in Table 3. Between-lab standard deviations are the square root of the sum of the two components of variance shown in Table 3. The coefficients of variation are equal to the respective standard deviations divided by the respective mean G_{mb} expressed as a percentage.

Table 3. Averages, Components of Variance and Variances for All Materials

			Components of Variance				Variance			
	Average		Pooled within lab, S_A^2 x 10^{-4}		Between-Lab, S_L^2 x 10^{-4}		Within-Lab x 10^{-4}		Between-Lab x 10^{-4}	
Material	SSD	Corelok	SSD	Corelok	SSD	Corelok	SSD	Corelok	SSD	Corelok
CG 15	2.226	2.188	11.195	9.819	1.301	2.839	11.195	9.819	12.495	12.657
CG 50	2.353	2.342	4.858	5.636	0.062	1.306	4.858	5.636	4.920	6.942
CG 100	2.403	2.393	2.846	4.605	0.000	0.000	2.846	4.605	2.846	4.605
FG 15	2.282	2.283	0.572	1.423	0.071	0.000	0.572	1.423	0.643	1.423
FG 50	2.356	2.360	3.146	1.477	0.490	0.059	3.146	1.477	3.635	1.536
FG 100	2.392	2.397	1.800	0.970	0.000	0.171	1.800	0.970	1.800	1.140
SMA 15	2.278	2.233	4.279	8.291	0.940	0.000	4.279	8.291	5.219	8.291
SMA 50	2.374	2.352	5.101	22.965	0.455	0.000	5.101	22.965	5.557	22.965
SMA 100	2.421	2.406	1.075	3.823	0.060	0.409	1.075	3.823	1.135	4.232

Table 4. Averages, Standard Deviations and Coefficients of Variation for All Materials

			Standard Deviations				Coefficient of Variation			
	Average		Within-Lab		Between-Lab		Within-Lab		Between-Lab	
Material	SSD	Corelok	SSD	Corelok	SSD	Corelok	SSD	Corelok	SSD	Corelok
CG 15	2.226	2.188	0.0335	0.0313	0.0353	0.0356	1.50	1.43	1.59	1.63
CG 50	2.353	2.342	0.0220	0.0237	0.0222	0.0263	0.94	1.01	0.94	1.13
CG 100	2.403	2.393	0.0169	0.0215	0.0169	0.0215	0.70	0.90	0.70	0.90
FG 15	2.282	2.283	0.0076	0.0119	0.0080	0.0119	0.33	0.52	0.35	0.52
FG 50	2.356	2.360	0.0177	0.0122	0.0191	0.0124	0.75	0.52	0.81	0.53
FG 100	2.392	2.397	0.0134	0.0098	0.0134	0.0107	0.56	0.41	0.56	0.45
SMA 15	2.278	2.233	0.0207	0.0288	0.0228	0.0288	0.91	1.29	1.00	1.29
SMA 50	2.374	2.352	0.0226	0.0479	0.0236	0.0479	0.95	2.04	0.99	2.04
SMA 100	2.421	2.406	0.0104	0.0196	0.0107	0.0206	0.43	0.81	0.44	0.86

The coefficient of variation is used to normalize the variability in terms of the measured test value.

An examination of the within- and between-lab standard deviations in Table 4 suggests that there is a trend of decreasing standard deviation with increasing G_{mb} for both coarse mixes (CG and SMA). It should be noted that since the same aggregate was used for all of the samples, the differences in G_{mb} correspond to changes in air void content. This trend suggests that the test results may be slightly more variable as void contents increase. However, the true compacted density of the samples may b more variable at low compaction levels. This trend is demonstrated in Figures 14 and 15 for the AASHTO T166 and the Corelok test results, respectively. Figure 14 indicates that the fine-graded Superpave mix compacted to 15 gyrations (FG 15) exhibited an extremely low variability compared to the remaining materials. Figure 15 also (Corelok results) indicates a low variability for the FG-15 mix, but a high variability for the 50-gyration SMA (SMA-50) mix. For both the AASHTO T166 and Corelok data, the trend towards decreasing standard deviation with increasing G_{mb} is heavily influenced by the materials compacted to 15 gyrations. At this compaction level, the air voids as measured by AASHTO T166 range from 7 to 12 percent. Typically these void levels would only be found in field cores.
Generally, if a test procedure does not have a relatively constant standard deviation, the standard deviation will tend to increase with increasing test values. When this occurs, the coefficient of variation often provides a more consistent measure of the test methods variability (6). However in this case, it appears that the standard deviation increases with increasing air voids (decreasing G_{mb}), therefore the use of the coefficient of variation based on G_{mb} would be inappropriate.

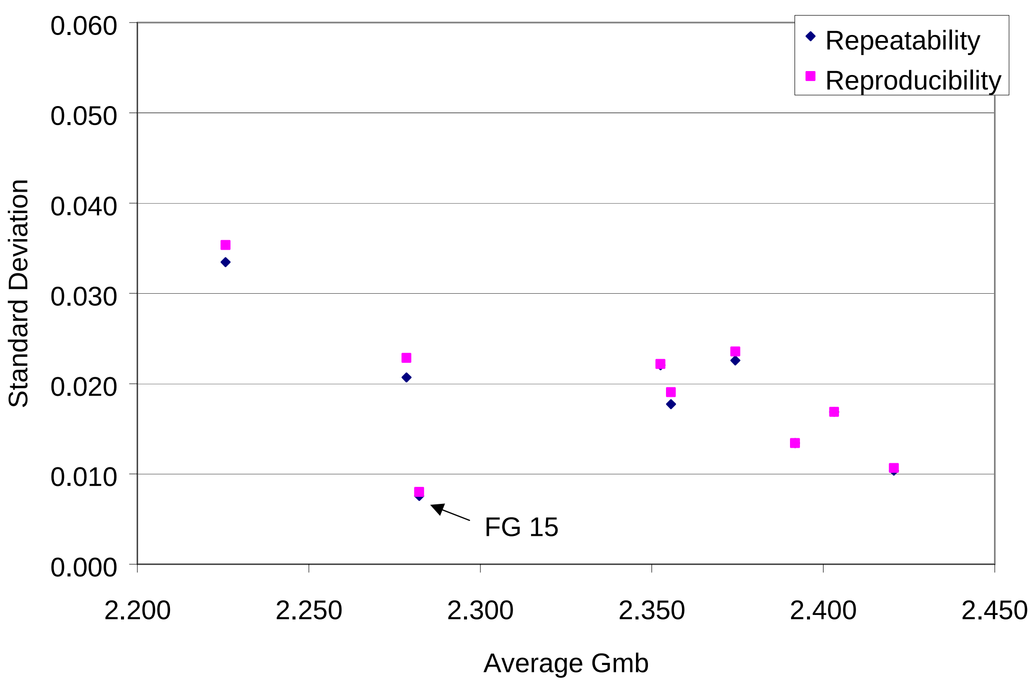

Figure 14. Standard Deviation (1s) versus Average G_{mb} for AASHTO T166 Results

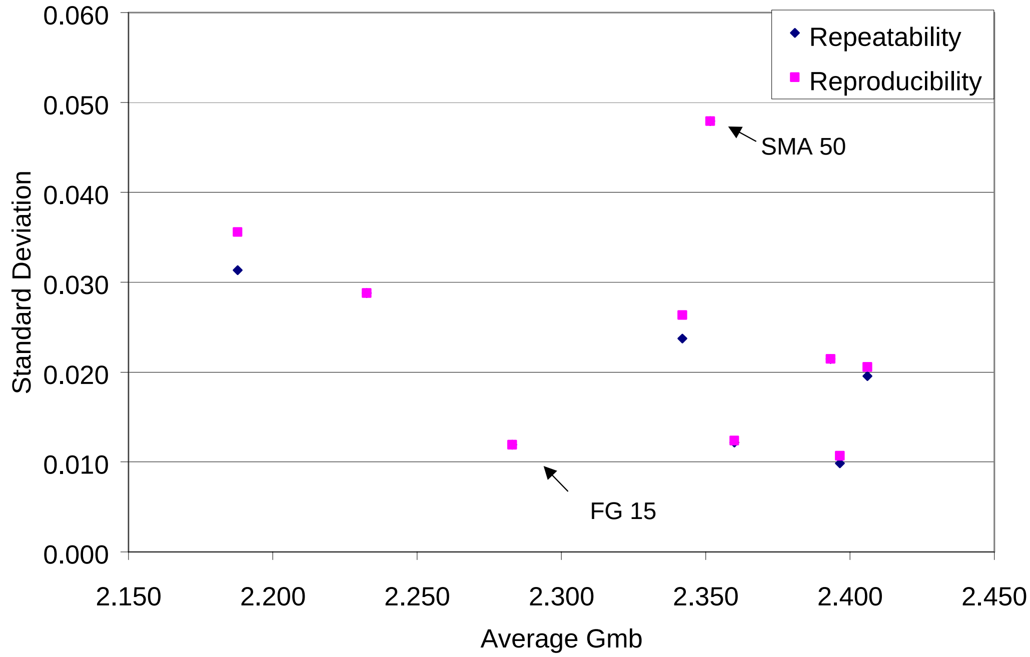

Figure 15. Standard Deviation (1s) versus Average G_{mb} for Corelok Results

Table 5 shows the pooled within-lab and between-lab standard deviations (1s) and acceptable difference between two results. The acceptable difference between two results (d2s) is calculated by multiplying the respective within- or between-lab standard deviation by 2√2 (=2.83). This represents the difference between two individual test results that should be exceeded only one case in twenty (95 percent confidence). It should be noted that if more than two test results are compared, the range is larger. The actual multiplier for comparing more than two samples can be found in ASTM C 670 (6).

The results labeled as "gyratory" in Table 5 refer to the uncorrected dimensional density of the samples calculated using the dry mass of the sample (measured at NCAT prior to shipment) and the height of the sample after the final gyration (15, 50 or 100 gyrations). The sample mass was divided by the volume of the sample, calculated using a diameter (150 mm) and height of the sample after compaction. The statistics for the uncorrected gravities were calculated in the same manner as the G_{mb} results obtained by the various labs using AASHTO T166 and Corelok methods. The complete gyratory results are shown in Appendix D. This provides some measure of the variability of the samples produced by NCAT. Note that the standard deviations are not truly within-lab or between-lab since all of the samples were prepared at NCAT, instead they represent the variability of the sample pool randomly supplied to the participating labs.

Table 5. Pooled Standard Deviations and Acceptable Differences Between Two Tests

Method	W/L Standard Deviation	B/L Standard Deviation	W/L d2s	B/L d2s
Gyratory	0.0097	0.0177	0.027	0.050
AASHTO T166	0.0183	0.0191	0.052	0.054
Corelok	0.0230	0.0240	0.065	0.068

Based on the data in Table 5, AASHTO T166 is slightly more repeatable than the Corelok method. An examination of Table 4 indicates that AASHTO T166 was slightly more repeatable in all cases except the CG 15 mixture. It should be noted that for the mixtures tested, a difference of 0.020 units of G_{mb} equals a difference of approximately 0.8 percent air voids. For both the AASHTO T166 and the Corelok methods, the within- and between-lab standard deviations are similar in value. Typically, one would expect the between-lab standard deviation to be greater. Table 6 presents the results of other round robins conducted to determine the variability of the SSD method (AASHTO T166 or ASTM D 2726). AASHTO T166 reports that the acceptable difference between two test results (d2s) by the same operator should be less than 0.020 (within-lab). It appears that AASHTO T166 underestimates the variability of the test method as indicated by the current and previous round robins since the all of the acceptable differences between two test results exceeds 0.020 in both Tables 5 and 6.

Table 6. Summary of Previous Round Robin Testing on the SSD Method

Round Robin	W/L Standard Deviation	B/L Standard Deviation	W/L d2s	B/L d2s
ASTM D 2726 Precision Statement (8)[1]	0.0124	0.0269	0.035	0.075
Stroup-Gardiner *et al* (9)[2]				
First Round Robin – Dense Mix	0.0092	0.0099	0.026	0.028
Second Round Robin – Open Grade No.1	0.0166	0.0220	0.046	0.062
Second Round Robin – Open Grade No.2	0.0099	0.0210	0.028	0.059
Second Round Robin – Cores	0.0197	0.0197	0.055	0.055

[1] Samples of plant-produced material from three different plants representing a range of aggregate types were distributed to the participating laboratories. Samples were compacted by the participating laboratories with Marshall hammers using 75 blows per face.

[2] Samples for the first round robin were compacted using the Hveem kneading compactor following ASTM D1561. Open graded samples for the second round robin were compacted using a Marshall Hammer according to ASTM D 1559 and D 1560. In both the first and second round robins, all of the laboratory prepared samples were compacted by the University of Minnesota prior to being shipped to the participating laboratories. This matches the procedure used in the current round robin. Cores tested in the second round robin were taken from a fine graded mix at Mn/ROAD.

When comparing precision results from various round-robins, it is important to understand that variability is a function of the materials variability plus the variability of the test method. In a round-robin to determine the precision of G_{mb} measurements, the materials variability would include the mixing and compaction of the hot-mix asphalt samples unless the same samples were tested by all of the participating laboratories. In the field, three cases of materials variability of interest to the practitioner exist: Case one, cores taken from the pavement in a manner meant to minimize variation (longitudinally with the direction of paving); Case two, properly split plant-mix compacted by two different laboratories; Case three, material batched, mixed and compacted by two different laboratories (mix design). One would expect the variability in G_{mb} to be greatest for Case three where the samples were batched, mixed, and compacted by different laboratories, since Case three includes both variability in the production of the HMA and the compaction of the HMA (differences in compaction equipment and different operators). The current round-robin most closely represents case one, though it is expected that the materials variability would be somewhat higher since each sample was individually batched and mixed. As noted previously, all compaction was done using the same SGC.

The ASTM D 2726 round-robin (8) represents Case two. The samples for this round robin were compacted to approximately four percent air voids. Thus, the within-lab standard deviations for the ASTM D 2726 round robin (0.0124) should be similar to the within-lab variability for the CG 100 (0.0169) and FG 100 (0.0134), which were also compacted to approximately four percent air voids shown in Table 4. A comparison of Tables 4 and 6 suggests that the results are in fact similar. A comparison of the between-lab case is not applicable since the ASTM D 2726 round robin samples were compacted by different laboratories, increasing materials variability as compared to the current case where all of the samples were compacted by NCAT.

The first round-robin dense mix and the second round-robin open graded No. 2 mixes reported by Stroup-Gardiner *et al* (9) both represent the same case as the current Corelok round-robin (this study). The average air voids of the dense and open graded No. 2 mixtures used in the round robins reported by Stroup-Gardiner *et al* (9) were 7.5 and 7.8 percent, respectively as measured by ASTM D2726 (An SSD method similar to AASHTO T166). Samples compacted to the 50-gyration compaction effort in the Corelok round-robin produced similar air voids. As shown in Table 4, gradation appears to affect the variability, with coarser mixes being more variable. The dense-graded mix used by Stroup-Gardiner *et al (9)* was slightly finer (53 percent passing the 4.75 mm sieve) than the coarse graded mix used in this Corelok study (47 percent passing the 4.75 mm sieve). The within- and between-lab standard deviations are higher for both CG50 (W/L 0.0220, B/L 0.0222) and FG50 (W/L 0.0177, B/L 0.0122) as compared to the Stroup-Gardiner *et al* dense graded mix (W/L 0.0092, B/L 0.0099). This may be due to less variable sample preparation using the Hveem compactor.

The gradation of the open grade No. 2 mix from the second round-robin reported by Stroup-Gardiner *et al* (9) is slightly coarser than the SMA gradation used in the Corelok study (19 as opposed to 23 percent passing the 4.75 mm sieve). The within-lab standard deviation for the SMA50 (0.0226) is significantly higher that that for the open graded No. 2 mix (0.0099), but the between-lab standard deviations are similar (0.0236 and 0.0210, respectively).

The cores tested in the second round-robin reported by Stroup-Gardiner *et al* (9) represents the aforementioned Case one. Notice that similar to the current round-robin, the results for within- and between-lab variability are identical. The cores were taken from a mix with a similar gradation to the FG mix used in the current study. The Mn/ROAD mix was reported as having 57 percent passing the 4.75 mm sieve whereas the FG mix has 63 percent passing the 4.75 mm sieve. The within- and between-lab standard deviations are similar to that of FG 50 (that would have had similar air voids as the field cores) shown in Table 4 as well as to the pooled standard deviations considering all the mixes shown in Table 5.

All of the studies shown in Table 6 used Hveem or Marshall compacted samples or field cores for determining the variability of G_{mb} using the SSD method. AASHTO Materials Reference Laboratory (AMRL) conducts periodic round-robins through the sample proficiency sample testing program. Samples compacted with the Superpave gyratory compactor (SGC) are included in this testing. AMRL sends fractionated aggregate and asphalt to the participating laboratories that must be batched, mixed, and compacted similar to Case three described above. Results from the AASHTO T166 proficiency samples tested to date are shown in Table 7. The between-lab standard deviations shown in Table 7 (pooled 0.0267) are slightly higher than the between-lab standard deviations shown in Table 4 (pooled 0.0191) for the samples compacted to 100 gyrations in this study. The higher standard deviations for the proficiency samples are expected due to increased materials variability, since each lab batched, mixed, and compacted their own samples. However, the within-lab standard deviations shown in Table 7 (pooled 0.0112) are lower than all of the within-lab standard deviations determined from the current round-robin (pooled 0.0183), except for FG15.

Table 7. Compilation of Statistics for AMRL Hot Mix Asphalt Gyratory Proficiency Samples (*10*)

Gyratory Samples	Number of Labs	Between-Lab First Sample, 1s	Between-Lab Second Sample, 1s	First and Second Sample Within-Lab, 1s
1,2	54	0.031	0.029	0.009
3,4	52	0.024	0.020	0.011
5,6	151	0.027	0.028	0.008
7,8	213	0.022	0.023	0.012
9,10	236	0.031	0.032	0.016

The comparisons with previous inter-laboratory precision studies for the SSD method indicate the between-lab standard deviations determined in this Corelok round robin are reasonable. However, the same comparisons indicate that the within-lab standard deviations for the AASHTO T166 method determined in the current round robin may be too high. This is most likely due to variability during sample production. Though variability would be expected any time 567 samples are prepared, based on the comparisons to the AMRL proficiency samples shown in Table 7, this variability is greater than that shown in the AMRL work when each lab had batched, mixed, and compacted their own samples. Figure 16 presents the uncorrected gyratory bulk gravities for the fine-graded mixes. Figure 16 indicates examples of systematic variability in the production of test samples, an example being FG 100 samples 25 through 34.

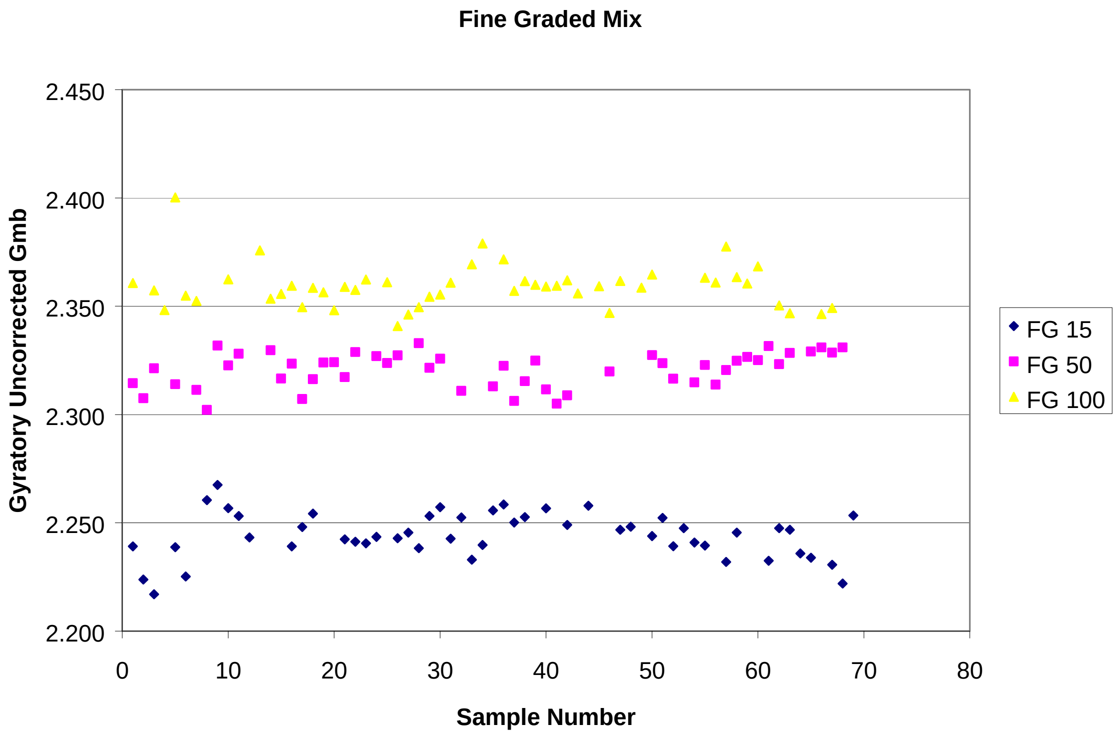

Figure 16. Uncorrected Gyratory G_{mb} for Fine Graded Mixes

Due to concerns about materials variability resulting from the production of the samples, an analysis was performed using the difference between the measured G_{mb} (for both AASHTO T166 and Corelok) and the uncorrected SGC G_{mb}. Since the materials variability may have masked actual testing outliers, the data was re-analyzed with the ASTM E 691 software (7) to determine the *h*- and *k*-statistics for both the AASHTO T166 and the Corelok datasets. The lab/material combinations that exceeded the critical *h*- and *k*-statistics were compared to an outlier analysis performed using the standardized residuals from regression analyses between the uncorrected gyratory G_{mb} and either the AASHTO T166 or Corelok G_{mb}. The standardized residual analysis is discussed later in the paper. If a sample identified as an outlier by the standardized residual analysis was also identified as exceeding the critical *h*- or *k*-statistics, then that test result was removed from the dataset.

Table 8 shows the repeatability and reproducibility statistics based on the difference between the measured G_{mb} values for both AASHTO T166 and Corelok and the uncorrected gyratory G_{mb} both with and without the outliers. The complete data are reported in Appendices E and F. For this analysis, the uncorrected gyratory G_{mb} is considered to be the reference standard. In reality there will also be a small amount of measurement variability in the uncorrected gyratory G_{mb}. The data in Table 8 would represent the case where two labs were testing cores taken in a manner to minimize material variability or samples compacted by a single lab. The data in Table 8 also represents a good estimate of the actual testing variability solely from the two test methods for determining G_{mb}. The reproducibility results shown in Table 8 would be lower than that expected if samples were compacted from loose mix or fully prepared in the laboratory and compacted by different laboratories. The pooled within-lab

Table 8. Averages and Standard Deviations Based on Difference Analysis for All Materials

	Complete Data Set (Except Lab 16)						Outliers Removed					
	Avg. Difference[1]		Within-Lab 1s		Between-Lab 1s		Avg. Difference[1]		Within-Lab 1s		Between-Lab 1s	
Material	SSD	Corelok	SSD	Corelok	SSD	Corelok	SSD	Corelok	SSD	Corelok	SSD	Corelok
CG 15	0.079	0.042	0.0126	0.0151	0.0157	0.0179	0.079	0.039	0.0126	0.0108	0.0157	0.0116
CG 50	0.064	0.053	0.0048	0.0142	0.0067	0.0156	0.064	0.051	0.0040	0.0046	0.0058	0.0066
CG 100	0.065	0.055	0.0101	0.0141	0.0101	0.0141	0.063	0.055	0.0067	0.0081	0.0068	0.0081
FG 15	0.038	0.039	0.0068	0.0098	0.0068	0.0099	0.038	0.039	0.0068	0.0098	0.0068	0.0099
FG 50	0.035	0.039	0.0148	0.0075	0.0166	0.0084	0.037	0.039	0.0031	0.0058	0.0043	0.0069
FG 100	0.035	0.037	0.0040	0.0103	0.0042	0.0103	0.035	0.039	0.0040	0.0053	0.0042	0.0056
SMA 15	0.124	0.078	0.0242	0.0171	0.0261	0.0173	0.121	0.076	0.0134	0.0088	0.0174	0.0094
SMA 50	0.092	0.068	0.0115	0.0417	0.0121	0.0441	0.093	0.075	0.0084	0.0103	0.0088	0.0120
SMA 100	0.071	0.058	0.0096	0.0109	0.0108	0.0145	0.071	0.059	0.0096	0.0091	0.0108	0.0126
Pooled			0.0109	0.0156	0.0121	0.0169			0.0076	0.0081	0.0090	0.0092

[1] – Difference between individual measured values (AASHTO T166 or Corelok) and the uncorrected SGC G_{mb}.

standard deviation (repeatability) for AASHTO T166 (0.0109) compares well with the pooled within-lab standard deviation from the AMRL proficiency samples shown in Table 7 (0.0112). The reproducibility (between-lab) results from the AMRL Proficiency samples indicated greater variability (standard deviations ranging from 0.020 to 0.032) than the results of this study (pooled standard deviation of 0.0121). This was as expected since multiple laboratories mixed and compacted the samples.

A number of laboratories that participated in the round-robin were relatively inexperienced with the Corelok method as compared to AASHTO T166. This was evident by the larger number of outliers identified for the Corelok method compared to the AASHTO T166 data by the *h*- and *k*-statistics as well as the standardized residual analysis. Another potential problem with the Corelok test method was that no ruggednesss study had been conducted. Therefore, certain components of the test method that may lead to increased variability had not been identified and tighter controls placed within the test method.

The repeatability and reproducibility results for the Corelok method with the outliers removed represent the expected precision of the test method once laboratories become familiar with the test method and once a method for identifying bag leaks is developed. An *F*-test was performed at the 95 percent confidence level to compare the variability of the AASHTO T166 and Corelok test results by mix type. The results are shown in Table 9. In 6 of 9 cases, the variances (a measure of the test variability) are statistically equal. In three cases, the variances of the T166 results are less than the Corelok results.

Table 9. *F*-Test Results to Compare Sample Variances by Mix Type

Mix	Number of Samples	*F*-Statistic	P-Value	Significant[1]
CG 15	51	1.008	0.997	No
CG 50	51	1.401	0.237	No
CG 100	51	1.581	1.109	No
FG 15	51	2.174	0.007	Yes – T166 less
FG 50	51	1.375	0.279	No
FG 100	50	1.681	0.078	No
SMA 15	51	1.266	0.407	No
SMA 50	51	6.529	0.000	Yes – T166 less
SMA 100	51	3.201	0.000	Yes – T166 less

[1]Significance at the 95 percent confidence level

It is desirable for a test method to produce a consistent level of variability regardless of the materials being tested (gradation or air void level). If the variability increases with increasing test values then the coefficient of variation is normally used. However, as discussed previously, the use of the coefficient of variation is not appropriate with measurements of G_{mb} due to the effect of aggregate specific gravity. Also, for a mixes composed of the same aggregate, variability actually increases with decreasing G_{mb} (increasing air voids). Therefore, an analysis was conducted to see if the variability of the two test methods was consistent regardless of gradation and air void content. It appears that the variability of the Corelok method is slightly less sensitive than the AASHTO T166 method to changes in air void content (or gyrations). *F*-Tests were performed to compare the variances between all materials (mix type and gyration level) by test type (Appendix G). This resulted in 36 comparisons for each test method. The comparisons were performed using the variances with and without the outliers. When the outliers were included in the dataset, statistical differences between the within-lab variances were found in 28 of 36 cases and 26 of 36 cases for the SSD and Corelok methods, respectively; statistical differences were found for the between-lab variances in 30 of 36 and 22 of 36 cases for the SSD and Corelok methods, respectively. When the outliers were removed from the dataset, statistical differences between the within-lab variances were found in 29 of 35 cases and 18 of 35 cases for the SSD and Corelok methods, respectively; statistical differences were found for the between-lab variances in 29 of 35 and 21 of 35 cases for the SSD and Corelok methods, respectively. These *F*-tests confirm that with and without the outliers, the testing variance of the Corelok method is less affected by changes in mix type and air voids (gyrations). It is interesting to note that the pooled between-lab standard deviation with outliers for the SSD method closely matches (0.0121 versus 0.0124) the current ASTM between-lab precision statement for that method. The data indicates that the variability of the Corelok method is less effected by gradation and air void content than AASHTO T166, however the Corelok method is more variable than AASHTO T166 in three of nine cases. The form of the precision statement for the Corelok procedure remains in question. The *F*-tests (Appendix G) indicate significant differences by material, in some cases, suggesting that the variances should not simply be pooled. The use of coefficient of variation in terms of G_{mb} is not practical since different aggregate types will have different specific gravities, potentially producing different G_{mb} values without changing the internal void structure. Graphs (Appendix G) were plotted comparing the within- and between-lab standard deviations, by material, to the average air void content of that material. The use of air void content would normalize the effect of differing aggregate gravities. Figure 17 shows the within- and between-lab standard deviations versus average air void content, by material, for the Corelok results with the outliers included. The Y-axis scale is exaggerated to include the SMA 50 results. Graphically, the SMA 50 results appear to be an outlier. Based on the *F*-test results, the SMA 50 results are statistically different from all of the other mixes. Based on this analysis, the Corelok results with outliers were pooled excluding the SMA 50 results. This results in the following precision statement:

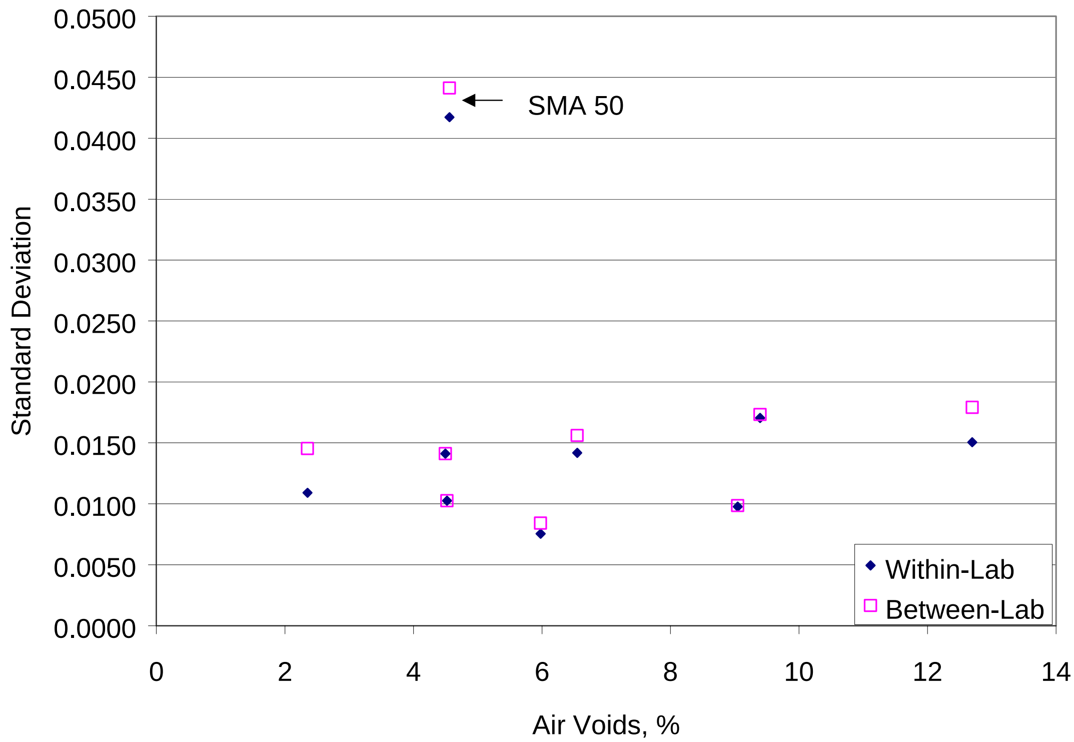

Figure 17. Corelok Standard Deviation Including Outliers Based on Difference Analysis Versus Average Air Voids

The single-operator standard deviation has been found to be 0.0124. Therefore, results of two properly conducted tests by the same operator on the same material should not differ by more than 0.035. The multi-laboratory standard deviation has been found to be 0.0135. Therefore results from two properly conducted tests from two different laboratories on samples of the same material should not differ by more than 0.038.

Comparison of Corelok and Water Displacement Test Methods to Measure G_{mb}

The first step in the comparison of the two G_{mb} test methods was to closely evaluate the test results. It was anticipated that some suspect data would result from this study as a total of 567 samples were tested. This equated to a total of 1,134 tests being conducted since both the Corelok and AASHTO T166 methods were performed on each sample.

A close inspection indicated several deficiencies in some of the test results. As stated previously, the Corelok test method was conducted first and AASHTO T166 was conducted after the Corelok procedure was concluded. Inspection of the data indicated that for eighteen samples, the “dry mass” for a given sample was different during the Corelok and AASHTO T166 testing. This was likely due to a small leak in the bags that was not identified during Corelok testing. Infiltration of water into the plastic bag can influence the determination of G_{mb}. However, it is currently unclear how much water infiltration is tolerable while maintaining the integrity of the test procedure.

Another potential problem with individual data was that the "dry mass" for a given sample was different at the time of testing than when weighed at NCAT prior to sending the samples to the participating laboratories. These differences ranged from 0.1 gram to as high as 30 grams. Differences of 1 gram or less were probably caused by variability in scales or the dislodgement of small pieces of HMA during shipment of the samples. Larger differences could be caused by a number of issues. First, sample identifications may have been misread. Secondly, scales may have been out of calibration. Lastly, values may have also been written down incorrectly. All three of these potential problems could affect a comparison between the two methods.

The method selected for identifying potential outlying data was to develop regressions between data sets and evaluate standardized residuals. The regressions selected to identify outliers was to regress Corelok results to gyratory results and AASHTO T166 results to gyratory results. Gyratory results were considered the bulk specific gravity measurements based upon volumes of compacted specimens in the gyratory and were used in the development of the precision statements. This, in essence, is a volumetric (height times area of cylindrical sample) bulk specific gravity. The gyratory results were considered to be a reasonably consistent measure of bulk specific gravity for a given material (i.e., gradation-gyration level combination). For a given material, the relationship between density and interconnected surface voids should remain reasonably consistent. This would allow for obvious outlier Corelok or AASHTO T166 data to be identified.

The steps in identifying outliers were to first regress (linear) the dependent data (Corelok or AASHTO T166 results) to the independent data (gyratory bulk specific gravity). This was done for each of the nine materials. Based upon the regression statistics for a given material, the residuals for each observation were then calculated. For a given material, there were 51 observations (17 laboratories [laboratory 16's results excluded] * 3 replicates). A residual is the difference between a dependent observation and its predicted value (from the regression equation). Standardized residuals were then calculated as follows:

$$d_{ij} = \frac{e_{ij}}{\sqrt{\frac{(n-1)}{n} MS_E}} \tag{8}$$

Where,

d_{ij} = standardized residual for an observation
e_{ij} = residual (observation minus predicted value) for an observation
n = number of observations
MS_E = variance of residuals

Montgomery (*11*) has indicated that for a normal population, standardized residuals should be approximately normal with a mean of zero and a variance of one. Approximately 68 percent of the standardized residuals should be within ± 1, 95 percent of the standardized residuals should be within ±2, and 99.9 percent of the standardized residuals should be within ± 3. Montgomery suggests that test results with standardized residuals greater than 3 or 4 are potential outliers. For the purposes of this study, observations with a standardized residual of greater than 3 were considered outliers.

Figures 18 and 19 illustrate this outlier identification technique. Figure 18 presents SMA 50-gyration material results for Corelok and gyratory bulk specific gravity measurements. As shown on the figure, two data points do not appear to be part of the sample population. Both of these data points have G_{mb} values, as measured with the Corelok, that are much lower than the companion gyratory G_{mb} values. For both samples, the submerged mass recorded by the participating lab was in the 2,600-gram range. The remaining 49 samples had submerged masses in the 2,800-gram range. This difference could have been caused by incorrectly recording the submerged mass on the data sheet.

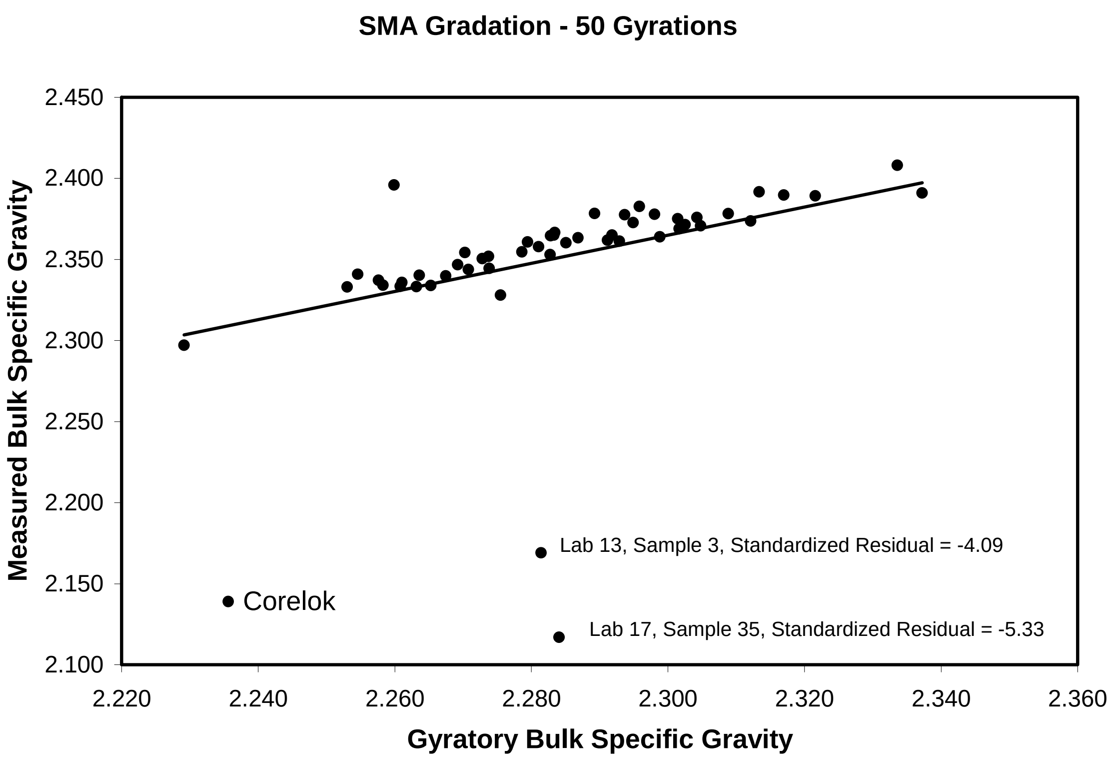

Figure 18. Outlier Identification for Corelok Results SMA- 50 Gyrations

Figure 19 shows a similar plot for the same material as Figure 18, except AASHTO T166 results were regressed with the gyratory G_{mb} values. For this sample population, a single data point had a standardized residual of greater than 3.

Tables 10 and 11 provide the data points identified as potential outliers for the Corelok and AASHTO T166 data, respectively. Included within these tables are the material tested (mix-gyration level), laboratory conducting the test, sample number, G_{mb} value, and the standardized residual. For the Corelok data, thirteen observations were identified as potential outliers. For AASHTO T166, six observations were identified as potential outliers. The difference in the number of potential outliers between the Corelok and AASHTO T166 data sets was not unexpected. For several of the laboratories, this round-robin study was the first time technicians had conducted the Corelok procedure. Therefore, experience with the device and procedure was low. Three laboratories being identified as having outlying data at least twice show this lack of experience. For AASHTO T166, only one laboratory has as many as two outlier observations. Also as stated previously, no ruggedness study had been conducted for the Corelok procedure.

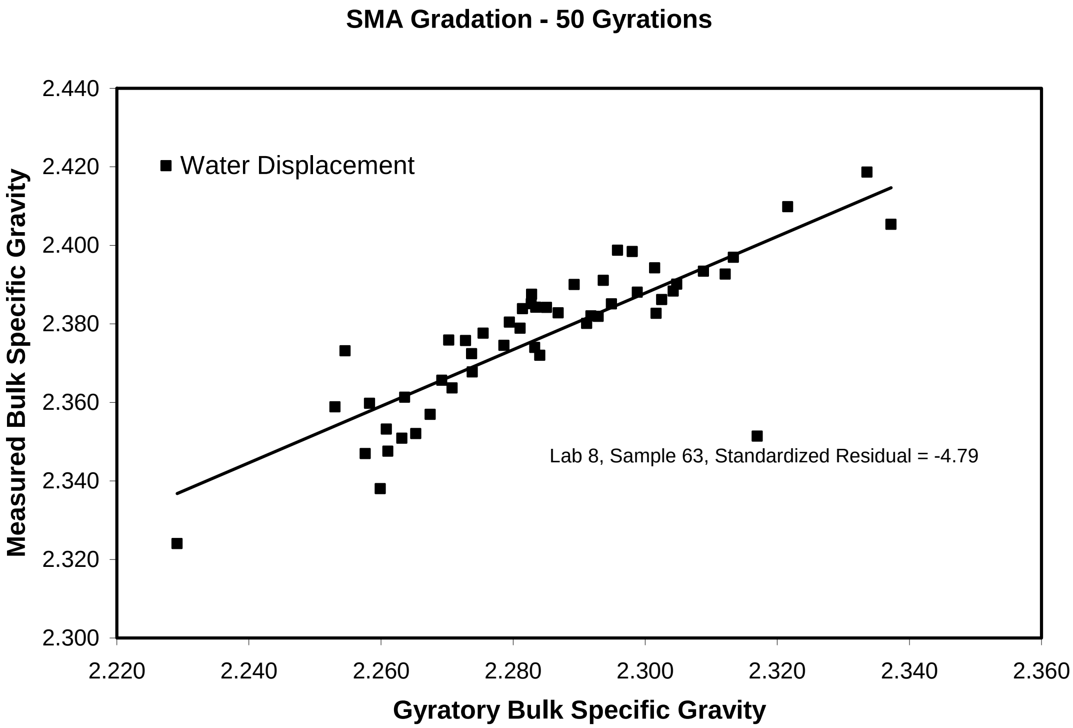

Figure 19. Outlier Identification for Water Displacement Results SMA- 50 Gyrations

Table 10. Potential Outliers for Corelok Data

Gradation	Gyration Level	Laboratory	Sample	G_{mb} Value	Standardized Residual
Fine	15	9	12	2.247	-3.75[1]
Fine	50	11	37	2.319	-3.02[2]
Fine	50	9	68	2.404	3.99
Fine	100	6	5	2.379	5.98
Coarse	15	21	16	2.285	3.82
Coarse	15	21	34	2.248	3.81
Coarse	50	1	58	2.417	6.37
Coarse	100	9	51	2.377	3.17
Coarse	100	10	12	2.339	-5.08
SMA	15	7	18	2.357	5.91
SMA	50	13	3	2.169	-4.09
SMA	50	21	35	2.117	-5.33
SMA	100	13	17	2.362	-3.79

[1] Not identified as outlier by h (-2.31) and k (1.89) analysis.
[2] Not identified as outlier by h (-1.65) and k (2.02) analysis.

Table 11: Potential Outliers for Water Displacement Data

Gradation	Gyration Level	Laboratory	Sample	G_{mb} Value	Standardized Residual
Fine	50	21	7	2.234	-6.67
Fine	100	7	20	2.401	4.06
Coarse	50	9	20	2.328	-3.71
Coarse	100	9	51	2.389	4.56
SMA	15	10	46	2.389	5.34
SMA	50	8	63	2.351	-4.79

The average, sample standard deviation, range and number of observations for the measured Corelok air void content, AASHTO T166 air void content, difference in measured air void contents between the Corelok and T166 methods and T166 water absorption are summarized by mix type in Table 12. CG 100, FG 100 and SMA 50 approximately represent the design case, where 4 percent air voids would be expected. For the coarser gradations, CG and SMA, there appears to be a difference between the air voids measured by Corelok and AASHTO T166, even for the design cases. On average for the fine-graded mixes, there is practically no difference between the Corelok and AASHTO T166 results at any gyration level. Surprisingly, for the FG 50 and FG 100 materials, the average Corelok G_{mb} values were less than the AASHTO T166 G_{mb} values. This may be due to the inability of the Corelok bag to tightly adhere to such a smooth specimen. Typically though, fine graded mixes do not exceed two percent water absorption.

The average water absorption values for the fine graded (FG) mixes, shown in Table 12, are all below the 2.0 percent, by volume, threshold specified by AASHTO T166. The average water absorption for the CG 15 and SMA 15 materials exceeds the 2.0 percent threshold limit established by AASHTO T166. At the 50 gyration levels, neither the CG or SMA materials had water absorptions greater than 2.0 percent. For these two materials, the average difference in air voids between the two G_{mb} methods was 0.5 and 1.0, respectively. Based on the average, standard deviation and range, shown in Table 12, the measured water absorptions are for the most part less than 2.0 percent.

The next step in comparing G_{mb} results from the Corelok and AASHTO T166 results was to conduct a paired *t*-test for each of the nine materials. This test method compares the difference between paired observations (Corelok and AASHTO T166 G_{mb} results for a given sample). Results of these analyses are presented in Table 13. Included in Table 13 are the material type, mean G_{mb} value for the Corelok method, mean G_{mb} value for AASHTO T166, mean difference (Corelok G_{mb} minus AASHTO T166 G_{mb}), t-value from the paired comparison, probability value (p-value) that the t-statistic is greater than t-critical, and whether G_{mb} results from the two methods are significantly different at a 95 percent confidence level.

Table 12. Summary of Measured Air Voids and Water Absorption by Material

	Mix	CG 15	CG 50	CG 100	FG 15	FG 50	FG 100	SMA 15	SMA 50	SMA 100
Number of Samples		49	50	51	51	51	51	51	51	51
Average	Corelok Air Voids, %	12.8	6.6	4.5	9.0	6.0	4.6	9.4	4.6	2.3
	T166 Air Voids, %	11.2	6.1	4.1	9.1	6.2	4.7	7.5	3.5	1.8
	Corelok-T166 Air Voids, %	1.6	0.5	0.4	0.0	-0.2	-0.1	1.9	1.0	0.5
	T166 Water Abs.,%	5.0	1.0	0.4	0.9	0.5	0.3	2.2	0.6	0.2
Standard Deviation	Corelok Air Voids, %	1.28	0.97	0.81	0.47	0.49	0.51	1.04	1.94	0.78
	T166 Air Voids, %	1.43	0.88	0.64	0.32	0.76	0.51	0.92	0.76	0.43
	Corelok-T166 Air Voids, %	0.65	0.28	0.45	0.36	0.65	0.39	0.59	1.18	0.51
	T166 Water Abs.,%	1.13	0.41	0.22	0.36	0.19	0.14	0.65	0.64	0.13
Range	Corelok Air Voids, %	9.0-15.6	3.8-8.7	2.6-7.0	8.0-10.5	4.2-7.6	3.6-6.6	4.4-11.3	2.3-14.1	1.1-5.6
	T166 Air Voids, %	8.3-13.8	3.6-8.3	3.0-6.0	8.2-9.8	5.6-11.0	3.1-7.0	3.1-10.1	1.8-5.7	1.0-3.4
	Corelok-T166 Air Voids, %	0.5-3.2	-0.2-1.3	-0.2-2.9	-1.3-1.4	-4.2-1.0	-0.5-2.1	0.9-3.5	0.2-8.7	-0.1-2.4
	T166 Water Abs.,%	2.7-7.2	0.3-2.1	0.1-1.0	0.4-2.0	0.2-1.0	0.0-0.6	1.1-4.8	0.2-4.8	0.1-0.6

Table 13. Results of Paired *t*-Tests To Compare Corelok and AASHTO T166 Test Results

Gradation	Gyration Level	Corelok Mean G_{mb}	AASHTO T166 G_{mb}	Mean Difference	*t*-Value	p-Value	Different?
Fine	15	2.284	2.282	0.002	1.43	0.159	No
Fine	50	2.360	2.358	0.002	2.25	0.029	Yes
Fine	100	2.397	2.393	0.004	4.81	0.000	Yes
Coarse	15	2.185	2.226	-0.041	-17.95	0.000	Yes
Coarse	50	2.341	2.353	-0.012	-13.62	0.000	Yes
Coarse	100	2.395	2.403	-0.008	-7.93	0.000	Yes
SMA	15	2.230	2.275	-0.045	-17.42	0.000	Yes
SMA	50	2.360	2.377	-0.017	-9.26	0.000	Yes
SMA	100	2.408	2.421	-0.013	-8.05	0.000	Yes

Based upon Table 13, there were significant differences in G_{mb} results between the two test methods for all materials except the Fine-15 gyration mixtures. However, practically speaking, there were no differences between any of the Fine gradation mixes. For the 50 gyration Fine mixes, the mean difference in G_{mb} was only 0.002 while for the 100 gyration mixes the difference was 0.004. Differences in G_{mb} values of 0.004 would result in differences in air void contents of less than 0.2 percent.

For the remaining materials, there were some large differences between G_{mb} values from the two test methods. Results for the Coarse-15 gyration material differed in G_{mb} by 0.041 and the SMA-15 gyration material differed by 0.045. For the Coarse and SMA gradations, there is a definite trend in the differences with changes in gyration level. The largest differences are at 15 gyrations while the smallest differences are for the 100 gyration mixes.

Figures 20 and 21 illustrate the relationships between G_{mb} measurements for the Superpave mixes using both the Corelok and AASHTO T166 results. Figure 20 presents the relationships for the three Fine gradation materials. Based upon this figure, G_{mb} measurements for both procedures fall near the line of equality. This is true for all three gyration levels. Interestingly, the majority of the data falls just below the line of equality, indicating that the Corelok G_{mb} values are slightly less than the AASHTO T166 G_{mb} values. Figure 20 and practical interpretation of the paired t-tests (Table 13) suggest that for the Fine gradation materials, the two methods of measuring the G_{mb} of compacted HMA provide similar results. Based upon past experiences with AASHTO T166 for conventional mixes (typically having a fine gradation), Figure 20 suggests that the Corelok does provide a good estimation of G_{mb}.

Figure 21 illustrates the relationship between the two G_{mb} measurement methods for the Coarse gradation materials. For the 15 gyration mixes, all of the data points fall above the line of equality. This indicates that G_{mb} measurements for AASHTO T166 were higher than those for the Corelok method. As shown in Table 11, the mean difference in G_{mb} for the 15 gyration mixes between the two methods was 0.041, which is approximately 1.6 percent difference in air void content (average of 12.8 and 11.2 percent air voids for the Corelok and AASHTO T166, respectively). Results for samples compacted to 50 gyrations were closer to the line of equality, but still had a mean difference in G_{mb} of 0.012. This difference equates to approximately 0.5 percent air voids. Data for the 100 gyration mixes were very close to the line of equality. The mean difference between the two methods at 100 gyrations was 0.008, or about 0.4 air voids.

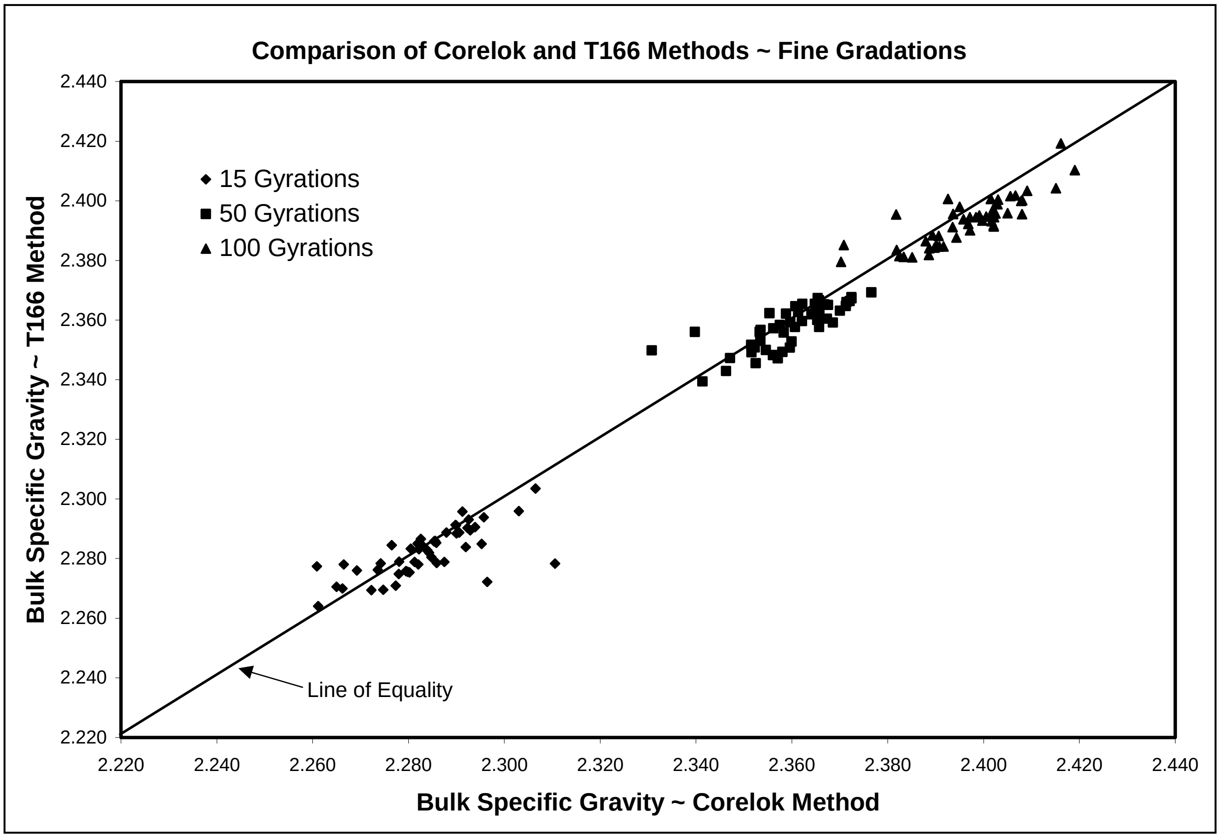

Figure 20. Relationship Between G_{mb} Measurements for Fine Gradation Materials

The results shown in Figure 21 are interesting in that as density increases (gyration level increases), G_{mb} measurements for the two methods become closer. Previously within this report, the problems associated with measuring G_{mb} utilizing AASHTO T166 was discussed. These problems most likely explain the differences in G_{mb} results for the two methods. Samples having higher air void contents (15 gyration samples) likely have large voids interconnected to the sample surface, which allows water to quickly enter the sample during submergence in water. Likewise these large interconnected voids also allow the water to quickly exit the sample after removing the sample from the water to attain the SSD condition. Several research studies have shown that there are density gradients within Superpave gyratory compacted samples (13, 14). These studies have indicated that density is highest within the center of the sample and the lowest density is near the perimeter of the sample. The combination of high overall air void contents and the density gradients within samples, it can be inferred that there are large interconnected voids near the surface of Superpave gyratory compacted samples.

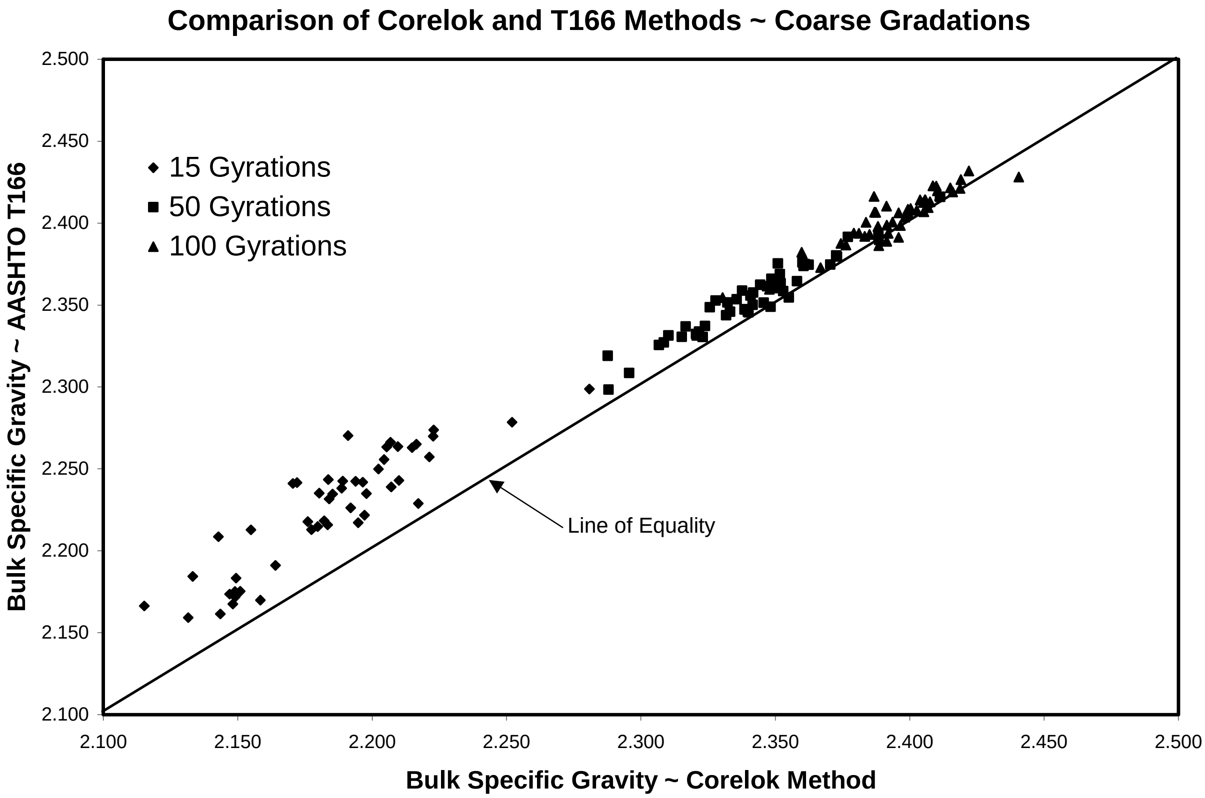

Figure 21. Relationship Between Two Methods in Measurement for Coarse Gradation

One possible method of determining whether an excessive amount of water enters a given sample during AASHTO T166 testing is to evaluate the amount of water absorption within samples. This analysis will not provide an exact measure of the volume of water that enters and exits a sample during AASHTO T166 testing, but rather provides a measure of the potential. As water absorption increases, the number and size of voids interconnected to the surface increases. Intuitively, as the water absorption increases, the potential for errors during AASHTO T166 testing also increases. If this hypothesis is correct, there should be a reasonable relationship between the difference in density measurements by the two methods and water absorption. Also if the hypothesis is correct, the AASHTO T166 results would overestimate density. Therefore, the Gmb values obtained by the Corelok method should be less than results from AASHTO T166 testing if the Corelok does provide a better estimation of density at high air void levels. This hypothesis was tested and shown correct by Buchanan (3). This is the reason that within the AASHTO T166 standard method of test, a provision requires the use of other test methods if the water absorption is greater than 2 percent.

Figure 22 presents the relationship for the Coarse gradation mixes between water absorption and G_{mb} determined by both the Corelok and water displacement methods. As shown on the figure, both relationships have high coefficients of determination (R^2) of 0.88. At high G_{mb} values (high gyration levels), both test methods have relatively low water absorptions. Also, there is little difference in G_{mb} between the two methods at low water absorption values. However, at the higher levels of water absorption the two methods begin to diverge. Generally, the Corelok G_{mb} values are smaller than the water displacement values.

Based upon the discussion of the problems with AASHTO T166, Figure 22 is logical. At high densities (high G_{mb} values), there are very low water absorptions and the two methods provide similar results. However, at lower densities there are higher water absorption values and large differences in G_{mb} values. Past experience has shown that at high densities (low absorption), AASHTO T166 provides a reliable estimation of density. If water is quickly entering and exiting a sample during AASHTO T166 testing, it would be expected that the density of a sample would be overestimated. Therefore, the relationship between the Corelok and water displacement results makes sense if the Corelok procedure is providing a more accurate measure of G_{mb} at lower densities (high water absorption). Because of how the Corelok method works, it can be surmised that since the method works at high densities, it also works at lower densities.

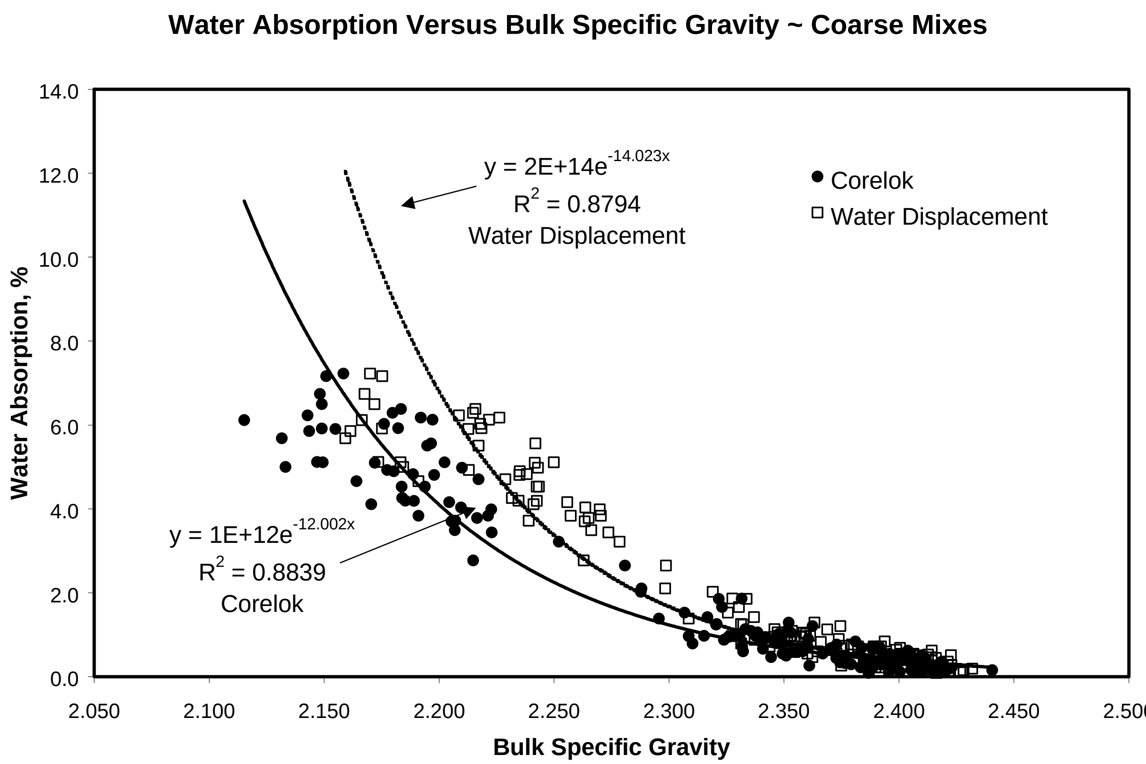

Figure 22. Relationship Between Water Absorption and G_{mb} for Coarse Mixes

Another way to look at Figure 22 would be to evaluate the relationship between the differences in air void contents resulting from G_{mb} measurements based upon both test methods versus the amount of water absorption (Figure 23). Figure 23 presents all of the data for the Coarse gradation mixes (all gyration levels). The R^2 value for Figure 23 is relatively low (0.5), but the relationship is significant (p-value = 0.000). Based upon the figure, the difference in air void content for a given sample tested by both the Corelok and AASHTO T166 at 2.0 percent water absorption would be approximately 0.8 percent.

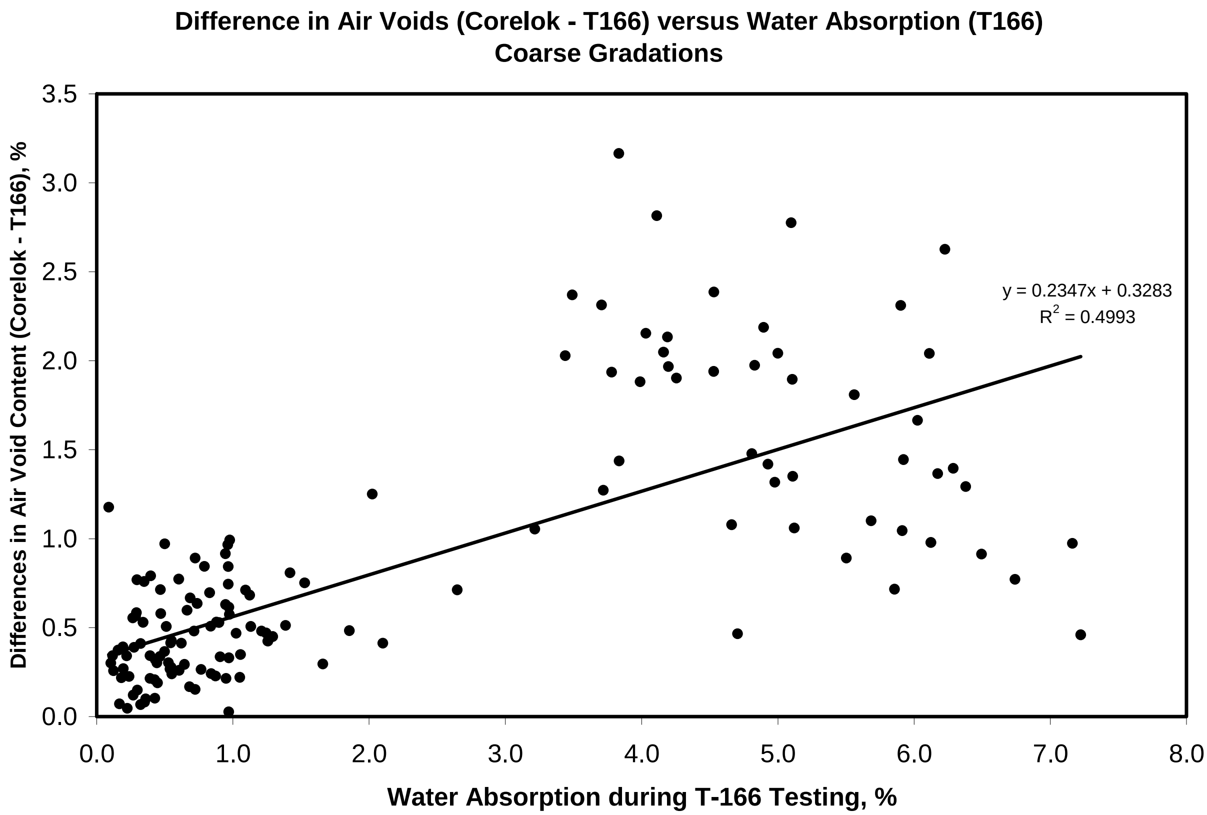

Figure 23. Difference in Air Void Contents Based Upon Water Absorption (Coarse Mixes)

Figure 24 presents the relationship between the two G_{mb} measurements for the SMA gradation materials (all gyration levels). Similar to the coarse gradation materials (Figure 20), the SMA materials show a wide difference in G_{mb} values at the 15 gyration level. The mean difference in G_{mb} between the two methods at 15 gyrations is 0.045, which is approximately 1.8 percent air voids. At 50 gyrations, the values become closer, but still not on the line of equality. The mean difference in G_{mb} was 0.017 or about 0.7 percent air voids for the 50 gyration mixes. At 100 gyrations, the results become even closer to the line of equality. The mean difference between the two methods was 0.013, which is 0.5 percent air voids.

Similar to the Coarse gradation (Figure 21), Figure 24 shows that as density increases the G_{mb} measurements become closer. The SMA gradation mixes are similar to the Coarse gradation mixes, in that they can contain large interconnected air voids. Additionally, the Corelok method may include more of the surface texture as air voids than AASHTO T166. Figure 25 illustrates the relationship between water absorption and G_{mb} values for the SMA gradations. At low values of water absorption (high density values), the differences in G_{mb} between the two test methods are similar. However, at high values of water absorption there is a large difference between the two test methods. This again infers that for high water absorption mixes, the water is quickly entering and exiting the mix during AASHTO T166 testing. The net result is AASHTO T166 is overestimating density.

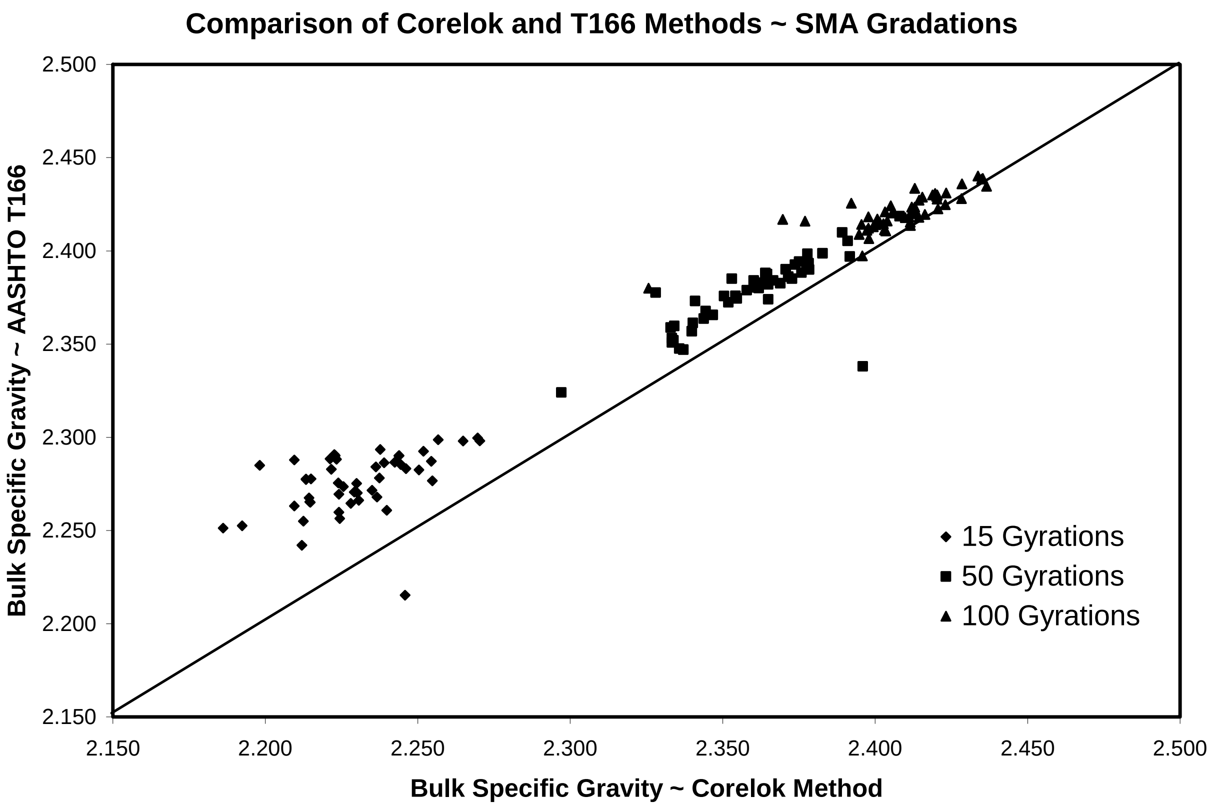

Figure 24. Relationship Between Two Methods of Measurement for SMA Gradations

Figure 26 presents the relationship between the differences in air void content resulting from the two G_{mb} methods versus water absorption. All three-gyration levels are shown. The R^2 value is again relatively low (0.3), but the relationship is significant (p-value = 0.000). Based upon Figure 26, the difference in air void content for a given sample tested by both the Corelok and AASHTO T166 at 2.0 percent water absorption would be approximately 1.8 percent.

Based upon the previous discussions about the test results and the potential problems with AASHTO T166, it appears that the Corelok does provide a more accurate measure of G_{mb} than AASHTO T166 at high levels of water absorption. This is based upon the similarity in test results for the Fine gradation mixes and the Coarse and SMA gradation mixes at the high compaction levels. Visual examination of coarse graded samples sealed with the Corelok device suggests that the plastic does conform to the surface voids. However, there is a slight potential for the Corelok device to over estimate air voids due to bridging of the plastic bag over a sample's surface voids. This potential may be greater for laboratory prepared samples, which have texture on all sides as opposed to field cores. Now the question must be asked, "When should the Corelok procedure be utilized?"

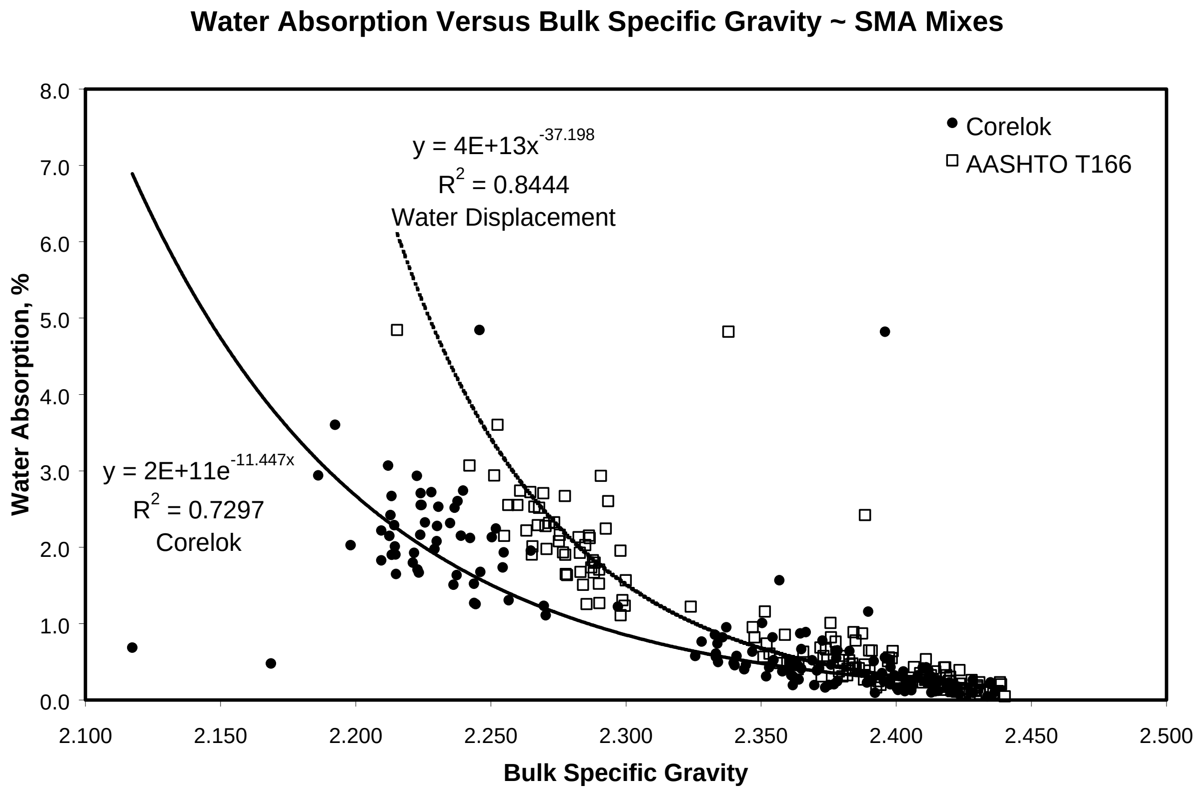

Figure 25. Relationship Between Water Absorption and G_{mb} for SMA Mixes

Results shown in Figures 22 and 25 indicated that there is a relationship between density and water absorption. To evaluate when the Corelok method should be used instead of AASHTO T166, the relationship between density and water absorption was evaluated for fine (FG) and coarse graded (CG and SMA) mixtures (all gyration levels). For the purposes of this analysis, the coarse-graded and SMA mixes were lumped into a single data set designated BRZ because both had gradations passing below the restricted zone. Because each of the different mixes had different properties, the density (G_{mb}) data was normalized to air void contents. Figure 27 presents this relationship.

Based upon Figure 27, the relationship between air voids and water absorption is different for the coarse and fine mixtures. There is a sound relationship between air void contents and water absorption for both test methods. The R^2 values for the BRZ mixes were 0.82 and 0.85 for the Corelok and water displacement regressions, respectively. The R^2 values for the fine graded mix were 0.56 for both the Corelok and water displacement methods. The best-fit line for the BRZ mixes is based on the natural log of water absorption while the best-fit line for the ARZ mix is a linear function. It is believed that this difference is related to the interconnectivity of the air voids. It appears that for the BRZ mixes; the air-voids begin to be interconnected above approximately 1.6 percent water absorption. After this point, the water absorption increases rapidly with small changes in air voids. It does not appear that the air voids

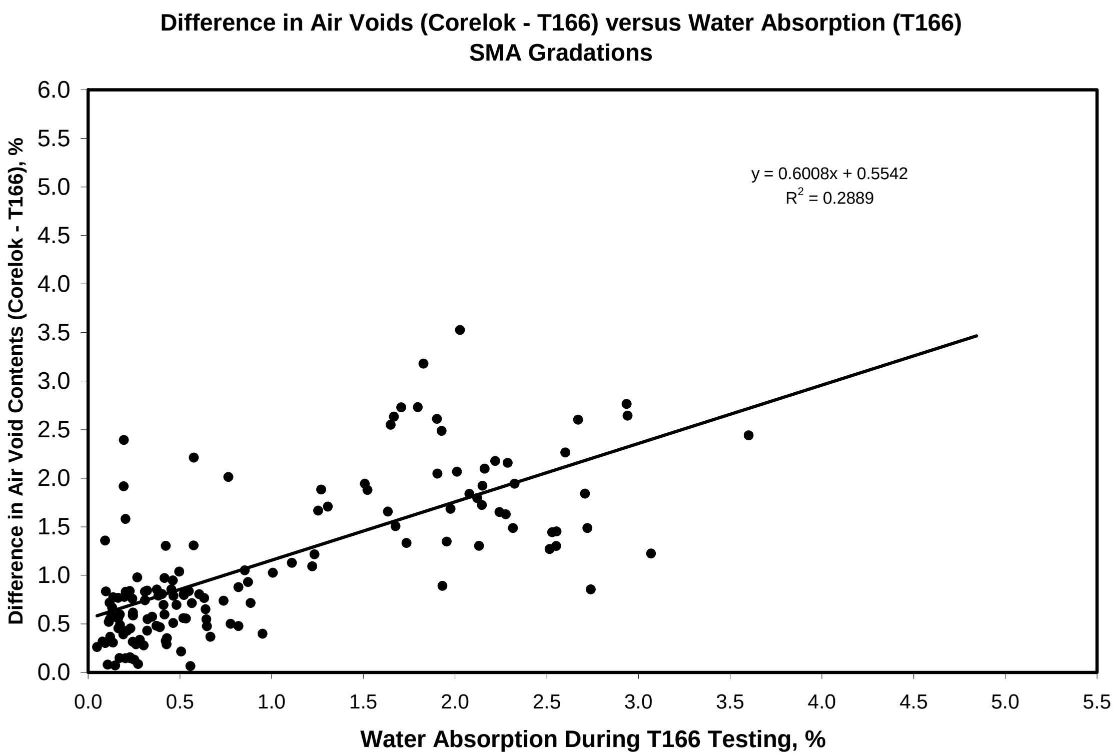

Figure 26. Difference in Air Void Content Based Upon Water Absorption (SMA Mixes)

in the ARZ mix become interconnected over the range of air voids tested. It should be pointed out that the relationships between air voids and water absorption depicted in Figure 27 may change as aggregate type changes. However, the relationship shown in Figure 27 is most likely representative and can be used to define when the Corelok method should be employed instead of AASHTO T166.

Figure 27 suggests that practically there is no difference between the air void contents measured by the Corelok and AASHTO T166 methods for the fine graded mixture. Further, over the range of air voids tested, all of the samples had less than 2.0 percent water absorption. This suggests that the AASHTO T166 method may be used for fine graded mixtures with less than 2.0 percent water absorption. This matches historical experience and the limits defined by both AASHTO T166 and ASTM D2726.

For the BRZ mixtures (CG and SMA) at low water absorptions, air void contents based upon the two G_{mb} measurement methods are similar. However, at some level of water absorption, the two methods begin to diverge and the Corelok method provides a higher air void content. The point at which the two methods diverge is when the Corelok method should be utilized to measure G_{mb} for BRZ mixtures.

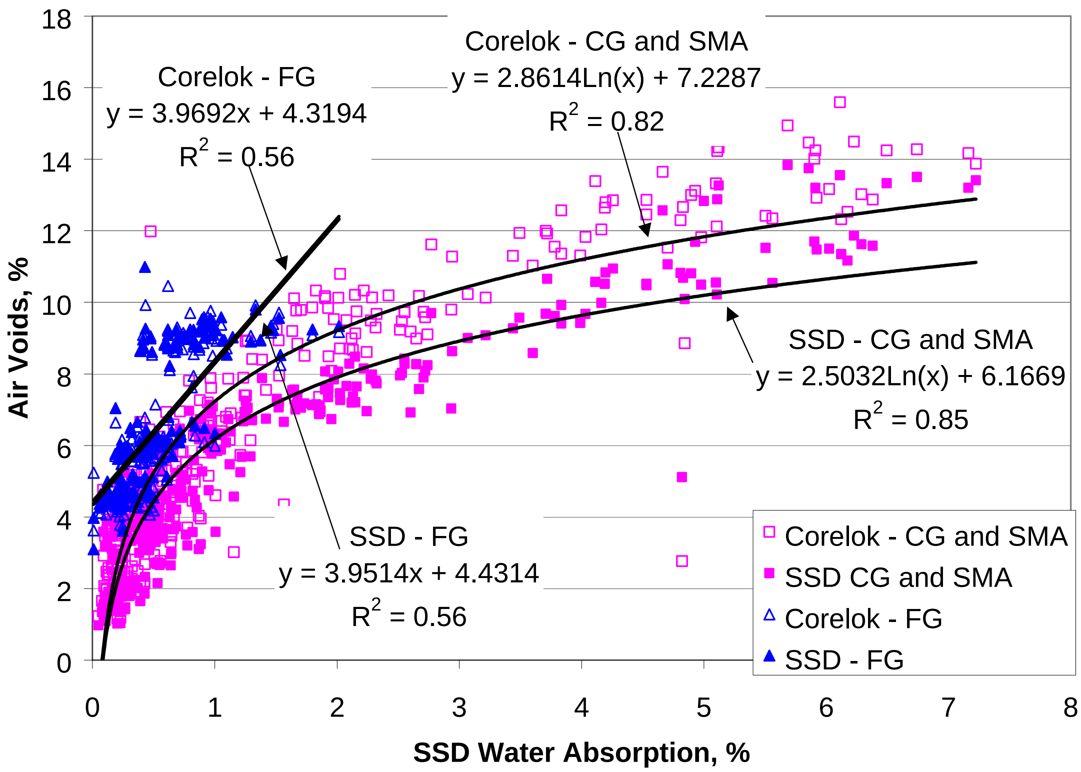

Figure 27. Relationship Between Air Void Content and Water Absorption for All Mixes

The method selected to define the point of divergence was to develop 95 percent confidence intervals for the two BRZ mixture regressions shown in Figure 27. The point at which the confidence intervals no longer overlap would define where the two methods provide significantly different results (when compared against water absorption). Figure 28 presents the 95 percent confidence intervals for the two regressions shown in Figure 27. Based upon Figure 28, the two relationships become significantly different at approximately 0.4 percent water absorption. This suggests that the Corelok procedure should be utilized for lab compacted HMA mixes having BRZ gradations and water absorptions above 0.4 percent. Only 29.3 percent of the BRZ samples (CG and SMA) had less than 0.4% water absorption. Considering the design case (at approximately 4 percent air voids), only 59.2 percent of the CG 100 samples and 25.0 percent the SMA 50 samples had less than 0.4 percent water absorption. The average difference between the measured Corelok and AASHTO T166 air voids (Table 12) is 0.4 and 0.6 percent respectively for the CG 100 and SMA 50 samples. Since the offset between the two methods is a function of the air void level and gradation, it would not be practical to develop a correction factor between the two G_{mb} methods. Since it is expected that even a significant portion of design samples would exceed 0.4 percent water absorption for BRZ mixes (CG and SMA), the

Corelok method should be used to determine G_{mb} for design and quality control gyratory samples having gradations below the restricted zone.

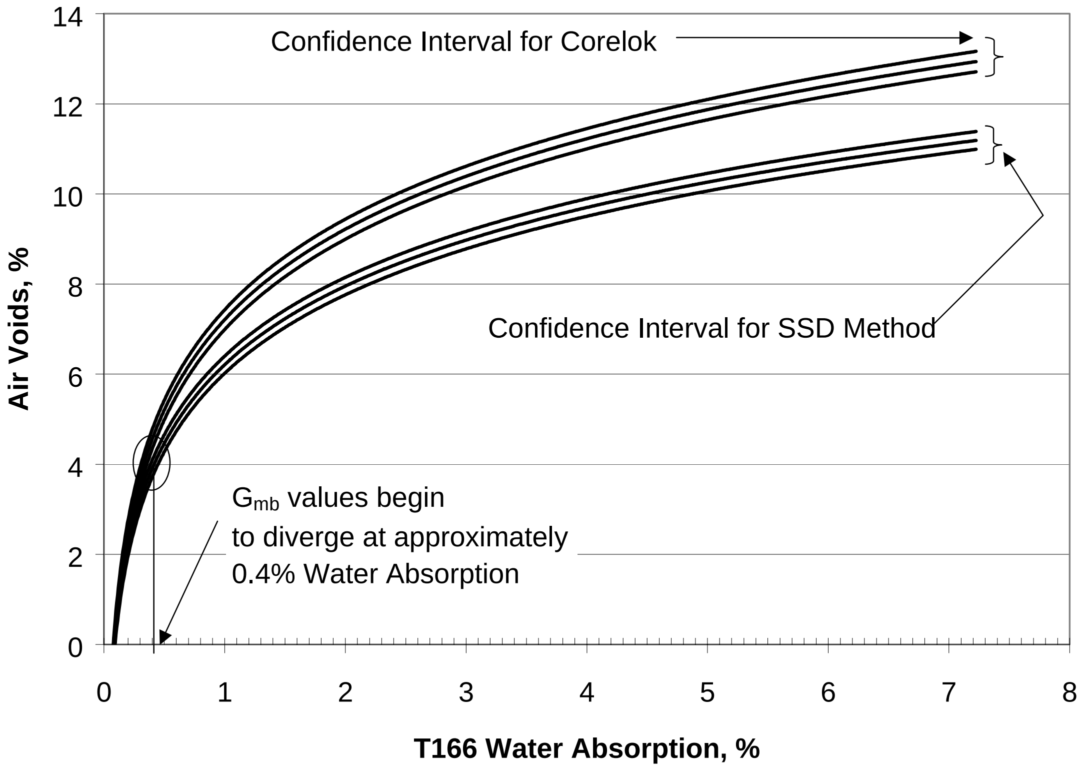

Figure 28. Divergence in Air Voids for the Two Methods

CONCLUSIONS

Analysis of the round robin data indicates that the Corelok procedure is slightly more variable than AASHTO T166. However, the participating laboratories had less experience with the Corelok procedure. An outlier analysis confirms that the laboratories produced more erroneous results (outliers) with the Corelok procedure. Leaks in the plastic bags used to seal the samples may also have caused some of the outliers. When the outlier's were removed from the dataset and the data was corrected for sample production variability, there was not a significant difference between the variability of the Corelok method and AASHTO T166 in six of nine cases. In three cases, AASHTO T166 was less variable. Further, the variability of the Corelok method appears to be less sensitive than AASHTO T166 to changes in air void contents.

The precision estimates for AASHTO T166 based on the difference analysis, including those samples identified as outliers, closely match the existing precision statement for ASTM D 2726. However, both the within-lab d2s from this round-robin (0.031) and ASTM D2726 (0.035) were larger than AASHTO T166 (0.020). The precision statement for the Corelok method based on this study, excluding the data from SMA 50, is as follows:

> The single-operator standard deviation has been found to be 0.0124. Therefore, results of two properly conducted tests by the same operator on the same material should not differ by more than 0.035. The multilaboratory standard deviation has been found to be 0.0135. Therefore results from two properly conducted tests from two different laboratories on samples of the same material should not differ by more than 0.038.

The AASHTO T166 and Corelok results were significantly different for the mixes having gradations passing below the restricted zone. The difference between the AASHTO T166 and Corelok results was not constant and varies with both changes in mix type (gradation) and air void content (gyrations). Comparisons with uncorrected gyratory densities suggest that the Corelok procedure does not overestimate G_{mb} at high air void levels in the same manner that AASHTO T166 does. This suggests that the Corelok procedure is a better measure of sample density, particularly at higher air void contents. Water absorption, as measured by AASHTO T166, was used to combine the effect of gradation and air voids (and the resulting potential for interconnected air voids) on G_{mb} measurement. For BRZ mixes (CG and SMA), comparisons between results of the AASHTO T166 and Corelok methods suggest that G_{mb} measurements diverge whenthe water absorption exceeds 0.4 percent. However, it should also be stated that this conclusion is for laboratory compacted samples only. No inferences are made within this report for roadway core samples.

RECOMMENDATIONS

Based upon the conclusions of this study, it appears that the Corelok procedure is a viable method for determining the bulk specific gravity of compacted hot mix asphalt. At high air void levels, the Corelok procedure provided a more accurate measure of bulk specific gravity, especially for mixes prone to high levels of water absorption (AASHTO T166). For BRZ mixes, it is recommended that the Corelok method be utilized when water absorption values exceed 0.4 percent, by volume. This suggests that the Corelok method will be the method of choice for determining the bulk specific gravity of BRZ mixtures: including design and production gyratory samples as well as field compacted samples (cores). For fine-graded mixtures, AASHTO T166 may be used when water absorption is less than 2.0 percent. This matches current criteria within both ASTM D2726 and AASHTO T166. Coarse- and fine-graded mixtures are defined as those having gradations passing below and above the restricted zone, respectively, as defined in AASHTO PP28-01.

A potential problem exists for defining coarse-and fine-graded mixes based upon the restricted zone. Recently, results of a National Cooperative Highway Research Program study *(12)* suggested that the restricted zone be deleted from AASHTO PP28-01. For this reason, it is recommended that research be conducted to define coarse- and fine-graded mixtures. As it relates to AASHTO T166 and the Corelok methods, this research should be based upon the interconnectivity of air void structures within HMA mixes. Interconnectivity of the air void structure is directly related to the amount of absorbed water within a sample when testing with AASHTO T166 or ASTM D2726.

An analysis of the raw data indicated that the variability (within- and between-lab) of the Corelok method was slightly more than that of AASHTO T166 (in most cases). The slight increase in variability was likely caused by lack of experience with the Corelok method by a number of participating laboratories. However, there were several components of the Corelok test method identified that may reduce the variability of the method. For this reason, these factors need to be evaluated in the form of a ruggedness study. The following factors should be included in a ruggedness study:

- Corelok bag thickness: A number of laboratories indicated that some bags were punctured during Corelok testing.
- Volume of water infiltrating the bag: During the evaluation of the data, a number of laboratories reported data that showed water infiltrating the Corelok bag. This was likely due to small punctures in the bags. A small volume of water infiltrating into the bags likely will not affect the integrity of the test results if taken into account. However, an acceptable volume of water infiltrating the bag is not known.
- Sample temperature: Since producers wish to obtain sample densities as soon as possible, evaluate the maximum temperature (or minimum cooling time) the samples may be tested without affecting the measured G_{mb}.
- Time samples are left sealed prior to testing: Some Corelok users have indicated that the Corelok bags can lose vacuum over time. If the bag loses vacuum, the volume of the samples can be overestimated.

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APPENDIX A

Corelok Test Method Used in Study

Standard Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Automatic Vacuum Sealing Method

1. Scope

1.1 This test method covers the determination of bulk specific gravity of compacted bituminous mixtures as defined in Terminology E12, by the vacuum sealing method.

1.2 This method can be used for with 100 and 150 mm diameter compacted bituminous laboratory and field specimens.

1.3 The bulk specific gravity of the compacted bituminous mixtures may be used in calculating the unit weight of the mixture.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory requirements prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 979 Practice for Sampling Bituminous Paving Mixtures

D 1461 Test Method for Moisture or Volatile Distillates in Bituminous Paving Mixtures

D 2726 Test Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Bituminous Mixtures

D 3203 Test Method for Percent Air Voids in Compacted Dense and Open Bituminous Paving Mixtures

D 4753 Specification for Evaluating, Selecting and Specifying Balances and Scales for Use in Soil, Rock, and Construction Materials Testing

E 12 Terminology Relating to Density and Specific Gravity of Solids, Liquids, and Gases

3. Significance and Use

3.1 The results obtained from this method can be used to determine the unit weight of compacted bituminous mixtures and in conjunction with Test Method D 3203, to obtain percent air voids. These values in turn may be used in determining the relative degree of compaction.

3.2 Since specific gravity has no units, it must be converted to density in order to do calculations that require units. This conversion is made by multiplying the specific gravity at a given temperature by the density of water at the same temperature.

3.3 This method can be used for 100 mm and 150 mm diameter asphalt specimens to correct for absorptive and open graded mixes. Mixes such as Stone Matrix Asphalt (SMA), porous friction course, and Superpave coarse graded mixes with significant surface texture and interconnected voids should be sealed for accurate bulk specific density results.

4. Apparatus

4.1 Balance, with ample capacity, and with sufficient sensitivity to enable bulk specific gravity of specimens to be calculated to at least four significant figures, that is to at least three decimal places. It shall be equipped with a suitable apparatus to permit weighing the specimen while it is suspended in water. The balance shall conform to Specification D 4753 as a class GP2 balance.

Note 1: Since there are no more significant figures in the quotient (bulk specific gravity) than appear in either the dividend (the mass of the specimen in air) or in the divisor (the volume of the specimen, obtained from the difference in mass of the specimen in air and in water), this means that the balance must have a sensitivity capable of providing both mass and volume values to at least four figures. For example, a sensitivity of 0.1 g would provide four significant figures for the determination of a mass in the range from 130.0 to 999.9 g when the specific gravity is 2.300.

4.2 Water bath with minimum dimensions (Length x Width x Depth) of 610 x 460 x 460 mm (24 x 18 x 18 in.), for completely submerging the specimen in water while suspended, equipped with an overflow outlet for maintaining a constant water level.

Note 2: It is preferable to keep the water temperature constant by using a temperature controlled heater.

4.3 Vacuum chamber, with a 0.93 kW (1.25 hp) pump capable of evacuating a sealed and enclosed chamber to 100 kPa vacuum (29.5 in. Hg vacuum) in less than 60 s, when at sea level. The chamber shall be capable of sealing 100 and 150 mm cores up to 150 mm in thickness. The device shall automatically seal the plastic bag and exhaust air back into the chamber in a controlled manner to ensure proper conformance of the plastic to the asphalt specimen. The air exhaust and vacuum operation time should be calibrated at the factory prior to initial use. The air exhaust system should be calibrated to bring the chamber to atmospheric pressure in 80 to 95 s, after the completion of the vacuum operation. The vacuum system should be provided with a latch to control the chamber door opening.

4.4 An absolute vacuum measurement gauge independent of the vacuum sealing device that could be placed directly inside the chamber to verify vacuum performance and the chamber door sealing condition of the unit. The vacuum gauge shall be capable of reading to 3 TORR (29.8 in. Hg) of vacuum.

4.5 Plastic bags used with the vacuum device shall be one of the two following sizes. The smaller bags shall have a minimum opening of 235 mm (9.25 in.) and maximum opening of 260 mm (10.25 in.) and the larger bags shall have a minimum of 375 mm (14.75 in.) and a maximum opening of 394 mm (15.5 in.). The bags shall be of plastic material that will not adhere to asphalt film, is puncture resistant, capable of withstanding sample temperatures of up to 70°C, is impermeable to water, containing no air channels for evacuation of air from the bag. The apparent specific gravity for the bags shall be provided by the manufacturer for each shipment.

4.6 Holder for water displacement of the sample having no sharp edges.

Note 3: To avoid accidental puncture of the plastic bags in the water bath, plastic coated holders have been found to work well for this test method.

4.7 Specimen sliding plate used within the chamber for reduction of friction on the plastic bags.

4.8 Bag cutting knife or scissors.

4.9 A 150 mm (6 in) diameter by 75 mm (3 in) granite or marble standard cylinder for verification of bag apparent density. This standard cylinder shall have a water absorption of 0.20 to 0.80% by weight.

5. Sampling

5.1 Test specimens may be molded from laboratory prepared samples or taken from bituminous pavement in the field. Field samples should be obtained in accordance with Practice D 979.

6. Test Specimens — It is recommended, (1) that the diameter of cylindrically molded or cored specimens, or the length of the sides of sawed specimens be at least equal to four times the maximum size of the aggregate; and (2) that the thickness of specimens be at least one and one half times the maximum size of the aggregate. Pavement specimens are to be taken by such means as coring, sawing of blocks, and so forth.

6.1 Take care to avoid distortion, bending, or cracking of specimens during and after removal from pavement or mold. Store specimens in a safe, cool place.

6.2 Specimens shall be free of foreign materials, such as sealcoat, tack coat, foundation material, soil, paper, or foil. When any of these materials are visually evident, they shall be removed. Sealcoat and/or tackcoat may be removed by sawing the bottom and/or the top faces of the sample.

6.3 If desired, specimens may be separated from other pavement layers by sawing or other suitable means.

7. Procedure — This procedure can be used for compacted field and laboratory specimens. Specifically, use this procedure, if the mix is absorptive as determined by Test Method D 2726 or if the mix is classified as an open graded mixture by the local mixture specifications. Follow the procedure outlined in this section for determination of bulk specific gravity.

7.1 Cool the specimen to 46°C (115°F) or less.

7.2 Mass of Unsealed Specimens — After the sample has been dried to a constant mass, determine the mass of the specimen. Designate this as mass A. Constant mass is defined as less than 0.05% change in mass between consecutive 15 minute drying intervals.

7.3 Mass of Sealed Specimen

7.3.1 Select an appropriate size bag. For all 100 mm (4 in) diameter samples and samples with 150 mm (6 in) diameter and less than 50 mm (2 in) thickness, it is possible to use the bag with smaller opening size as specified in 4.5. For 150 mm (6 in) samples with greater than 50 mm (2 in) thickness, use the larger opening size bags as specified in 4.5. For samples that weigh more than 5500 g or abnormally shaped samples, use manufacturer's recommendation for appropriate bag size and configuration.

7.3.2 Place a bag inside the vacuum chamber on top of the sliding plate.

7.3.3 Gently open the bag and place the specimen in the plastic bag on top of the sliding plate, being careful not to handle the bag in such a manner that would create a puncture. Follow manufacturer's recommendations for handling the specimens and the bags.

7.3.4 Allow the vacuum chamber to remove the air from the chamber and the plastic bag. The vacuum chamber shall automatically seal the bag once the air is removed.
7.3.5 Exhaust air into the chamber until the chamber door opens indicating atmospheric pressure within the chamber. The chamber door latch can be used to avoid automatic opening of the door after completion of the test.
7.3.6 Remove the sealed sample from the vacuum chamber. Handle the sealed sample with extreme care.
7.3.7 Determine the mass of the sealed specimen in air. Designate this mass as B.
7.3.8 Determine the mass of the sealed specimen in a water bath at 25°C (77°F). Designate this mass as E. Measure the temperature of the water and if it is different from 25°C ± 1°C (77°F ± 1.8°F), a correction to the bulk specific gravity to 25°C must be made in accordance with 8.3. If the temperature of the specimen differs from the temperature of the water bath by more than 2°C (3.6°F), the specimen shall be immersed in the water bath for 10 to 15 min.

8. **Calculations**

8.1 Calculate the bulk specific gravity of the sealed specimen as follows:

$$Bulk\ Specific\ Gravity = \frac{A}{B - E - \dfrac{B - A}{F_T}}$$

Where:
A = mass of dry specimen in air, g,
B = mass of dry, sealed specimen, g,
E = mass of sealed specimen underwater, g, and
F_T = apparent specific gravity of plastic sealing material at 25°C (77°F).

8.2 Calculate the density of the specimen as follows:

$$Density = (Bulk\ Specific\ Gravity)\ \gamma$$

Where:
g = density of water at 25°C (77°F) (997.0 kg/m^3, 0.997 g/cm^3 or 62.4 lb/ft^3).

8.3 Correction for Water Bath Temperature Other Than 25°C (77°F):

8.3.1 For a difference of water temperature less than or equal to 3°C (5.4°F), determine the specific gravity as follows:

Bulk Specific Gravity at 25 ℃ = K (Bulk at other temperature)

Where:

K = determined from Table 1.

Table A-1: Relative Density of Water and Conversion Factor K for Various Temperatures

Temperature °C	Absolute Density of Water[A]	Correction Factor K
10	0.999728	1.002661
11	0.999634	1.002567
12	0.999526	1.002458
13	0.999406	1.002338
14	0.999273	1.002204
15	0.999129	1.002060
16	0.998972	1.001903
17	0.998804	1.001734
18	0.998625	1.001555
19	0.998435	1.001364
20	0.998234	1.001162
21	0.998022	1.000950
22	0.997801	1.000728
23	0.997569	1.000495
24	0.997327	1.000253
25	0.997075	1.000000
26	0.996814	0.999738
27	0.996544	0.999467
28	0.996264	0.999187
29	0.995976	0.998898
30	0.995678	0.998599

[A] Data taken from Handbook of Chemistry and Physics, 55th ed., CRC Press, Inc.

8.3.2 For a difference of water temperature greater than 3°C (5.4°F), determine the correction based on the following equation:

$$Correction = \Delta T \; K_s \left(B - E - \frac{B - A}{F_T} \right)$$

Where:

ΔT = 25°C minus the temperature of the water bath,
K_s = 63 x 10^{-5} ml/ml/°C average coefficient of cubical thermal expansion of bituminous concrete, and
$(B-E-(B-A)/F_T)$ = mass of the volume of water for the volume of the specimen at 25°C.

8.3.3 The mass of displaced water can be corrected for water temperatures difference greater than 3°C (5.4°F), by the following equation:

$$Bulk\ Specific\ Gravity = \frac{A}{B - E - \dfrac{B - E}{FT} + Correction}$$

8.3.4 The bulk specific gravity calculated in section 8.3.3 can be adjusted by the correction factor, K, to obtain the bulk specific gravity at 25°C as described in section 9.3.

9. Verification

9.1 System Verification:

9.1.1 The vacuum settings of the device should be verified once every three months, after major repairs, after each shipment or relocation.

9.1.2 Verification should be performed with an absolute vacuum gauge capable of being placed inside the chamber and reading the vacuum setting of the sealing device.

9.1.3 Place the gauge inside the chamber and record the setting. The gauge should indicate a reading of 10 TORR (29.5 in. Hg) or less. The unit should not be used if the gauge reading is above 10 TORR.

9.1.4 Vacuum gauge used for verification shall be calibrated or verified for accuracy once every three years.

Note 4: On line vacuum gauges, while capable of indicating vacuum performance of the pump, are not suitable for use in enclosed vacuum chambers and can not accurately measure vacuum levels.

9.2 Plastic Bag Verification

9.2.1 The plastic bag apparent specific gravity provided by the manufacturer shall be verified for each shipment.

9.2.2 Use a standard granite cylinder as specified in 4.10 to verify the bags.

9.2.3 Take 3 bags from each size and use the procedure in section 7 to measure the density of the granite cylinder for each individual bag.

9.2.4 Average the three granite densities obtained for each bag.

9.2.5 The average bulk specific gravity calculated for the granite cylinder shall be within ± 0.010 g/cm^3 of the density provided by the manufacturer for the granite cylinder or as determined by ASTM 2726.

9.2.6 Repeat this section for each bag size.

10. Report

10.1 Report the following information:

10.1.1 Apparent specific gravity of plastic bag to three decimal places.

10.1.2 Bulk specific gravity at 25°C ± 1°C (77°C ± 1.8°F) to four significant figures.

10.1.3 Density to four significant figures.

11. Precision and Bias

11.1 The precision of the procedure in this method for measuring bulk specific gravity and density of the compacted bituminous mixture is being determined and will be available on or before June 2005. It is not feasible to specify precision of this procedure at this time because sufficient data is not available.

11.2 Since there is no accepted reference material suitable for determining the bias for the procedure for measuring density, no statement on the bias of this test method is being made.

12. Keywords

12.1 Bituminous paving mixtures — compacted; bulk specific gravity; density

APPENDIX B

AASHTO T166 Data

T166 Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL A (CG15)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.274	2.184	2.191	2.216333	0.050	0.002506	-0.41	1.49
2	2.216	2.222	2.226	2.221333	0.005	0.000025	-0.18	0.15
3	2.270	2.256	2.266	2.264000	0.007	0.000052	1.77	0.22
4	2.235	2.257	2.183	2.225000	0.038	0.001444	-0.01	1.13
5	2.232	2.174	2.159	2.188333	0.039	0.001486	-1.69	1.15
6	2.263	2.238	2.166	2.222333	0.050	0.002536	-0.13	1.50
7	2.235	2.243	2.241	2.239667	0.004	0.000017	0.66	0.12
8	2.239	2.278	2.161	2.226000	0.060	0.003549	0.03	1.78
9	2.265	2.242	2.175	2.227333	0.047	0.002186	0.10	1.39
10	2.299	2.270	2.264	2.277667	0.019	0.000350	2.40	0.56
11	2.213	2.217	2.229	2.219667	0.008	0.000069	-0.26	0.25
12	2.242	2.250	2.175	2.222333	0.041	0.001696	-0.13	1.23
13	2.243	2.242	2.209	2.231333	0.019	0.000374	0.28	0.58
14	2.170	2.215	2.168	2.184333	0.027	0.000706	-1.87	0.79
15	2.172	2.243	2.218	2.211000	0.036	0.001297	-0.65	1.07
16	2.184	2.216	2.253	2.217667	0.035	0.001192	-0.35	1.03
20	2.213	2.235	2.218	2.222000	0.012	0.000133	-0.15	0.34
21	2.237	2.214	2.263	2.238000	0.025	0.000601	0.58	0.73

Average of all Labs	2.225	
Std. Dev. Between Cell Averages (S_x)	0.021845	
Repeatability Standard Deviation (S_r)	0.033519	
Reproducibility Standard Deviation (S_R)	0.035017	
Between Lab Standard Deviation of Lab Means(S_L)	0.010135	
Pooled within lab variance (S_A^2)	0.001124	(Components of variance) W/L
Between Lab Variance of Lab Means(S_L^2)	0.000103	(Components of variance) B/L
W/L Variance	0.001124	
B/L Variance	0.001226	

T166 Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	LAB	MATERIAL B (CG50)						
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.376	2.334	2.365	2.358333	0.022	0.000474	0.51	1.01
2	2.334	2.416	2.349	2.366333	0.044	0.001906	1.12	2.03
3	2.349	2.375	2.331	2.351667	0.022	0.000489	-0.01	1.03
4	2.332	2.353	2.337	2.340667	0.011	0.000120	-0.86	0.51
5	2.326	2.380	2.344	2.350000	0.027	0.000756	-0.14	1.28
6	2.331	2.392	2.347	2.356667	0.032	0.001000	0.38	1.47
7	2.352	2.327	2.331	2.336667	0.013	0.000180	-0.17	0.63
8	2.308	2.360	2.298	2.322000	0.033	0.001108	-0.23	1.55
9	2.328	2.359	2.392	2.359667	0.032	0.001024	0.61	1.49
10	2.369	2.358	2.361	2.362667	0.006	0.000032	0.84	0.26
11	2.350	2.346	2.345	2.347000	0.003	0.000007	-0.37	0.12
12	2.374	2.375	2.363	2.370667	0.007	0.000044	1.46	0.31
13	2.356	2.319	2.337	2.337333	0.019	0.000342	-1.12	0.86
14	2.347	2.380	2.366	2.364333	0.017	0.000274	0.97	0.77
15	2.359	2.346	2.330	2.345000	0.015	0.000211	-0.53	0.68
16	2.332	2.344	2.343	2.339667	0.007	0.000044	-0.94	0.31
20	2.375	2.353	2.362	2.363333	0.011	0.000122	0.89	0.51
21	2.375	2.355	2.351	2.360333	0.013	0.000165	0.66	0.60

Average of all Labs	2.352
Std. Dev. Between Cell Averages (S_x)	0.012940
Repeatability Standard Deviation (S_r)	0.021477
Reproducibility Standard Deviation (S_R)	0.021793
Between Lab Standard Deviation of Lab Means(S_L)	0.003700
Pooled within lab variance (S_A^2)	0.000461
Between Lab Variance of Lab Means(S_L^2)	0.000014
W/L Variance	0.000461
B/L Variance	0.000475

T166 Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	LAB	MATERIAL C (CG100)						
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.432	2.410	2.387	2.409667	0.023	0.000506	0.82	1.35
2	2.406	2.414	2.404	2.408000	0.005	0.000028	0.64	0.32
3	2.420	2.427	2.409	2.418667	0.009	0.000082	1.78	0.55
4	2.417	2.355	2.392	2.388000	0.031	0.000973	-1.51	1.87
5	2.406	2.413	2.388	2.402333	0.013	0.000166	0.03	0.77
6	2.407	2.409	2.390	2.402000	0.010	0.000109	-0.01	0.63
7	2.422	2.391	2.407	2.406667	0.016	0.000240	0.49	0.93
8	2.428	2.373	2.419	2.406667	0.030	0.000870	0.49	1.77
9	2.389	2.389	2.416	2.398000	0.016	0.000243	-0.43	0.94
10	2.413	2.413	2.414	2.413333	0.001	0.000000	1.21	0.03
11	2.408	2.386	2.401	2.398333	0.011	0.000126	-0.40	0.68
12	2.400	2.394	2.423	2.405667	0.015	0.000234	0.39	0.92
13	2.407	2.394	2.406	2.402333	0.007	0.000052	0.03	0.43
14	2.360	2.393	2.399	2.384000	0.021	0.000441	-1.93	1.26
15	2.421	2.399	2.392	2.404000	0.015	0.000229	0.21	0.91
16	2.396	2.372	2.381	2.383000	0.012	0.000147	-2.04	0.73
20	2.408	2.414	2.382	2.401333	0.017	0.000289	-0.08	1.02
21	2.423	2.394	2.398	2.405000	0.016	0.000247	0.32	0.94

Average of all Labs	2.402
Std. Dev. Between Cell Averages (S_x)	0.009337
Repeatability Standard Deviation (S_r)	0.016642
Reproducibility Standard Deviation (S_R)	0.016642
Between Lab Standard Deviation of Lab Means(S_L)	0.000000
Pooled within lab variance (S_A^2)	0.000277
Between Lab Variance of Lab Means(S_L^2)	0.000000
W/L Variance	0.000277
B/L Variance	0.000277

T166 Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	LAB	MATERIAL						
		D (FG15)						
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.285	2.291	2.289	2.288333	0.003	0.000009	1.22	0.41
2	2.296	2.278	2.276	2.283333	0.011	0.000121	0.32	1.48
3	2.285	2.289	2.293	2.289000	0.004	0.000016	1.34	0.54
4	2.288	2.291	2.264	2.281000	0.015	0.000219	-0.11	1.99
5	2.290	2.294	2.271	2.285000	0.012	0.000151	0.62	1.65
6	2.280	2.283	2.275	2.279333	0.004	0.000016	-0.41	0.54
7	2.291	2.284	2.279	2.284667	0.006	0.000036	0.56	0.81
8	2.277	2.269	2.272	2.272667	0.004	0.000016	-1.62	0.54
9	2.278	2.282	2.283	2.281000	0.003	0.000007	-0.11	0.35
10	2.270	2.276	2.279	2.275000	0.005	0.000021	-1.20	0.61
11	2.285	2.276	2.279	2.280000	0.005	0.000021	-0.29	0.61
12	2.296	2.287	2.278	2.287000	0.009	0.000081	0.98	1.21
13	2.283	2.282	2.286	2.283667	0.002	0.000004	0.38	0.28
14	2.285	2.283	2.303	2.290333	0.011	0.000121	1.59	1.48
15	2.286	2.279	2.284	2.283000	0.004	0.000013	0.26	0.48
16	2.278	2.270	2.268	2.272000	0.005	0.000028	-1.74	0.71
20	2.276	2.290	2.270	2.278667	0.010	0.000105	-0.53	1.38
21	2.275	2.271	2.278	2.274667	0.004	0.000012	-1.26	0.47

Average of all Labs	2.282
Std. Dev. Between Cell Averages (S_x)	0.005511
Repeatability Standard Deviation (S_r)	0.007454
Reproducibility Standard Deviation (S_R)	0.008210
Between Lab Standard Deviation of Lab Means(S_L)	0.003443
Pooled within lab variance (S_A^2)	0.000056
Between Lab Variance of Lab Means(S_L^2)	0.000012
W/L Variance	0.000056
B/L Variance	0.000067

T166 Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	LAB	MATERIAL E (FG50)						
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.367	2.363	2.367	2.365667	0.002	0.000005	0.87	0.13
2	2.351	2.369	2.347	2.355667	0.012	0.000137	0.06	0.68
3	2.365	2.363	2.362	2.363333	0.002	0.000002	0.68	0.09
4	2.365	2.366	2.362	2.364333	0.002	0.000004	0.76	0.12
5	2.343	2.346	2.368	2.352333	0.014	0.000186	-0.21	0.79
6	2.353	2.365	2.358	2.358667	0.006	0.000036	0.30	0.35
7	2.347	2.365	2.365	2.359000	0.010	0.000108	0.33	0.60
8	2.350	2.350	2.360	2.353333	0.006	0.000033	-0.13	0.33
9	2.369	2.362	2.363	2.364667	0.004	0.000014	0.79	0.22
10	2.363	2.365	2.358	2.362000	0.004	0.000013	0.57	0.21
11	2.359	2.360	2.343	2.354000	0.010	0.000091	-0.07	0.55
12	2.358	2.357	2.367	2.360667	0.006	0.000030	0.46	0.32
13	2.356	2.339	2.357	2.350667	0.010	0.000102	-0.34	0.59
14	2.352	2.366	2.349	2.355667	0.009	0.000082	0.06	0.53
15	2.353	2.360	2.349	2.354000	0.006	0.000031	-0.07	0.32
16	2.340	2.344	2.347	2.343667	0.004	0.000012	-0.91	0.20
20	2.359	2.365	2.356	2.360000	0.005	0.000021	0.41	0.27
21	2.234	2.348	2.351	2.311000	0.067	0.004449	-3.56	3.87

Average of all Labs	2.355
Std. Dev. Between Cell Averages (S_x)	0.012356
Repeatability Standard Deviation (S_r)	0.017256
Reproducibility Standard Deviation (S_R)	0.018740
Between Lab Standard Deviation of Lab Means(S_L)	0.007308
Pooled within lab variance (S_A^2)	0.000298
Between Lab Variance of Lab Means(S_L^2)	0.000053
W/L Variance	0.000298
B/L Variance	0.000351

T166 Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	LAB	MATERIAL F (FG100)						
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.397	2.401	2.402	2.400000	0.003	0.000007	0.94	0.22
2	2.393	2.396	2.396	2.395000	0.002	0.000003	0.32	0.14
3	2.396	2.392	2.400	2.396000	0.004	0.000016	0.45	0.33
4	2.390	2.410	2.395	2.398333	0.010	0.000108	0.73	0.87
5	2.395	2.384	2.400	2.393000	0.008	0.000067	0.08	0.68
6	2.319	2.404	2.392	2.371667	0.046	0.002116	2.09	1.71
7	2.394	2.401	2.402	2.399000	0.004	0.000019	0.81	0.36
8	2.385	2.385	2.384	2.384667	0.001	0.000000	-0.95	0.05
9	2.393	2.398	2.381	2.390667	0.009	0.000076	-0.21	0.73
10	2.395	2.395	2.381	2.390333	0.008	0.000065	-0.25	0.68
11	2.385	2.388	2.382	2.385000	0.003	0.000009	-0.91	0.25
12	2.399	2.395	2.388	2.394000	0.006	0.000031	0.20	0.47
13	2.395	2.419	2.386	2.400000	0.017	0.000291	0.94	1.43
14	2.403	2.333	2.385	2.373667	0.036	0.001321	-2.31	3.04
15	2.391	2.396	2.400	2.395667	0.005	0.000020	0.40	0.38
16	2.388	2.377	2.391	2.385333	0.007	0.000054	-0.87	0.62
20	2.380	2.384	2.388	2.384000	0.004	0.000016	-1.03	0.33
21	2.381	2.395	2.391	2.389000	0.007	0.000052	-0.42	0.60

Average of all Labs	2.390
Std. Dev. Between Cell Averages (S_x)	0.008341
Repeatability Standard Deviation (S_r)	0.015409
Reproducibility Standard Deviation (S_R)	0.015409
Between Lab Standard Deviation of Lab Means(S_L)	0.000000
Pooled within lab variance (S_A^2)	0.000237
Between Lab Variance of Lab Means(S_L^2)	0.000000
W/L Variance	0.000237
B/L Variance	0.000237

T166 Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	LAB	MATERIAL G (SMA15)						
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.284	2.290	2.299	2.291000	0.008	0.000057	0.80	0.37
2	2.298	2.253	2.260	2.270333	0.024	0.000586	-0.28	1.19
3	2.283	2.278	2.288	2.283000	0.005	0.000025	0.38	0.25
4	2.278	2.285	2.285	2.282667	0.004	0.000016	0.37	0.20
5	2.298	2.251	2.255	2.268000	0.026	0.000679	-0.40	1.28
6	2.286	2.277	2.273	2.278667	0.007	0.000044	0.16	0.33
7	2.300	2.288	2.278	2.288667	0.011	0.000121	0.68	0.54
8	2.300	2.269	2.271	2.280000	0.017	0.000301	0.23	0.85
9	2.265	2.290	2.288	2.281000	0.014	0.000193	0.28	0.68
10	2.389	2.275	2.287	2.317000	0.063	0.003924	2.16	3.08
11	2.277	2.261	2.242	2.260000	0.018	0.000307	-0.82	0.86
12	2.291	2.293	2.293	2.292333	0.001	0.000001	0.87	0.06
13	2.290	2.287	2.265	2.280667	0.014	0.000186	0.26	0.67
14	2.266	2.265	2.282	2.271000	0.010	0.000091	-0.24	0.47
15	2.270	2.268	2.272	2.270000	0.002	0.000004	-0.29	0.10
16	2.230	2.213	2.239	2.227333	0.013	0.000174	-2.52	0.65
20	2.283	2.267	2.276	2.275333	0.008	0.000064	-0.02	0.39
21	2.215	2.263	2.256	2.244667	0.026	0.000672	-1.61	1.27

Average of all Labs	2.276
Std. Dev. Between Cell Averages (S_x)	0.019187
Repeatability Standard Deviation (S_r)	0.020342
Reproducibility Standard Deviation (S_R)	0.025377
Between Lab Standard Deviation of Lab Means(S_L)	0.015172
Pooled within lab variance (S_A^2)	0.000414
Between Lab Variance of Lab Means(S_L^2)	0.000230
W/L Variance	0.000414
B/L Variance	0.000644

T166 Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	LAB	MATERIAL						
		H (SMA50)						
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.410	2.373	2.384	2.389000	0.019	0.000361	1.01	1.08
2	2.399	2.384	2.366	2.383000	0.017	0.000273	0.60	0.94
3	2.394	2.379	2.372	2.381667	0.011	0.000126	0.51	0.64
4	2.353	2.380	2.351	2.361333	0.016	0.000262	-0.86	0.92
5	2.368	2.393	2.386	2.382333	0.013	0.000166	0.56	0.73
6	2.383	2.374	2.338	2.365000	0.024	0.000567	-0.61	1.35
7	2.360	2.361	2.382	2.367667	0.012	0.000154	-0.43	0.71
8	2.357	2.382	2.351	2.363333	0.016	0.000270	-0.73	0.93
9	2.393	2.385	2.364	2.380667	0.015	0.000224	0.45	0.85
10	2.388	2.359	2.383	2.376667	0.016	0.000240	0.18	0.88
11	2.277	2.385	2.391	2.351000	0.064	0.004116	0.04	1.32
12	2.376	2.387	2.398	2.387000	0.011	0.000121	0.87	0.63
13	2.390	2.384	2.378	2.384000	0.006	0.000036	0.67	0.34
14	2.374	2.419	2.380	2.391000	0.024	0.000597	1.14	1.39
15	2.397	2.390	2.376	2.387667	0.011	0.000114	0.92	0.61
16	2.326	2.342	2.369	2.345667	0.022	0.000472	-1.92	1.24
20	2.338	2.352	2.324	2.338000	0.014	0.000196	-2.44	0.80
21	2.347	2.372	2.405	2.374667	0.029	0.000846	0.04	1.65

Average of all Labs	2.373
Std. Dev. Between Cell Averages (S_x)	0.015767
Repeatability Standard Deviation (S_r)	0.022539
Reproducibility Standard Deviation (S_R)	0.024234
Between Lab Standard Deviation of Lab Means(S_L)	0.008904
Pooled within lab variance (S_A^2)	0.000508
Between Lab Variance of Lab Means(S_L^2)	0.000079
W/L Variance	0.000508
B/L Variance	0.000587

T166 Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	LAB	MATERIAL							
		I (SMA100)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k	
1	2.427	2.424	2.418	2.423000	0.005	0.000021	0.44	0.43	1
2	2.418	2.420	2.420	2.419333	0.001	0.000001	0.03	0.11	
3	2.431	2.436	2.440	2.435667	0.005	0.000020	1.86	0.42	
4	2.423	2.428	2.421	2.424000	0.004	0.000013	0.55	0.34	
5	2.415	2.409	2.418	2.414000	0.005	0.000021	-0.57	0.43	
6	2.415	2.411	2.411	2.412333	0.002	0.000005	-0.76	0.22	
7	2.429	2.416	2.417	2.420667	0.007	0.000052	0.18	0.67	
8	2.430	2.421	2.415	2.422000	0.008	0.000057	0.33	0.70	
9	2.426	2.380	2.420	2.408667	0.025	0.000625	-1.17	2.33	
10	2.429	2.425	2.431	2.428333	0.003	0.000009	1.04	0.28	
11	2.438	2.397	2.418	2.417667	0.021	0.000420	-0.16	1.91	
12	2.439	2.411	2.423	2.424333	0.014	0.000197	0.59	1.31	
13	2.434	2.414	2.421	2.423000	0.010	0.000103	0.44	0.95	
14	2.430	2.424	2.420	2.424667	0.005	0.000025	0.63	0.47	
15	2.414	2.428	2.407	2.416333	0.011	0.000114	-0.31	1.00	
16	2.376	2.399	2.406	2.393667	0.016	0.000246	-2.85	1.46	
20	2.412	2.416	2.414	2.414000	0.002	0.000004	-0.57	0.19	
21	2.417	2.413	2.435	2.421667	0.012	0.000137	0.29	1.09	

Average of all Labs	2.419
Std. Dev. Between Cell Averages (S_x)	0.008922
Repeatability Standard Deviation (S_r)	0.010734
Reproducibility Standard Deviation (S_R)	0.012507
Between Lab Standard Deviation of Lab Means(S_L)	0.006418
Pooled within lab variance (S_A^2)	0.000115
Between Lab Variance of Lab Means(S_L^2)	0.000041
W/L Variance	0.000115
B/L Variance	0.000156

APPENDIX C

Corelok Data

CORELOK Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB		MATERIAL A (CG15)						
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.223	2.133	2.164	2.173333	0.046	0.002090	-0.55	1.46
2	2.183	2.197	2.192	2.190667	0.007	0.000050	0.16	0.23
3	2.191	2.204	2.207	2.200667	0.009	0.000072	0.57	0.27
4	2.180	2.221	2.149	2.183333	0.036	0.001304	-0.14	1.15
5	2.184	2.147	2.132	2.154333	0.027	0.000716	-1.33	0.85
6	2.205	2.189	2.115	2.169667	0.048	0.002305	-0.71	1.53
7	2.185	2.189	2.171	2.181667	0.009	0.000089	-0.21	0.30
8	2.207	2.252	2.144	2.201000	0.054	0.002943	0.58	1.73
9	2.216	2.194	2.149	2.186333	0.034	0.001166	-0.02	1.09
10	2.281	2.223	2.210	2.238000	0.038	0.001429	2.10	1.20
11	2.177	2.195	2.217	2.196333	0.020	0.000401	0.39	0.64
12	2.197	2.202	2.151	2.183333	0.028	0.000790	-0.14	0.90
13	2.143	2.184	2.172	2.166333	0.021	0.000444	-0.84	0.67
14	2.180	2.158	2.148	2.162000	0.016	0.000268	-1.02	0.52
15	2.210	2.182	2.149	2.180333	0.031	0.000932	-0.27	0.97
16	2.207	2.152	2.151	2.170000	0.032	0.001027	-0.69	1.02
20	2.155	2.198	2.176	2.176333	0.022	0.000462	-0.43	0.69
21	2.285	2.248	2.215	2.249333	0.035	0.001226	2.57	1.12

Average of all Labs	2.187	
Std. Dev. Between Cell Averages (S_x)	0.024349	
Repeatability Standard Deviation (S_r)	0.031375	
Reproducibility Standard Deviation (S_R)	0.035343	
Between Lab Standard Deviation of Lab Means(S_L)	0.016271	
Pooled within lab variance (S_A^2)	0.000984	(Components of variance) W/L
Between Lab Variance of Lab Means(S_L^2)	0.000265	(Components of variance) B/L
W/L Variance	0.000984	
B/L Variance	0.001249	

CORELOK Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	LAB	MATERIAL B (CG50)						
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.360	2.417	2.358	2.378333	0.034	0.001122	1.85	1.41
2	2.322	2.411	2.348	2.360333	0.046	0.002094	1.00	1.92
3	2.326	2.361	2.310	2.332333	0.026	0.000680	-0.31	1.09
4	2.324	2.320	2.328	2.324000	0.004	0.000016	-0.70	0.17
5	2.307	2.373	2.332	2.337333	0.033	0.001110	-0.08	1.40
6	2.321	2.388	2.339	2.349333	0.035	0.001202	0.49	1.46
7	2.332	2.309	2.315	2.318667	0.012	0.000142	-0.95	0.50
8	2.296	2.349	2.288	2.311000	0.033	0.001099	-1.31	1.39
9	2.332	2.338	2.377	2.349000	0.024	0.000597	0.47	1.03
10	2.347	2.352	2.342	2.347000	0.005	0.000025	0.38	0.21
11	2.342	2.333	2.340	2.338333	0.005	0.000022	-0.03	0.20
12	2.361	2.362	2.352	2.358333	0.006	0.000030	0.91	0.23
13	2.288	2.341	2.317	2.315333	0.027	0.000704	-1.11	1.11
14	2.349	2.373	2.339	2.353667	0.017	0.000305	0.69	0.73
15	2.323	2.353	2.340	2.338667	0.015	0.000226	-0.01	0.63
16	2.302	2.260	2.305	2.289000	0.025	0.000633	-2.34	1.06
20	2.351	2.336	2.344	2.343667	0.008	0.000056	0.22	0.32
21	2.370	2.355	2.346	2.357000	0.012	0.000147	0.85	0.51

Average of all Labs	2.339
Std. Dev. Between Cell Averages (S_x)	0.021335
Repeatability Standard Deviation (S_r)	0.023821
Reproducibility Standard Deviation (S_R)	0.028870
Between Lab Standard Deviation of Lab Means(S_L)	0.016310
Pooled within lab variance (S_A^2)	0.000567
Between Lab Variance of Lab Means(S_L^2)	0.000266
W/L Variance	0.000567
B/L Variance	0.000833

CORELOK Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	LAB	MATERIAL C (CG100)						
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.422	2.391	2.376	2.396333	0.023	0.000550	0.39	1.12
2	2.396	2.406	2.398	2.400000	0.005	0.000028	0.64	0.25
3	2.410	2.419	2.400	2.409667	0.010	0.000090	1.32	0.45
4	2.411	2.330	2.383	2.374667	0.041	0.001692	-1.14	1.96
5	2.399	2.408	2.374	2.393667	0.018	0.000310	0.20	0.84
6	2.405	2.407	2.389	2.400333	0.010	0.000097	0.67	0.47
7	2.415	2.396	2.387	2.399333	0.014	0.000204	0.60	0.68
8	2.441	2.367	2.416	2.408000	0.038	0.001417	1.21	1.79
9	2.387	2.377	2.391	2.385000	0.007	0.000052	-0.41	0.34
10	2.339	2.404	2.405	2.382667	0.038	0.001430	-0.57	1.80
11	2.399	2.389	2.394	2.394000	0.005	0.000025	0.22	0.24
12	2.384	2.381	2.410	2.391667	0.016	0.000254	0.06	0.76
13	2.379	2.387	2.399	2.388333	0.010	0.000101	-0.18	0.48
14	2.391	2.348	2.385	2.374667	0.023	0.000542	-1.14	1.11
15	2.396	2.419	2.389	2.401333	0.016	0.000246	0.74	0.75
16	2.362	2.346	2.340	2.349333	0.011	0.000129	-2.92	0.54
20	2.403	2.406	2.360	2.389667	0.026	0.000662	-0.08	1.22
21	2.409	2.392	2.388	2.396333	0.011	0.000124	0.39	0.53

Average of all Labs	2.391
Std. Dev. Between Cell Averages (S_x)	0.014222
Repeatability Standard Deviation (S_r)	0.021026
Reproducibility Standard Deviation (S_R)	0.022294
Between Lab Standard Deviation of Lab Means(S_L)	0.007410
Pooled within lab variance (S_A^2)	0.000442
Between Lab Variance of Lab Means(S_L^2)	0.000055
W/L Variance	0.000442
B/L Variance	0.000497

CORELOK Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	LAB	MATERIAL D (FG15)						
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.291	2.277	2.290	2.286000	0.008	0.000061	0.46	0.60
2	2.303	2.282	2.280	2.288333	0.013	0.000162	0.67	0.97
3	2.282	2.288	2.293	2.287667	0.006	0.000030	0.61	0.42
4	2.290	2.294	2.261	2.281667	0.018	0.000324	0.08	1.37
5	2.293	2.296	2.265	2.284667	0.017	0.000292	0.34	1.30
6	2.285	2.284	2.278	2.282333	0.004	0.000014	0.14	0.29
7	2.290	2.283	2.278	2.283667	0.006	0.000036	0.26	0.46
8	2.261	2.272	2.296	2.276333	0.018	0.000320	-0.40	1.36
9	2.247	2.282	2.266	2.265000	0.018	0.000307	-1.41	1.34
10	2.266	2.274	2.281	2.273667	0.008	0.000056	-0.64	0.57
11	2.295	2.287	2.279	2.287000	0.008	0.000064	0.55	0.61
12	2.291	2.283	2.274	2.282667	0.009	0.000072	0.17	0.65
13	2.280	2.284	2.285	2.283000	0.003	0.000007	0.20	0.20
14	2.286	2.307	2.284	2.292333	0.013	0.000162	1.03	0.97
15	2.286	2.292	2.286	2.288000	0.003	0.000012	0.64	0.26
16	2.274	2.230	2.228	2.244000	0.026	0.000676	-3.28	1.98
20	2.269	2.292	2.275	2.278667	0.012	0.000142	-0.19	0.91
21	2.280	2.277	2.311	2.289333	0.019	0.000354	0.76	1.44

Average of all Labs	2.281
Std. Dev. Between Cell Averages (S_x)	0.011222
Repeatability Standard Deviation (S_r)	0.013113
Reproducibility Standard Deviation (S_R)	0.015510
Between Lab Standard Deviation of Lab Means(S_L)	0.008284
Pooled within lab variance (S_A^2)	0.000172
Between Lab Variance of Lab Means(S_L^2)	0.000069
W/L Variance	0.000172
B/L Variance	0.000241

CORELOK Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	LAB 1	MATERIAL E (FG50) 2	3	Avg.	Std. Dev.	Variance	h	k
1	2.365	2.366	2.372	2.367667	0.004	0.000014	0.88	0.32
2	2.360	2.377	2.357	2.364667	0.011	0.000116	0.60	0.91
3	2.361	2.366	2.355	2.360667	0.006	0.000030	0.24	0.46
4	2.365	2.372	2.359	2.365333	0.007	0.000042	0.66	0.55
5	2.346	2.352	2.372	2.356667	0.014	0.000185	-0.12	1.15
6	2.360	2.371	2.366	2.365667	0.006	0.000030	0.69	0.46
7	2.347	2.367	2.365	2.359667	0.011	0.000121	0.15	0.93
8	2.331	2.355	2.362	2.349333	0.016	0.000264	-0.78	1.37
9	2.361	2.364	2.404	2.376333	0.024	0.000576	1.66	2.02
10	2.361	2.368	2.370	2.366333	0.005	0.000022	0.75	0.40
11	2.319	2.367	2.369	2.351667	0.028	0.000801	-0.57	2.39
12	2.358	2.356	2.366	2.360000	0.005	0.000028	0.18	0.45
13	2.341	2.353	2.353	2.349000	0.007	0.000048	-0.81	0.58
14	2.371	2.352	2.352	2.358333	0.011	0.000120	0.03	0.92
15	2.358	2.353	2.365	2.358667	0.006	0.000036	0.06	0.51
16	2.328	2.319	2.326	2.324333	0.005	0.000022	-3.04	0.40
20	2.360	2.362	2.358	2.360000	0.002	0.000004	0.18	0.17
21	2.340	2.356	2.352	2.349333	0.008	0.000069	-0.78	0.70

Average of all Labs	2.358
Std. Dev. Between Cell Averages (S_x)	0.011064
Repeatability Standard Deviation (S_r)	0.011863
Reproducibility Standard Deviation (S_R)	0.014705
Between Lab Standard Deviation of Lab Means(S_L)	0.008689
Pooled within lab variance (S_A^2)	0.000141
Between Lab Variance of Lab Means(S_L^2)	0.000076
W/L Variance	0.000141
B/L Variance	0.000216

CORELOK Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	LAB	MATERIAL F (FG100)						
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.406	2.402	2.402	2.403333	0.002	0.000005	0.92	0.17
2	2.403	2.402	2.405	2.403333	0.002	0.000002	0.92	0.11
3	2.394	2.397	2.403	2.398000	0.005	0.000021	0.41	0.33
4	2.397	2.419	2.398	2.404667	0.012	0.000154	1.05	0.89
5	2.402	2.389	2.408	2.399667	0.010	0.000094	0.57	0.70
6	2.379	2.415	2.402	2.398667	0.018	0.000332	0.47	1.30
7	2.396	2.393	2.407	2.398667	0.007	0.000054	0.47	0.53
8	2.391	2.392	2.390	2.391000	0.001	0.000001	-0.26	0.07
9	2.382	2.395	2.400	2.392333	0.009	0.000086	-0.13	0.67
10	2.402	2.383	2.382	2.389000	0.011	0.000127	-0.45	0.81
11	2.389	2.371	2.394	2.384667	0.012	0.000146	-0.86	0.87
12	2.403	2.399	2.389	2.397000	0.007	0.000052	0.31	0.52
13	2.388	2.416	2.397	2.400333	0.014	0.000204	0.63	1.02
14	2.409	2.390	2.343	2.380667	0.034	0.001154	-1.25	2.43
15	2.402	2.408	2.408	2.406000	0.003	0.000012	1.17	0.25
16	2.380	2.331	2.385	2.365333	0.030	0.000890	-2.71	2.14
20	2.370	2.382	2.391	2.381000	0.011	0.000111	-1.21	0.75
21	2.385	2.401	2.394	2.393333	0.008	0.000064	-0.04	0.57

Average of all Labs	2.394
Std. Dev. Between Cell Averages (S_x)	0.010472
Repeatability Standard Deviation (S_r)	0.013970
Reproducibility Standard Deviation (S_R)	0.015485
Between Lab Standard Deviation of Lab Means(S_L)	0.006679
Pooled within lab variance (S_A^2)	0.000195
Between Lab Variance of Lab Means(S_L^2)	0.000045
W/L Variance	0.000195
B/L Variance	0.000240

CORELOK Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	LAB	MATERIAL						
		G (SMA15)						
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.244	2.236	2.257	2.245667	0.011	0.000112	1.19	0.38
2	2.265	2.192	2.224	2.227000	0.037	0.001339	-0.27	1.31
3	2.222	2.215	2.221	2.219333	0.004	0.000014	-0.87	0.14
4	2.237	2.198	2.244	2.226333	0.025	0.000614	-0.33	0.88
5	2.270	2.186	2.212	2.222667	0.043	0.001849	-0.61	1.53
6	2.239	2.213	2.226	2.226000	0.013	0.000169	-0.35	0.46
7	2.357	2.210	2.213	2.260000	0.084	0.007059	2.31	3.00
8	2.270	2.224	2.229	2.241000	0.025	0.000637	0.82	0.90
9	2.223	2.215	2.244	2.227333	0.015	0.000224	-0.25	0.53
10	2.242	2.230	2.213	2.228333	0.015	0.000212	-0.17	0.52
11	2.240	2.212	2.255	2.235667	0.022	0.000476	0.40	0.78
12	2.223	2.252	2.238	2.237667	0.015	0.000210	0.56	0.52
13	2.254	2.223	2.215	2.230667	0.021	0.000424	0.01	0.74
14	2.231	2.250	2.228	2.236333	0.012	0.000142	0.46	0.43
15	2.230	2.235	2.237	2.234000	0.004	0.000013	0.27	0.13
16	2.196	2.203	2.190	2.196333	0.007	0.000042	-2.67	0.23
20	2.246	2.214	2.224	2.228000	0.016	0.000268	-0.20	0.58
21	2.246	2.210	2.224	2.226667	0.018	0.000329	-0.30	0.65

Average of all Labs	2.231
Std. Dev. Between Cell Averages (S_x)	0.012774
Repeatability Standard Deviation (S_r)	0.028025
Reproducibility Standard Deviation (S_R)	0.028025
Between Lab Standard Deviation of Lab Means(S_L)	0.000000
Pooled within lab variance (S_A^2)	0.000785
Between Lab Variance of Lab Means(S_L^2)	0.000000
W/L Variance	0.000785
B/L Variance	0.000785

CORELOK Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	LAB	MATERIAL H (SMA50)						
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.341	2.360	2.389	2.363333	0.024	0.000584	0.49	0.51
2	2.383	2.367	2.347	2.365667	0.018	0.000325	0.57	0.38
3	2.375	2.358	2.352	2.361667	0.012	0.000142	0.43	0.25
4	2.333	2.362	2.333	2.342667	0.017	0.000280	-0.26	0.36
5	2.344	2.378	2.371	2.364333	0.018	0.000322	0.52	0.38
6	2.363	2.365	2.396	2.374667	0.019	0.000342	0.90	0.39
7	2.334	2.340	2.361	2.345000	0.014	0.000201	-0.18	0.30
8	2.340	2.365	2.390	2.365000	0.025	0.000625	0.55	0.53
9	2.344	2.353	2.374	2.357000	0.015	0.000237	0.26	0.33
10	2.369	2.333	2.376	2.359333	0.023	0.000532	0.34	0.49
11	2.378	2.336	2.373	2.362333	0.023	0.000526	0.45	0.49
12	2.350	2.365	2.378	2.364333	0.014	0.000196	0.52	0.30
13	2.328	2.169	2.371	2.289333	0.106	0.011322	-2.19	2.26
14	2.408	2.361	2.355	2.374667	0.029	0.000842	0.90	0.62
15	2.354	2.378	2.392	2.374667	0.019	0.000369	0.90	0.41
16	2.331	2.289	2.340	2.320000	0.027	0.000741	-1.08	0.58
20	2.364	2.334	2.297	2.331667	0.034	0.001126	-0.66	0.71
21	2.337	2.117	2.391	2.281667	0.145	0.021065	-2.47	3.09

Average of all Labs	2.350
Std. Dev. Between Cell Averages (S_x)	0.027625
Repeatability Standard Deviation (S_r)	0.047012
Reproducibility Standard Deviation (S_R)	0.047292
Between Lab Standard Deviation of Lab Means(S_L)	0.005141
Pooled within lab variance (S_A^2)	0.002210
Between Lab Variance of Lab Means(S_L^2)	0.000026
W/L Variance	0.002210
B/L Variance	0.002237

CORELOK Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	LAB 1	MATERIAL I (SMA100) 2	3	Avg.	Std. Dev.	Variance	h	k
1	2.405	2.414	2.398	2.405667	0.008	0.000064	0.15	0.40
2	2.411	2.416	2.352	2.393000	0.036	0.001267	-0.53	1.78
3	2.423	2.428	2.434	2.428333	0.006	0.000030	1.38	0.28
4	2.421	2.420	2.403	2.414667	0.010	0.000102	0.64	0.51
5	2.402	2.395	2.414	2.403667	0.010	0.000092	0.04	0.48
6	2.411	2.403	2.403	2.405667	0.005	0.000021	0.15	0.23
7	2.415	2.404	2.401	2.406667	0.007	0.000054	0.21	0.37
8	2.403	2.419	2.406	2.409333	0.009	0.000072	0.35	0.43
9	2.326	2.406	2.392	2.374667	0.043	0.001825	-1.52	2.14
10	2.420	2.420	2.423	2.421000	0.002	0.000003	0.98	0.09
11	2.410	2.435	2.396	2.413667	0.020	0.000390	0.58	0.99
12	2.435	2.397	2.412	2.414667	0.019	0.000366	0.64	0.96
13	2.413	2.362	2.396	2.390333	0.026	0.000674	-0.67	1.30
14	2.412	2.420	2.413	2.415000	0.004	0.000019	0.66	0.22
15	2.398	2.412	2.428	2.412667	0.015	0.000225	0.53	0.75
16	2.328	2.378	2.339	2.348333	0.026	0.000690	-2.94	1.31
20	2.398	2.377	2.400	2.391667	0.013	0.000162	-0.60	0.64
21	2.437	2.399	2.370	2.402000	0.034	0.001129	-0.04	1.68

Average of all Labs	2.403
Std. Dev. Between Cell Averages (S_x)	0.018531
Repeatability Standard Deviation (S_r)	0.019986
Reproducibility Standard Deviation (S_R)	0.024692
Between Lab Standard Deviation of Lab Means(S_L)	0.014501
Pooled within lab variance (S_A^2)	0.000399
Between Lab Variance of Lab Means(S_L^2)	0.000210
W/L Variance	0.000399
B/L Variance	0.000610

APPENDIX D

Uncorrected SGC Data

Uncorrected Gyratory (SGC) Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL A (CG15)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.174	2.115	2.115	2.134721	0.034	0.001161		
2	2.138	2.147	2.162	2.148753	0.012	0.000146		
3	2.161	2.164	2.159	2.161182	0.003	0.000008		
4	2.140	2.177	2.118	2.144989	0.030	0.000900		
5	2.157	2.116	2.109	2.127012	0.026	0.000680		
6	2.156	2.134	2.080	2.123345	0.039	0.001497		
7	2.153	2.159	2.130	2.147362	0.015	0.000229		
8	2.177	2.199	2.096	2.157144	0.054	0.002904		
9	2.173	2.153	2.105	2.143522	0.034	0.001186		
10	2.230	2.180	2.162	2.190672	0.036	0.001266		
11	2.156	2.141	2.163	2.153026	0.011	0.000127		
12	2.163	2.160	2.114	2.145527	0.027	0.000745		
13	2.133	2.159	2.139	2.143699	0.013	0.000179		
14	2.139	2.117	2.106	2.120871	0.017	0.000280		
15	2.156	2.131	2.108	2.131563	0.024	0.000569		
20	2.151	2.155	2.138	2.148014	0.009	0.000083		
21	2.174	2.140	2.183	2.165830	0.023	0.000508		

Average of all Labs	2.146	
Std. Dev. Between Cell Averages (S_X)	0.017063	
Repeatability Standard Deviation (S_r)	0.027084	
Reproducibility Standard Deviation (S_R)	0.027932	
Between Lab Standard Deviation of Lab Means(S_L)	0.006828	
Pooled within lab variance (S_A^2)	0.000734	(Components of variance) W/L
Between Lab Variance of Lab Means(S_L^2)	0.000047	(Components of variance) B/L
W/L Variance	0.000734	
B/L Variance	0.000780	

Uncorrected Gyratory (SGC) Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL B (CG50)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.307	2.264	2.298	2.289996	0.023	0.000514		
2	2.270	2.353	2.294	2.305816	0.043	0.001807		
3	2.276	2.306	2.261	2.281043	0.023	0.000519		
4	2.271	2.265	2.291	2.275533	0.014	0.000182		
5	2.257	2.320	2.282	2.286177	0.032	0.001014		
6	2.261	2.332	2.284	2.292596	0.036	0.001298		
7	2.281	2.254	2.269	2.267812	0.013	0.000177		
8	2.252	2.296	2.244	2.264009	0.028	0.000789		
9	2.288	2.303	2.329	2.306686	0.021	0.000423		
10	2.290	2.292	2.290	2.290645	0.001	0.000001		
11	2.288	2.285	2.290	2.287713	0.002	0.000006		
12	2.309	2.314	2.296	2.306496	0.009	0.000082		
13	2.245	2.292	2.270	2.269060	0.024	0.000560		
14	2.294	2.313	2.279	2.295656	0.017	0.000298		
15	2.266	2.291	2.285	2.280464	0.013	0.000163		
20	2.319	2.295	2.300	2.304446	0.012	0.000156		
21	2.319	2.300	2.293	2.304029	0.014	0.000187		

Average of all Labs	2.289
Std. Dev. Between Cell Averages (S_x)	0.014195
Repeatability Standard Deviation (S_r)	0.021927
Reproducibility Standard Deviation (S_R)	0.022848
Between Lab Standard Deviation of Lab Means(S_L)	0.006421
Pooled within lab variance (S_A^2)	0.000481
Between Lab Variance of Lab Means(S_L^2)	0.000041
W/L Variance	0.000481
B/L Variance	0.000522

Uncorrected Gyratory (SGC) Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL C (CG100)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.366	2.338	2.324	2.342657	0.021	0.000439		
2	2.333	2.359	2.342	2.344662	0.013	0.000172		
3	2.356	2.363	2.342	2.353756	0.011	0.000115		
4	2.353	2.271	2.333	2.318789	0.043	0.001818		
5	2.343	2.352	2.322	2.338836	0.015	0.000236		
6	2.347	2.350	2.334	2.343687	0.008	0.000070		
7	2.356	2.344	2.330	2.343309	0.013	0.000169		
8	2.366	2.318	2.357	2.346930	0.025	0.000640		
9	2.324	2.272	2.355	2.316926	0.042	0.001744		
10	2.350	2.345	2.349	2.347990	0.003	0.000007		
11	2.347	2.324	2.342	2.337913	0.012	0.000143		
12	2.331	2.324	2.351	2.335495	0.014	0.000195		
13	2.327	2.340	2.345	2.337242	0.010	0.000091		
14	2.293	2.329	2.325	2.315874	0.020	0.000387		
15	2.339	2.376	2.331	2.348844	0.024	0.000558		
20	2.353	2.348	2.308	2.336159	0.025	0.000618		
21	2.360	2.338	2.343	2.346945	0.012	0.000133		

Average of all Labs	2.339
Std. Dev. Between Cell Averages (S_x)	0.011346
Repeatability Standard Deviation (S_r)	0.021054
Reproducibility Standard Deviation (S_R)	0.021054
Between Lab Standard Deviation of Lab Means(S_L)	0.000000
Pooled within lab variance (S_A^2)	0.000443
Between Lab Variance of Lab Means(S_L^2)	0.000000
W/L Variance	0.000443
B/L Variance	0.000443

Uncorrected Gyratory (SGC) Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL D (FG15)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.243	2.245	2.248	2.245474	0.003	0.000007		
2	2.258	2.240	2.222	2.239759	0.018	0.000323		
3	2.243	2.256	2.258	2.252260	0.008	0.000071		
4	2.224	2.253	2.253	2.243455	0.017	0.000288		
5	2.254	2.257	2.231	2.247381	0.015	0.000212		
6	2.239	2.240	2.232	2.237362	0.004	0.000018		
7	2.260	2.253	2.241	2.251345	0.010	0.000097		
8	2.242	2.247	2.232	2.240362	0.008	0.000058		
9	2.243	2.233	2.244	2.240011	0.006	0.000038		
10	2.217	2.240	2.239	2.231981	0.013	0.000169		
11	2.248	2.249	2.246	2.247522	0.002	0.000003		
12	2.253	2.252	2.234	2.246480	0.011	0.000119		
13	2.244	2.257	2.247	2.248991	0.007	0.000047		
14	2.267	2.250	2.236	2.251133	0.016	0.000250		
15	2.239	2.241	2.252	2.244208	0.007	0.000049		
20	2.225	2.257	2.248	2.243160	0.016	0.000263		
21	2.239	2.238	2.247	2.241485	0.005	0.000027		

Average of all Labs	2.244
Std. Dev. Between Cell Averages (S_X)	0.005431
Repeatability Standard Deviation (S_r)	0.010958
Reproducibility Standard Deviation (S_R)	0.010958
Between Lab Standard Deviation of Lab Means(S_L)	0.000000
Pooled within lab variance (S_A^2)	0.000120
Between Lab Variance of Lab Means(S_L^2)	0.000000
W/L Variance	0.000120
B/L Variance	0.000120

Uncorrected Gyratory (SGC) Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL E (FG50)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.326	2.325	2.331	2.327195	0.003	0.000011		
2	2.317	2.333	2.305	2.318205	0.014	0.000197		
3	2.324	2.327	2.323	2.324498	0.002	0.000003		
4	2.321	2.328	2.329	2.326297	0.004	0.000018		
5	2.308	2.309	2.332	2.315980	0.014	0.000184		
6	2.314	2.324	2.324	2.320843	0.006	0.000031		
7	2.311	2.327	2.329	2.322275	0.010	0.000097		
8	2.316	2.320	2.323	2.319667	0.003	0.000011		
9	2.330	2.321	2.331	2.327075	0.006	0.000032		
10	2.317	2.324	2.325	2.322023	0.004	0.000017		
11	2.332	2.327	2.306	2.321672	0.014	0.000185		
12	2.323	2.317	2.325	2.321290	0.004	0.000018		
13	2.302	2.313	2.315	2.309960	0.007	0.000046		
14	2.307	2.327	2.312	2.315353	0.011	0.000112		
15	2.314	2.322	2.314	2.316414	0.004	0.000020		
20	2.328	2.329	2.315	2.324113	0.008	0.000057		
21	2.311	2.323	2.323	2.319168	0.007	0.000046		

Average of all Labs	2.321
Std. Dev. Between Cell Averages (S_x)	0.004610
Repeatability Standard Deviation (S_r)	0.007993
Reproducibility Standard Deviation (S_R)	0.007993
Between Lab Standard Deviation of Lab Means(S_L)	0.000000
Pooled within lab variance (S_A^2)	0.000064
Between Lab Variance of Lab Means(S_L^2)	0.000000
W/L Variance	0.000064
B/L Variance	0.000064

Uncorrected Gyratory (SGC) Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL F (FG100) 1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.360	2.362	2.360	2.360687	0.001	0.000001		
2	2.357	2.362	2.361	2.360253	0.003	0.000007		
3	2.353	2.356	2.365	2.358179	0.006	0.000033		
4	2.355	2.359	2.379	2.364103	0.013	0.000169		
5	2.362	2.350	2.372	2.361204	0.011	0.000124		
6	2.400	2.376	2.359	2.378490	0.021	0.000421		
7	2.361	2.348	2.368	2.359114	0.010	0.000105		
8	2.356	2.354	2.347	2.352371	0.005	0.000022		
9	2.358	2.359	2.347	2.354451	0.007	0.000045		
10	2.359	2.341	2.359	2.353083	0.011	0.000113		
11	2.355	2.357	2.346	2.352987	0.006	0.000033		
12	2.363	2.361	2.350	2.358170	0.007	0.000047		
13	2.352	2.362	2.378	2.363873	0.013	0.000161		
14	2.369	2.349		2.359266	0.014	0.000202		
15	2.361	2.362	2.363	2.362113	0.001	0.000002		
20	2.348	2.346	2.356	2.350104	0.005	0.000026		
21	2.350	2.359	2.359	2.355812	0.005	0.000029		

Average of all Labs	2.359
Std. Dev. Between Cell Averages (S_X)	0.006495
Repeatability Standard Deviation (S_r)	0.009516
Reproducibility Standard Deviation (S_R)	0.010127
Between Lab Standard Deviation of Lab Means(S_L)	0.003465
Pooled within lab variance (S_A^2)	0.000091
Between Lab Variance of Lab Means(S_L^2)	0.000012
W/L Variance	0.000091
B/L Variance	0.000103

Uncorrected Gyratory (SGC) Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL G (SMA15)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.164	2.173	2.174	2.170460	0.005	0.000028		
2	2.185	2.133	2.138	2.151787	0.029	0.000816		
3	2.139	2.133	2.150	2.140523	0.009	0.000074		
4	2.152	2.160	2.142	2.151409	0.009	0.000079		
5	2.198	2.146	2.141	2.161844	0.031	0.000989		
6	2.159	2.132	2.145	2.145123	0.014	0.000188		
7	2.177	2.128	2.145	2.149741	0.025	0.000620		
8	2.193	2.145	2.153	2.163680	0.025	0.000640		
9	2.187	2.166	2.143	2.165103	0.022	0.000500		
10	2.171	2.158	2.128	2.152492	0.022	0.000483		
11	2.182	2.170	2.138	2.163350	0.023	0.000528		
12	2.136	2.179	2.151	2.155530	0.022	0.000468		
13	2.143	2.172	2.141	2.151970	0.017	0.000305		
14	2.154	2.150	2.167	2.156773	0.009	0.000086		
15	2.157	2.148	2.143	2.149373	0.007	0.000044		
20	2.169	2.142	2.146	2.152250	0.015	0.000213		
21	2.160	2.141	2.146	2.148956	0.010	0.000100		

Average of all Labs	2.155
Std. Dev. Between Cell Averages (S_X)	0.007844
Repeatability Standard Deviation (S_r)	0.019038
Reproducibility Standard Deviation (S_R)	0.019038
Between Lab Standard Deviation of Lab Means(S_L)	0.000000
Pooled within lab variance (S_A^2)	0.000362
Between Lab Variance of Lab Means(S_L^2)	0.000000
W/L Variance	0.000362
B/L Variance	0.000362

Uncorrected Gyratory (SGC) Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL H (SMA50)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.322	2.255	2.285	2.287076	0.034	0.001125		
2	2.296	2.283	2.269	2.282824	0.013	0.000178		
3	2.301	2.281	2.274	2.285413	0.014	0.000206		
4	2.261	2.263	2.291	2.271722	0.017	0.000285		
5	2.274	2.309	2.303	2.295058	0.019	0.000348		
6	2.287	2.283	2.260	2.276677	0.015	0.000214		
7	2.258	2.264	2.293	2.271586	0.019	0.000348		
8	2.267	2.292	2.317	2.292077	0.025	0.000613		
9	2.283	2.271	2.312	2.288559	0.021	0.000452		
10	2.302	2.253	2.304	2.286307	0.029	0.000832		
11	2.261	2.295	2.294	2.283218	0.019	0.000369		
12	2.273	2.283	2.298	2.284560	0.013	0.000161		
13	2.281	2.275	2.305	2.287235	0.015	0.000240		
14	2.334	2.279	2.279	2.297215	0.032	0.000993		
15	2.270	2.313	2.289	2.290962	0.022	0.000466		
20	2.299	2.265	2.229	2.264412	0.035	0.001214		
21	2.258	2.284	2.337	2.292979	0.041	0.001644		

Average of all Labs	2.285
Std. Dev. Between Cell Averages (S_x)	0.008937
Repeatability Standard Deviation (S_r)	0.023871
Reproducibility Standard Deviation (S_R)	0.023871
Between Lab Standard Deviation of Lab Means(S_L)	0.000000
Pooled within lab variance (S_A^2)	0.000570
Between Lab Variance of Lab Means(S_L^2)	0.000000
W/L Variance	0.000570
B/L Variance	0.000570

Uncorrected Gyratory (SGC) Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL I (SMA100)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	2.344	2.344	2.331	2.339723	0.008	0.000059		
2	2.332	2.349	2.341	2.341061	0.009	0.000074		
3	2.363	2.363	2.383	2.369782	0.011	0.000129		
4	2.359	2.346	2.363	2.356136	0.009	0.000079		
5	2.350	2.326	2.359	2.345049	0.017	0.000290		
6	2.335	2.327	2.332	2.331314	0.004	0.000016		
7	2.344	2.343	2.340	2.342541	0.002	0.000006		
8	2.332	2.364	2.350	2.348338	0.016	0.000256		
9	2.359	2.282	2.353	2.331043	0.043	0.001826		
10	2.374	2.380	2.361	2.371740	0.010	0.000102		
11	2.389	2.326	2.337	2.350733	0.034	0.001126		
12	2.345	2.377	2.329	2.350306	0.024	0.000584		
13	2.372	2.357	2.336	2.354937	0.018	0.000322		
14	2.345	2.349	2.353	2.348694	0.004	0.000016		
15	2.339	2.366	2.337	2.347164	0.016	0.000259		
20	2.345	2.346	2.347	2.346098	0.001	0.000001		
21	2.388	2.350	2.350	2.362722	0.022	0.000495		

Average of all Labs	2.349
Std. Dev. Between Cell Averages (S_X)	0.011405
Repeatability Standard Deviation (S_r)	0.018214
Reproducibility Standard Deviation (S_R)	0.018741
Between Lab Standard Deviation of Lab Means(S_L)	0.004413
Pooled within lab variance (S_A^2)	0.000332
Between Lab Variance of Lab Means(S_L^2)	0.000019
W/L Variance	0.000332
B/L Variance	0.000351

APPENDIX E

Difference Data – (Corelok – SGC)

Difference CORELOK Gravity - SGC Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL A (CG15)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	0.0488	0.0184	0.0489	0.038679	0.018	0.000310	-0.22	1.17
2	0.0457	0.0504	0.0303	0.042129	0.010	0.000110	0.05	0.70
3	0.0302	0.0402	0.0483	0.039587	0.009	0.000082	-0.15	0.60
4	0.0401	0.0442	0.0317	0.038680	0.006	0.000040	-0.22	0.42
5	0.0271	0.0314	0.0230	0.027185	0.004	0.000018	-1.10	0.28
6	0.0497	0.0547	0.0348	0.046420	0.010	0.000108	0.37	0.69
7	0.0320	0.0304	0.0404	0.034272	0.005	0.000028	-0.56	0.36
8	0.0305	0.0534	0.0473	0.043744	0.012	0.000141	0.17	0.79
9	0.0440	0.0413	0.0435	0.042932	0.001	0.000002	0.11	0.10
10	0.0504	0.0430	0.0477	0.047039	0.004	0.000014	0.42	0.25
11	0.0217	0.0542	0.0544	0.043448	0.019	0.000355	0.15	1.25
12	0.0336	0.0428	0.0368	0.037729	0.005	0.000022	-0.29	0.31
13	0.0096	0.0249	0.0330	0.022494	0.012	0.000141	-1.46	0.79
14	0.0405	0.0415	0.0418	0.041257	0.001	0.000000	-0.02	0.05
15	0.0543	0.0510	0.0411	0.048826	0.007	0.000047	0.56	0.46
20	0.0040	0.0425	0.0383	0.028276	0.021	0.000445	-1.02	1.40
21	0.1105	0.1080	0.0320	0.083529	0.045	0.001990	3.22	2.96

Average of all Labs	0.042	
Std. Dev. Between Cell Averages (S_x)	0.013023	
Repeatability Standard Deviation (S_r)	0.015056	
Reproducibility Standard Deviation (S_R)	0.017909	
Between Lab Standard Deviation of Lab Means(S_L)	0.009696	
Pooled within lab variance (S_A^2)	0.000227	(Components of variance) W/L
Between Lab Variance of Lab Means(S_L^2)	0.000094	(Components of variance) B/L
W/L Variance	0.000227	
B/L Variance	0.000321	

Difference CORELOK Gravity - SGC Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL B (CG50)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	0.0527	0.1522	0.0599	0.088267	0.055	0.003077	3.36	3.91
2	0.0514	0.0585	0.0539	0.054604	0.004	0.000013	0.14	0.25
3	0.0493	0.0552	0.0493	0.051253	0.003	0.000012	-0.18	0.24
4	0.0534	0.0552	0.0370	0.048538	0.010	0.000101	-0.44	0.71
5	0.0502	0.0529	0.0496	0.050907	0.002	0.000003	-0.21	0.12
6	0.0593	0.0564	0.0542	0.056634	0.003	0.000007	0.34	0.18
7	0.0516	0.0545	0.0464	0.050849	0.004	0.000017	-0.22	0.29
8	0.0432	0.0534	0.0444	0.047033	0.006	0.000031	-0.59	0.39
9	0.0433	0.0348	0.0482	0.042110	0.007	0.000046	-1.05	0.48
10	0.0571	0.0600	0.0515	0.056181	0.004	0.000019	0.29	0.30
11	0.0532	0.0482	0.0504	0.050574	0.002	0.000006	-0.24	0.18
12	0.0513	0.0486	0.0556	0.051844	0.004	0.000012	-0.12	0.25
13	0.0428	0.0486	0.0467	0.046011	0.003	0.000009	-0.68	0.21
14	0.0541	0.0595	0.0599	0.057851	0.003	0.000010	0.45	0.23
15	0.0569	0.0625	0.0551	0.058169	0.004	0.000015	0.48	0.27
20	0.0325	0.0408	0.0444	0.039245	0.006	0.000038	-1.33	0.43
21	0.0512	0.0551	0.0528	0.053057	0.002	0.000004	-0.01	0.14

Average of all Labs	0.053
Std. Dev. Between Cell Averages (S_x)	0.010461
Repeatability Standard Deviation (S_r)	0.014179
Reproducibility Standard Deviation (S_R)	0.015604
Between Lab Standard Deviation of Lab Means(S_L)	0.006513
Pooled within lab variance (S_A^2)	0.000201
Between Lab Variance of Lab Means(S_L^2)	0.000042
W/L Variance	0.000201
B/L Variance	0.000243

Difference CORELOK Gravity - SGC Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL C (CG100) 1	2	3	Avg.	Std. Dev.	Variance	h	k
1	0.0564	0.0534	0.0519	0.053914	0.002	0.000005	-0.12	0.16
2	0.0626	0.0468	0.0566	0.055298	0.008	0.000064	0.10	0.56
3	0.0544	0.0558	0.0583	0.056167	0.002	0.000004	0.22	0.14
4	0.0582	0.0594	0.0508	0.056131	0.005	0.000022	0.22	0.33
5	0.0562	0.0558	0.0525	0.054860	0.002	0.000004	0.02	0.14
6	0.0577	0.0573	0.0546	0.056539	0.002	0.000003	0.28	0.12
7	0.0594	0.0515	0.0570	0.055964	0.004	0.000016	0.19	0.29
8	0.0746	0.0486	0.0595	0.060880	0.013	0.000170	0.94	0.92
9	0.0676	0.1049	0.0319	0.068153	0.036	0.001331	2.04	2.58
10	-0.0111	0.0588	0.0565	0.034722	0.040	0.001579	-3.03	2.81
11	0.0522	0.0641	0.0513	0.055897	0.007	0.000051	0.18	0.51
12	0.0528	0.0568	0.0587	0.056094	0.003	0.000009	0.21	0.21
13	0.0525	0.0476	0.0542	0.051436	0.003	0.000012	-0.49	0.24
14	0.0545	0.0622	0.0600	0.058892	0.004	0.000016	0.64	0.28
15	0.0571	0.0430	0.0571	0.052384	0.008	0.000066	-0.35	0.58
20	0.0497	0.0577	0.0522	0.053201	0.004	0.000017	-0.23	0.29
21	0.0487	0.0543	0.0449	0.049325	0.005	0.000022	-0.82	0.33

Average of all Labs	0.055
Std. Dev. Between Cell Averages (S_x)	0.006598
Repeatability Standard Deviation (S_r)	0.014124
Reproducibility Standard Deviation (S_R)	0.014124
Between Lab Standard Deviation of Lab Means(S_L)	0.000000
Pooled within lab variance (S_A^2)	0.000199
Between Lab Variance of Lab Means(S_L^2)	0.000000
W/L Variance	0.000199
B/L Variance	0.000199

Difference CORELOK Gravity - SGC Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL D (FG15)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	0.0337	0.0445	0.0424	0.040195	0.006	0.000033	0.26	0.59
2	0.0452	0.0425	0.0579	0.048518	0.008	0.000068	1.70	0.84
3	0.0393	0.0322	0.0342	0.035202	0.004	0.000013	-0.60	0.37
4	0.0373	0.0368	0.0405	0.038208	0.002	0.000004	-0.09	0.21
5	0.0387	0.0385	0.0343	0.037149	0.002	0.000006	-0.27	0.25
6	0.0457	0.0434	0.0455	0.044861	0.001	0.000002	1.06	0.13
7	0.0293	0.0302	0.0372	0.032237	0.004	0.000018	-1.12	0.44
8	0.0185	0.0255	0.0645	0.036144	0.025	0.000616	-0.44	2.54
9	0.0042	0.0336	0.0383	0.025351	0.018	0.000340	-2.31	1.89
10	0.0492	0.0338	0.0421	0.041701	0.008	0.000060	0.52	0.79
11	0.0472	0.0305	0.0420	0.039878	0.009	0.000073	0.21	0.87
12	0.0381	0.0301	0.0403	0.036172	0.005	0.000029	-0.44	0.55
13	0.0370	0.0276	0.0386	0.034392	0.006	0.000036	-0.74	0.61
14	0.0391	0.0335	0.0500	0.040836	0.008	0.000070	0.37	0.86
15	0.0464	0.0446	0.0397	0.043586	0.003	0.000012	0.84	0.35
20	0.0440	0.0356	0.0272	0.035591	0.008	0.000071	-0.54	0.86
21	0.0415	0.0391	0.0631	0.047888	0.013	0.000175	1.59	1.35

Average of all Labs	0.039
Std. Dev. Between Cell Averages (S_x)	0.005787
Repeatability Standard Deviation (S_r)	0.009775
Reproducibility Standard Deviation (S_R)	0.009858
Between Lab Standard Deviation of Lab Means(S_L)	0.001281
Pooled within lab variance (S_A^2)	0.000096
Between Lab Variance of Lab Means(S_L^2)	0.000002
W/L Variance	0.000096
B/L Variance	0.000097

Difference CORELOK Gravity - SGC Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL E (FG50)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	0.0396	0.0409	0.0415	0.040674	0.001	0.000001	0.25	0.13
2	0.0430	0.0436	0.0521	0.046221	0.005	0.000026	1.22	0.67
3	0.0371	0.0390	0.0321	0.036088	0.004	0.000013	-0.56	0.47
4	0.0375	0.0369	0.0430	0.039123	0.003	0.000011	-0.02	0.45
5	0.0388	0.0437	0.0408	0.041078	0.002	0.000006	0.32	0.33
6	0.0456	0.0473	0.0415	0.044812	0.003	0.000009	0.97	0.40
7	0.0362	0.0394	0.0363	0.037311	0.002	0.000003	-0.34	0.24
8	0.0145	0.0347	0.0393	0.029495	0.013	0.000175	-1.70	1.75
9	0.0344	0.0408	0.0728	0.049353	0.021	0.000424	1.76	2.73
10	0.0434	0.0438	0.0450	0.044053	0.001	0.000001	0.84	0.11
11	0.0367	0.0404	0.0124	0.029863	0.015	0.000231	-1.65	2.02
12	0.0350	0.0396	0.0408	0.038489	0.003	0.000009	-0.14	0.41
13	0.0392	0.0406	0.0385	0.039430	0.001	0.000001	0.03	0.14
14	0.0444	0.0441	0.0400	0.042817	0.002	0.000006	0.62	0.33
15	0.0395	0.0438	0.0443	0.042523	0.003	0.000007	0.57	0.35
20	0.0316	0.0333	0.0429	0.035966	0.006	0.000037	-0.58	0.81
21	0.0284	0.0334	0.0288	0.030203	0.003	0.000008	-1.58	0.37

Average of all Labs	0.039
Std. Dev. Between Cell Averages (S_X)	0.005721
Repeatability Standard Deviation (S_r)	0.007543
Reproducibility Standard Deviation (S_R)	0.008406
Between Lab Standard Deviation of Lab Means(S_L)	0.003711
Pooled within lab variance (S_A^2)	0.000057
Between Lab Variance of Lab Means(S_L^2)	0.000014
W/L Variance	0.000057
B/L Variance	0.000071

Difference CORELOK Gravity - SGC Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL F (FG100)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	0.0421	0.0399	0.0451	0.042361	0.003	0.000007	0.89	0.25
2	0.0444	0.0427	0.0414	0.042818	0.001	0.000002	0.97	0.15
3	0.0402	0.0404	0.0384	0.039656	0.001	0.000001	0.41	0.11
4	0.0424	0.0399	0.0401	0.040795	0.001	0.000002	0.61	0.14
5	0.0398	0.0392	0.0362	0.038365	0.002	0.000004	0.18	0.19
6	-0.0216	0.0393	0.0426	0.020100	0.036	0.001310	-3.05	3.53
7	0.0350	0.0444	0.0383	0.039247	0.005	0.000023	0.33	0.47
8	0.0350	0.0372	0.0428	0.038377	0.004	0.000016	0.17	0.39
9	0.0375	0.0407	0.0357	0.037960	0.003	0.000006	0.11	0.25
10	0.0426	0.0425	0.0224	0.035837	0.012	0.000136	-0.27	1.13
11	0.0154	0.0372	0.0422	0.031603	0.014	0.000202	-1.02	1.39
12	0.0397	0.0382	0.0390	0.038966	0.001	0.000001	0.28	0.07
13	0.0354	0.0355	0.0386	0.036522	0.002	0.000003	-0.15	0.18
14	0.0398	0.0409		0.040348	0.001	0.000001	0.53	0.05
15	0.0413	0.0461	0.0446	0.043970	0.002	0.000006	1.18	0.24
20	0.0220	0.0357	0.0348	0.030817	0.008	0.000058	-1.15	0.75
21	0.0356	0.0413	0.0349	0.037271	0.004	0.000012	-0.02	0.34

Average of all Labs	0.037
Std. Dev. Between Cell Averages (S_x)	0.005645
Repeatability Standard Deviation (S_r)	0.010263
Reproducibility Standard Deviation (S_R)	0.010263
Between Lab Standard Deviation of Lab Means(S_L)	0.000000
Pooled within lab variance (S_A^2)	0.000105
Between Lab Variance of Lab Means(S_L^2)	0.000000
W/L Variance	0.000105
B/L Variance	0.000105

Difference CORELOK Gravity - SGC Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL G (SMA15)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	0.0718	0.0711	0.0823	0.075083	0.006	0.000040	-0.26	0.37
2	0.0802	0.0592	0.0865	0.075299	0.014	0.000205	-0.24	0.84
3	0.0827	0.0821	0.0713	0.078706	0.006	0.000041	0.09	0.38
4	0.0857	0.0843	0.0558	0.075236	0.017	0.000285	-0.24	0.99
5	0.0722	0.0400	0.0711	0.061132	0.018	0.000335	-1.61	1.07
6	0.0799	0.0817	0.0809	0.080833	0.001	0.000001	0.30	0.05
7	0.1800	0.0818	0.0686	0.110116	0.061	0.003707	3.13	3.57
8	0.0771	0.0788	0.0760	0.077270	0.001	0.000002	-0.05	0.08
9	0.0566	0.0577	0.0720	0.062124	0.009	0.000074	-1.52	0.50
10	0.0711	0.0721	0.0845	0.075900	0.007	0.000056	-0.18	0.44
11	0.0726	0.0697	0.0742	0.072169	0.002	0.000005	-0.54	0.13
12	0.0864	0.0730	0.0862	0.081857	0.008	0.000059	0.40	0.45
13	0.0797	0.0823	0.0741	0.078697	0.004	0.000018	0.09	0.25
14	0.0744	0.0811	0.0832	0.079557	0.005	0.000021	0.17	0.27
15	0.0800	0.0869	0.0867	0.084520	0.004	0.000015	0.66	0.23
20	0.0771	0.0725	0.0779	0.075846	0.003	0.000009	-0.19	0.17
21	0.0857	0.0688	0.0784	0.077620	0.009	0.000072	-0.01	0.50

Average of all Labs	0.078
Std. Dev. Between Cell Averages (S_X)	0.010317
Repeatability Standard Deviation (S_r)	0.017053
Reproducibility Standard Deviation (S_R)	0.017330
Between Lab Standard Deviation of Lab Means(S_L)	0.003083
Pooled within lab variance (S_A^2)	0.000291
Between Lab Variance of Lab Means(S_L^2)	0.000010
W/L Variance	0.000291
B/L Variance	0.000300

Difference CORELOK Gravity - SGC Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL H (SMA50) 1	2	3	Avg.	Std. Dev.	Variance	h	k
1	0.0676	0.0863	0.0751	0.076355	0.009	0.000089	0.33	0.23
2	0.0869	0.0831	0.0775	0.082517	0.005	0.000022	0.55	0.11
3	0.0736	0.0768	0.0781	0.076197	0.002	0.000005	0.33	0.06
4	0.0725	0.0701	0.0707	0.071106	0.001	0.000002	0.15	0.03
5	0.0706	0.0694	0.0690	0.069666	0.001	0.000001	0.10	0.02
6	0.0765	0.0816	0.1360	0.098069	0.033	0.001087	1.11	0.79
7	0.0759	0.0767	0.0683	0.073595	0.005	0.000021	0.24	0.11
8	0.0724	0.0731	0.0727	0.072730	0.000	0.000000	0.21	0.01
9	0.0702	0.0730	0.0616	0.068271	0.006	0.000035	0.05	0.14
10	0.0673	0.0799	0.0716	0.072923	0.006	0.000041	0.21	0.15
11	0.0747	0.0778	0.0839	0.078790	0.005	0.000022	0.42	0.11
12	0.0776	0.0817	0.0798	0.079706	0.002	0.000004	0.45	0.05
13	-0.1128	0.0526	0.0659	0.001879	0.100	0.009909	-2.32	2.39
14	0.0744	0.0760	0.0813	0.077270	0.004	0.000013	0.37	0.09
15	0.0839	0.0783	0.0891	0.083773	0.005	0.000029	0.60	0.13
20	0.0652	0.0686	0.0679	0.067227	0.002	0.000003	0.01	0.04
21	0.0795	-0.1667	0.0537	-0.011172	0.135	0.018315	-2.79	3.24

Average of all Labs	0.067
Std. Dev. Between Cell Averages (S_x)	0.028011
Repeatability Standard Deviation (S_r)	0.041726
Reproducibility Standard Deviation (S_R)	0.044106
Between Lab Standard Deviation of Lab Means(S_L)	0.014293
Pooled within lab variance (S_A^2)	0.001741
Between Lab Variance of Lab Means(S_L^2)	0.000204
W/L Variance	0.001741
B/L Variance	0.001945

Difference CORELOK Gravity - SGC Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL I (SMA100)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	0.0701	0.0611	0.0669	0.066041	0.005	0.000021	0.70	0.42
2	0.0788	0.0669	0.0717	0.072452	0.006	0.000036	1.26	0.55
3	0.0603	0.0650	0.0508	0.058720	0.007	0.000052	0.06	0.66
4	0.0616	0.0570	0.0571	0.058559	0.003	0.000007	0.05	0.24
5	0.0511	0.0687	0.0555	0.058480	0.009	0.000084	0.04	0.84
6	0.0768	0.0760	0.0713	0.074696	0.003	0.000009	1.45	0.27
7	0.0711	0.0605	0.0609	0.064172	0.006	0.000036	0.54	0.55
8	0.0710	0.0551	0.0563	0.060784	0.009	0.000078	0.25	0.81
9	0.0336	0.0439	0.0529	0.043458	0.010	0.000094	-1.26	0.89
10	0.0486	0.0399	0.0591	0.049190	0.010	0.000092	-0.76	0.88
11	0.0460	0.0699	0.0725	0.062760	0.015	0.000213	0.42	1.34
12	0.0666	0.0587	0.0684	0.064547	0.005	0.000026	0.57	0.47
13	0.0411	0.0049	0.0594	0.035144	0.028	0.000771	-1.99	2.54
14	0.0675	0.0717	0.0603	0.066494	0.006	0.000033	0.74	0.53
15	0.0723	0.0626	0.0614	0.065441	0.006	0.000036	0.65	0.55
20	0.0526	0.0308	0.0532	0.045545	0.013	0.000162	-1.08	1.17
21	0.0481	0.0491	0.0201	0.039125	0.016	0.000271	-1.64	1.51

Average of all Labs	0.058
Std. Dev. Between Cell Averages (S_X)	0.011497
Repeatability Standard Deviation (S_r)	0.010903
Reproducibility Standard Deviation (S_R)	0.014541
Between Lab Standard Deviation of Lab Means(S_L)	0.009621
Pooled within lab variance (S_A^2)	0.000119
Between Lab Variance of Lab Means(S_L^2)	0.000093
W/L Variance	0.000119
B/L Variance	0.000211

APPENDIX F

Difference Data – (AASHTO T166 – SGC)

Difference T166 Specific Gravity - SGC Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL A (CG15)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	0.0996	0.0695	0.0759	0.081679	0.016	0.000252	0.19	1.26
2	0.0781	0.0749	0.0645	0.072504	0.007	0.000050	-0.58	0.56
3	0.1095	0.0915	0.1077	0.102924	0.010	0.000098	1.98	0.79
4	0.0949	0.0802	0.0656	0.080232	0.015	0.000216	0.07	1.16
5	0.0748	0.0580	0.0506	0.061129	0.012	0.000155	-1.53	0.98
6	0.1077	0.1042	0.0859	0.099288	0.012	0.000137	1.68	0.93
7	0.0813	0.0839	0.1109	0.092024	0.016	0.000269	1.07	1.30
8	0.0624	0.0798	0.0652	0.069149	0.009	0.000087	-0.86	0.74
9	0.0925	0.0899	0.0697	0.084032	0.012	0.000155	0.39	0.99
10	0.0683	0.0901	0.1017	0.086711	0.017	0.000289	0.62	1.35
11	0.0573	0.0765	0.0661	0.066630	0.010	0.000093	-1.07	0.76
12	0.0790	0.0903	0.0612	0.076812	0.015	0.000215	-0.21	1.17
13	0.0754	0.0847	0.1025	0.087545	0.014	0.000189	0.69	1.09
14	0.0755	0.0530	0.0611	0.063198	0.011	0.000130	-1.36	0.91
15	0.0873	0.0872	0.0640	0.079530	0.013	0.000181	0.01	1.07
20	0.0619	0.0795	0.0800	0.073829	0.010	0.000106	-0.47	0.82
21	0.0627	0.0734	0.0801	0.072043	0.009	0.000077	-0.61	0.70

Average of all Labs	0.079	
Std. Dev. Between Cell Averages (S_x)	0.011883	
Repeatability Standard Deviation (S_r)	0.012600	
Reproducibility Standard Deviation (S_R)	0.015718	
Between Lab Standard Deviation of Lab Means(S_L)	0.009396	
Pooled within lab variance (S_A^2)	0.000159	(Components of variance) W/L
Between Lab Variance of Lab Means(S_L^2)	0.000088	(Components of variance) B/L
W/L Variance	0.000159	
B/L Variance	0.000247	

Difference T166 Specific Gravity - SGC Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL B (CG50)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	0.0686	0.0696	0.0665	0.068218	0.002	0.000003	0.83	0.33
2	0.0636	0.0632	0.0546	0.060456	0.005	0.000026	-0.62	1.05
3	0.0722	0.0691	0.0704	0.070586	0.002	0.000003	1.26	0.32
4	0.0667	0.0670	0.0618	0.065186	0.003	0.000008	0.26	0.60
5	0.0690	0.0604	0.0617	0.063717	0.005	0.000022	-0.01	0.96
6	0.0699	0.0602	0.0629	0.064362	0.005	0.000025	0.10	1.04
7	0.0710	0.0731	0.0618	0.068663	0.006	0.000036	0.90	1.24
8	0.0561	0.0641	0.0548	0.058327	0.005	0.000026	-1.01	1.04
9	0.0393	0.0559	0.0627	0.052643	0.012	0.000145	-2.07	2.49
10	0.0714	0.0771	0.0673	0.071943	0.005	0.000024	1.51	1.02
11	0.0616	0.0609	0.0557	0.059403	0.003	0.000010	-0.81	0.67
12	0.0646	0.0607	0.0669	0.064028	0.003	0.000010	0.05	0.65
13	0.0741	0.0636	0.0669	0.068202	0.005	0.000029	0.82	1.11
14	0.0716	0.0661	0.0682	0.068627	0.003	0.000008	0.90	0.57
15	0.0643	0.0680	0.0612	0.064499	0.003	0.000012	0.13	0.70
20	0.0568	0.0587	0.0623	0.059258	0.003	0.000008	-0.84	0.58
21	0.0554	0.0546	0.0586	0.056186	0.002	0.000004	-1.41	0.44

Average of all Labs	0.064
Std. Dev. Between Cell Averages (S_x)	0.005388
Repeatability Standard Deviation (S_r)	0.004838
Reproducibility Standard Deviation (S_R)	0.006681
Between Lab Standard Deviation of Lab Means(S_L)	0.004608
Pooled within lab variance (S_A^2)	0.000023
Between Lab Variance of Lab Means(S_L^2)	0.000021
W/L Variance	0.000023
B/L Variance	0.000045

Difference T166 Specific Gravity - SGC Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL C (CG100)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	0.0662	0.0724	0.0622	0.066961	0.005	0.000027	0.41	0.51
2	0.0730	0.0552	0.0619	0.063377	0.009	0.000080	-0.19	0.89
3	0.0638	0.0633	0.0669	0.064657	0.002	0.000004	0.03	0.19
4	0.0639	0.0836	0.0594	0.068939	0.013	0.000166	0.75	1.28
5	0.0630	0.0613	0.0658	0.063357	0.002	0.000005	-0.19	0.23
6	0.0595	0.0599	0.0557	0.058396	0.002	0.000005	-1.04	0.23
7	0.0658	0.0470	0.0769	0.063218	0.015	0.000228	-0.22	1.50
8	0.0621	0.0546	0.0625	0.059744	0.004	0.000020	-0.81	0.44
9	0.0651	0.1171	0.0614	0.081218	0.031	0.000970	2.82	3.09
10	0.0622	0.0692	0.0641	0.065141	0.004	0.000013	0.11	0.36
11	0.0614	0.0619	0.0582	0.060515	0.002	0.000004	-0.68	0.20
12	0.0695	0.0695	0.0714	0.070126	0.001	0.000001	0.95	0.11
13	0.0672	0.0668	0.0609	0.064968	0.004	0.000012	0.08	0.35
14	0.0662	0.0695	0.0681	0.067944	0.002	0.000003	0.58	0.16
15	0.0591	0.0455	0.0608	0.055138	0.008	0.000071	-1.58	0.83
20	0.0549	0.0663	0.0746	0.065242	0.010	0.000098	0.13	0.98
21	0.0629	0.0560	0.0547	0.057864	0.004	0.000019	-1.12	0.44

Average of all Labs	0.065
Std. Dev. Between Cell Averages (S_x)	0.005925
Repeatability Standard Deviation (S_r)	0.010077
Reproducibility Standard Deviation (S_R)	0.010139
Between Lab Standard Deviation of Lab Means(S_L)	0.001120
Pooled within lab variance (S_A^2)	0.000102
Between Lab Variance of Lab Means(S_L^2)	0.000001
W/L Variance	0.000102
B/L Variance	0.000103

Difference T166 Specific Gravity - SGC Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL D (FG15) 1	2	3	Avg.	Std. Dev.	Variance	h	k
1	0.0417	0.0457	0.0406	0.042671	0.003	0.000007	1.25	0.39
2	0.0381	0.0385	0.0537	0.043446	0.009	0.000079	1.45	1.31
3	0.0424	0.0330	0.0347	0.036694	0.005	0.000025	-0.31	0.74
4	0.0402	0.0353	0.0372	0.037568	0.002	0.000006	-0.09	0.36
5	0.0353	0.0366	0.0399	0.037246	0.002	0.000006	-0.17	0.35
6	0.0413	0.0422	0.0423	0.041958	0.001	0.000000	1.06	0.08
7	0.0308	0.0317	0.0380	0.033515	0.004	0.000015	-1.15	0.58
8	0.0350	0.0226	0.0403	0.032626	0.009	0.000082	-1.38	1.33
9	0.0388	0.0451	0.0392	0.041058	0.003	0.000012	0.82	0.52
10	0.0530	0.0365	0.0397	0.043056	0.009	0.000077	1.36	1.28
11	0.0369	0.0269	0.0333	0.032370	0.005	0.000026	-1.45	0.74
12	0.0427	0.0341	0.0445	0.040456	0.006	0.000031	0.66	0.82
13	0.0398	0.0252	0.0390	0.034689	0.008	0.000067	-0.85	1.20
14	0.0360	0.0332	0.0495	0.039579	0.009	0.000076	0.44	1.28
15	0.0468	0.0373	0.0317	0.038579	0.008	0.000058	0.18	1.12
20	0.0509	0.0336	0.0220	0.035482	0.015	0.000211	-0.63	2.13
21	0.0367	0.0326	0.0308	0.033365	0.003	0.000009	-1.19	0.44

Average of all Labs	0.038
Std. Dev. Between Cell Averages (S_x)	0.003813
Repeatability Standard Deviation (S_r)	0.006807
Reproducibility Standard Deviation (S_R)	0.006807
Between Lab Standard Deviation of Lab Means(S_L)	0.000000
Pooled within lab variance (S_A^2)	0.000046
Between Lab Variance of Lab Means(S_L^2)	0.000000
W/L Variance	0.000046
B/L Variance	0.000046

Difference T166 Specific Gravity - SGC Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL E (FG50)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	0.0416	0.0381	0.0364	0.038708	0.003	0.000007	0.34	0.18
2	0.0341	0.0363	0.0421	0.037541	0.004	0.000017	0.23	0.28
3	0.0410	0.0360	0.0391	0.038674	0.003	0.000006	0.34	0.17
4	0.0408	0.0368	0.0373	0.038284	0.002	0.000005	0.30	0.15
5	0.0354	0.0367	0.0361	0.036077	0.001	0.000000	0.10	0.04
6	0.0384	0.0408	0.0335	0.037552	0.004	0.000014	0.24	0.25
7	0.0363	0.0379	0.0369	0.037051	0.001	0.000001	0.19	0.05
8	0.0335	0.0301	0.0369	0.033472	0.003	0.000012	-0.12	0.23
9	0.0323	0.0422	0.0378	0.037418	0.005	0.000025	0.22	0.33
10	0.0404	0.0413	0.0381	0.039937	0.002	0.000003	0.45	0.11
11	0.0273	0.0335	0.0366	0.032466	0.005	0.000023	-0.22	0.32
12	0.0358	0.0407	0.0418	0.039428	0.003	0.000010	0.40	0.22
13	0.0372	0.0438	0.0412	0.040736	0.003	0.000011	0.52	0.22
14	0.0420	0.0386	0.0402	0.040258	0.002	0.000003	0.48	0.11
15	0.0390	0.0385	0.0355	0.037692	0.002	0.000004	0.25	0.13
20	0.0312	0.0365	0.0404	0.036044	0.005	0.000021	0.10	0.31
21	-0.0772	0.0256	0.0273	-0.008083	0.060	0.003583	-3.81	4.03

Average of all Labs	0.035
Std. Dev. Between Cell Averages (S_X)	0.011291
Repeatability Standard Deviation (S_r)	0.014839
Reproducibility Standard Deviation (S_R)	0.016562
Between Lab Standard Deviation of Lab Means(S_L)	0.007354
Pooled within lab variance (S_A^2)	0.000220
Between Lab Variance of Lab Means(S_L^2)	0.000054
W/L Variance	0.000220
B/L Variance	0.000274

Difference T166 Specific Gravity - SGC Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL F (FG100)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	0.0372	0.0390	0.0411	0.039134	0.002	0.000004	1.59	0.49
2	0.0359	0.0336	0.0346	0.034683	0.001	0.000001	-0.09	0.29
3	0.0421	0.0358	0.0358	0.037880	0.004	0.000013	1.13	0.91
4	0.0352	0.0360	0.0313	0.034192	0.002	0.000006	-0.29	0.63
5	0.0321	0.0346	0.0283	0.031659	0.003	0.000010	-1.24	0.79
6	0.0321	0.0284	0.0323	0.030923	0.002	0.000005	-1.52	0.55
7	0.0330	0.0525	0.0334	0.039641	0.011	0.000125	1.79	2.79
8	0.0290	0.0303	0.0373	0.032198	0.005	0.000020	-1.04	1.12
9	0.0404	0.0343	0.0348	0.036489	0.003	0.000012	0.60	0.85
10	0.0360	0.0404	0.0361	0.037471	0.003	0.000006	0.98	0.63
11	0.0297	0.0306	0.0354	0.031898	0.003	0.000009	-1.15	0.77
12	0.0357	0.0341	0.0381	0.035970	0.002	0.000004	0.39	0.50
13	0.0340	0.0329	0.0417	0.036202	0.005	0.000023	0.48	1.20
14	0.0340	0.0359		0.034988	0.001	0.000002	0.01	0.24
15	0.0305	0.0383	0.0320	0.033595	0.004	0.000017	-0.51	1.04
20	0.0313	0.0374	0.0324	0.033661	0.003	0.000011	-0.47	0.81
21	0.0315	0.0355	0.0325	0.033172	0.002	0.000004	-0.67	0.52

Average of all Labs	0.035
Std. Dev. Between Cell Averages (S_X)	0.002630
Repeatability Standard Deviation (S_r)	0.003999
Reproducibility Standard Deviation (S_R)	0.004192
Between Lab Standard Deviation of Lab Means(S_L)	0.001259
Pooled within lab variance (S_A^2)	0.000016
Between Lab Variance of Lab Means(S_L^2)	0.000002
W/L Variance	0.000016
B/L Variance	0.000018

Difference T166 Specific Gravity - SGC Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL G (SMA15)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	0.1197	0.1174	0.1244	0.120492	0.004	0.000013	-0.19	0.15
2	0.1133	0.1194	0.1223	0.118335	0.005	0.000021	-0.32	0.19
3	0.1440	0.1449	0.1386	0.142522	0.003	0.000012	1.10	0.14
4	0.1265	0.1253	0.1426	0.131465	0.010	0.000093	0.45	0.40
5	0.1000	0.1052	0.1136	0.106269	0.007	0.000047	-1.03	0.28
6	0.1273	0.1458	0.1288	0.133943	0.010	0.000105	0.60	0.42
7	0.1232	0.1601	0.1329	0.138735	0.019	0.000365	0.88	0.79
8	0.1070	0.1241	0.1175	0.116215	0.009	0.000074	-0.45	0.36
9	0.1030	0.1226	0.1229	0.116163	0.011	0.000130	-0.45	0.47
10	0.1154	0.1173	0.2602	0.164300	0.083	0.006897	2.38	3.43
11	0.0945	0.0907	0.1044	0.096546	0.007	0.000050	-1.60	0.29
12	0.1545	0.1136	0.1420	0.136705	0.021	0.000438	0.76	0.87
13	0.1470	0.1151	0.1245	0.128873	0.016	0.000268	0.30	0.68
14	0.1110	0.1167	0.1153	0.114318	0.003	0.000009	-0.56	0.12
15	0.1113	0.1235	0.1268	0.120534	0.008	0.000066	-0.19	0.34
20	0.1142	0.1256	0.1296	0.123148	0.008	0.000063	-0.04	0.33
21	0.0552	0.1224	0.1104	0.096007	0.036	0.001284	-1.63	1.48

Average of all Labs	0.124
Std. Dev. Between Cell Averages (S_x)	0.017044
Repeatability Standard Deviation (S_r)	0.024176
Reproducibility Standard Deviation (S_R)	0.026079
Between Lab Standard Deviation of Lab Means(S_L)	0.009781
Pooled within lab variance (S_A^2)	0.000584
Between Lab Variance of Lab Means(S_L^2)	0.000096
W/L Variance	0.000584
B/L Variance	0.000680

Difference T166 Specific Gravity - SGC Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL H (SMA50)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	0.0883	0.1185	0.0991	0.101958	0.015	0.000236	1.28	1.33
2	0.1029	0.1008	0.0964	0.100021	0.003	0.000011	1.03	0.29
3	0.0928	0.0978	0.0987	0.096415	0.003	0.000010	0.56	0.28
4	0.0924	0.0877	0.0890	0.089659	0.002	0.000006	-0.32	0.21
5	0.0939	0.0846	0.0837	0.087380	0.006	0.000032	-0.62	0.49
6	0.0960	0.0907	0.0781	0.088246	0.009	0.000084	-0.51	0.80
7	0.1015	0.0977	0.0890	0.096058	0.006	0.000041	0.51	0.56
8	0.0895	0.0902	0.0344	0.071382	0.032	0.001025	-2.72	2.79
9	0.1023	0.0929	0.0805	0.091914	0.011	0.000119	-0.03	0.95
10	0.0810	0.1058	0.0841	0.090316	0.014	0.000183	-0.24	1.18
11	0.0865	0.0901	0.0974	0.091318	0.006	0.000031	-0.11	0.48
12	0.1029	0.1047	0.1004	0.102645	0.002	0.000005	1.37	0.19
13	0.1024	0.1021	0.0853	0.096628	0.010	0.000096	0.58	0.85
14	0.0850	0.0959	0.1010	0.093960	0.008	0.000067	0.24	0.71
15	0.1056	0.0836	0.1008	0.096640	0.012	0.000133	0.59	1.01
20	0.0893	0.0867	0.0949	0.090289	0.004	0.000017	-0.24	0.37
21	0.0893	0.0879	0.0681	0.081789	0.012	0.000141	-1.36	1.03

Average of all Labs	0.092
Std. Dev. Between Cell Averages (S_x)	0.007647
Repeatability Standard Deviation (S_r)	0.011467
Reproducibility Standard Deviation (S_R)	0.012089
Between Lab Standard Deviation of Lab Means(S_L)	0.003827
Pooled within lab variance (S_A^2)	0.000131
Between Lab Variance of Lab Means(S_L^2)	0.000015
W/L Variance	0.000131
B/L Variance	0.000146

Difference T166 Specific Gravity - SGC Specific Gravity

TMD Coarse Graded (CG)	2.506
TMD Fine Graded (FG)	2.510
TMD SMA	2.464

LAB	MATERIAL I (SMA100)							
	1	2	3	Avg.	Std. Dev.	Variance	h	k
1	0.0829	0.0802	0.0874	0.083479	0.004	0.000013	1.65	0.38
2	0.0859	0.0701	0.0785	0.078176	0.008	0.000063	0.93	0.82
3	0.0681	0.0725	0.0572	0.065929	0.008	0.000061	-0.72	0.82
4	0.0692	0.0746	0.0591	0.067623	0.008	0.000062	-0.49	0.82
5	0.0649	0.0829	0.0592	0.068992	0.012	0.000153	-0.31	1.29
6	0.0806	0.0843	0.0784	0.081123	0.003	0.000009	1.32	0.31
7	0.0845	0.0725	0.0773	0.078130	0.006	0.000036	0.92	0.63
8	0.0828	0.0663	0.0710	0.073350	0.008	0.000072	0.28	0.89
9	0.0670	0.0984	0.0677	0.077691	0.018	0.000321	0.87	1.87
10	0.0503	0.0489	0.0702	0.056505	0.012	0.000142	-1.99	1.24
11	0.0496	0.0714	0.0804	0.067136	0.016	0.000252	-0.56	1.65
12	0.0780	0.0623	0.0821	0.074120	0.010	0.000109	0.39	1.09
13	0.0617	0.0638	0.0781	0.067877	0.009	0.000080	-0.46	0.93
14	0.0753	0.0813	0.0708	0.075818	0.005	0.000028	0.61	0.55
15	0.0744	0.0623	0.0700	0.068911	0.006	0.000038	-0.32	0.64
20	0.0671	0.0698	0.0670	0.067955	0.002	0.000003	-0.44	0.17
21	0.0463	0.0627	0.0674	0.058782	0.011	0.000122	-1.68	1.15

Average of all Labs	0.071
Std. Dev. Between Cell Averages (S_x)	0.007422
Repeatability Standard Deviation (S_r)	0.009590
Reproducibility Standard Deviation (S_R)	0.010789
Between Lab Standard Deviation of Lab Means(S_L)	0.004943
Pooled within lab variance (S_A^2)	0.000092
Between Lab Variance of Lab Means(S_L^2)	0.000024
W/L Variance	0.000092
B/L Variance	0.000116

APPENDIX G

F-Test Results Comparing Material Variances Based on Difference Analysis

SSD Variances with Outliers

SSD Within-Lab Variances — 7 of 36 not significantly different

				1FG 100	CG 50	FG 15	SMA 100	CG 100	SMA 50	CG 15	FG 50	SMA 15
			n	50	50	51	50	50	50	51	51	50
			s	0.0040	0.0048	0.0068	0.0096	0.0101	0.0115	0.0126	0.0148	0.0242
	2n	s	s^2	0.000016	0.000023	0.000046	0.000092	0.000102	0.000131	0.000159	0.000220	0.000584
FG 100	50	0.0040	0.000016		1.46	2.90	5.75	6.35	8.22	9.93	13.77	36.55
CG 50	50	0.0048	0.000023			1.98	3.93	4.34	5.62	6.78	9.41	24.97
FG 15	51	0.0068	0.000046				1.98	2.19	2.84	3.43	4.75	12.61
SMA 100	50	0.0096	0.000092					1.10	1.43	1.73	2.39	6.35
CG 100	50	0.0101	0.000102						1.29	1.56	2.17	5.76
SMA 50	50	0.0115	0.000131							1.21	1.67	4.44
CG 15	51	0.0126	0.000159								1.39	3.68
FG 50	51	0.0148	0.000220									2.65
SMA 15	50	0.0242	0.000584									

F critical for V1 = v2 = 50 = 1.61 at alpha = 0.05 (95% confidence)

= significant difference at 90% confidence'

SSD Between Lab Variances — 5 of 36 not significantly different

				1FG 100	CG 50	FG 15	CG 100	SMA 100	SMA 50	CG 15	FG 50	SMA 15
			n	50	50	51	50	50	50	51	51	50
			s	0.0042	0.0067	0.0068	0.0101	0.0108	0.0121	0.0157	0.0166	0.0261
	2n	s	s^2	0.000018	0.000045	0.000046	0.000103	0.000116	0.000146	0.000247	0.000274	0.000680
FG 100	50	0.0042	0.000018		2.54	2.64	5.85	6.62	8.31	14.06	15.61	38.70
CG 50	50	0.0067	0.000045			1.04	2.30	2.61	3.27	5.53	6.14	15.24
FG 15	51	0.0068	0.000046				2.22	2.51	3.15	5.33	5.92	14.68
CG 100	50	0.0101	0.000103					1.13	1.42	2.40	2.67	6.62
SMA 100	50	0.0108	0.000116						1.26	2.12	2.36	5.84
SMA 50	50	0.0121	0.000146							1.69	1.88	4.65
CG 15	51	0.0157	0.000247								1.11	2.75
FG 50	51	0.0166	0.000274									2.48
SMA 15	50	0.0261	0.000680									

Corelok Variances With Outliers

Corelok Within-lab variances 9 of 36 not significantly different

				1FG 50	FG 15	FG 100	SMA 100	CG 100	CG 50	CG 15	SMA 15	SMA 50
			n	51	51	50	50	50	50	51	50	50
			s	0.0075	0.0098	0.0103	0.0109	0.0141	0.0142	0.0151	0.0171	0.0417
	2n	s	s^2	0.000057	0.000096	0.000105	0.000119	0.000199	0.000201	0.000227	0.000291	0.001741
FG 50	51	0.0075	0.000057		1.68	1.85	2.09	3.51	3.53	3.98	5.11	30.60
FG 15	51	0.0098	0.000096			1.10	1.24	2.09	2.10	2.37	3.04	18.22
FG 100	50	0.0103	0.000105				1.13	1.89	1.91	2.15	2.76	16.53
SMA 100	50	0.0109	0.000119					1.68	1.69	1.91	2.45	14.65
CG 100	50	0.0141	0.000199						1.01	1.14	1.46	8.73
CG 50	50	0.0142	0.000201							1.13	1.45	8.66
CG 15	51	0.0151	0.000227								1.28	7.68
SMA 15	50	0.0171	0.000291									5.99
SMA 50	50	0.0417	0.001741									

F critical for V1 = v2 = 50 = 1.61 at alpha = 0.05 (95% confidence)

= significant difference at 90% confidence'

Corelok Between Lab Variances 13 of 36 not significantly different

				1FG 50	FG 15	FG 100	CG 100	SMA 100	CG 50	SMA 15	CG 15	SMA 50
			n	51	51	50	50	50	50	50	51	50
			s	0.0084	0.0099	0.0103	0.0141	0.0145	0.0156	0.0173	0.0179	0.0441
	2n	s	s^2	0.000071	0.000097	0.000105	0.000199	0.000211	0.000243	0.000300	0.000321	0.001945
FG 50	51	0.0084	0.000071		1.38	1.49	2.82	2.99	3.45	4.25	4.54	27.53
FG 15	51	0.0099	0.000097			1.08	2.05	2.18	2.51	3.09	3.30	20.02
FG 100	50	0.0103	0.000105				1.89	2.01	2.31	2.85	3.05	18.47
CG 100	50	0.0141	0.000199					1.06	1.22	1.51	1.61	9.75
SMA 100	50	0.0145	0.000211						1.15	1.42	1.52	9.20
CG 50	50	0.0156	0.000243							1.23	1.32	7.99
SMA 15	50	0.0173	0.000300								1.07	6.48
CG 15	51	0.0179	0.000321									6.07
SMA 50	50	0.0441	0.001945									

SSD Variances Without Outliers

SSD Within Lab Variances

			1	FG 50	FG 100	CG 50	CG 100	FG 15	SMA 50	SMA 100	CG 15	SMA 15
			n	51	50	50	50	51	50	50	51	50
			s	0.0031	0.0040	0.0040	0.0067	0.0068	0.0084	0.0096	0.0126	0.0134
	n	s	s^2	0.000010	0.000016	0.000016	0.000045	0.000046	0.000071	0.000092	0.000159	0.000179
FG 50	51	0.0031	0.000010		1.676383	1.699162	4.703222	4.857881	7.466254	9.64202	16.64489	18.74982
FG 100	50	0.0040	0.000016			1.013588	2.805577	2.897834	4.453787	5.75168	9.929051	11.18469
CG 50	50	0.0040	0.000016				2.767966	2.858987	4.394081	5.674575	9.795945	11.03475
CG 100	50	0.0067	0.000045					1.032883	1.587476	2.050088	3.53904	3.98659
FG 15	51	0.0068	0.000046						1.536936	1.98482	3.426369	3.859671
SMA 50	50	0.0084	0.000071							1.291413	2.22935	2.511275
SMA 100	50	0.0096	0.000092								1.726287	1.944595
CG 15	51	0.0126	0.000159									1.126461
SMA 15	50	0.0134	0.000179									

F critical for V1 = v2 = 50 = 1.61 at alpha = 0.05 (95% confidence)

= significant difference at 90% confidence'

SSD Between Lab Variances

			1	FG 100	FG 50	CG 50	FG 15	CG 100	SMA 50	SMA 100	CG 15	SMA 15
			n	50	51	50	51	50	50	50	51	50
			s	0.0042	0.0043	0.0058	0.0068	0.0068	0.0088	0.0108	0.0157	0.0174
	2n	s	s^2	0.000018	0.000018	0.000033	0.000046	0.000046	0.000078	0.000116	0.000247	0.000302
FG 100	50	0.0042	0.000018		1.048926	1.886805	2.636375	2.64515	4.441375	6.622626	14.05608	17.19446
FG 50	51	0.0043	0.000018			1.798797	2.513405	2.52177	4.234213	6.313722	13.40045	16.39244
CG 50	50	0.0058	0.000033				1.397269	1.40192	2.353913	3.509968	7.449671	9.113002
FG 15	51	0.0068	0.000046					1.003328	1.684652	2.51202	5.331592	6.522008
CG 100	50	0.0068	0.000046						1.679063	2.503686	5.313905	6.500371
SMA 50	50	0.0088	0.000078							1.491121	3.164803	3.871427
SMA 100	50	0.0108	0.000116								2.122433	2.59632
CG 15	51	0.0157	0.000247									1.223276
SMA 15	50	0.0174	0.000302									

Corelok Variances Without Outliers

Corelok Within-Lab Variances

			1	CG 50	FG 100	FG 50	CG 100	SMA 15	SMA 100	FG 15	SMA 50	CG 15
			n	50	50	51	50	50	50	51	50	51
			s	0.0046	0.0053	0.0058	0.0081	0.0088	0.0091	0.0098	0.0103	0.0108
	2n	s	s^2	0.000022	0.000029	0.000033	0.000066	0.000078	0.000083	0.000096	0.000106	0.000117
CG 50	50	0.0046	0.000022		1.323539	1.532373	3.047347	3.601706	3.855389	4.419492	4.886605	5.389405
FG 100	50	0.0053	0.000029			1.157785	2.302424	2.721269	2.91294	3.339147	3.692075	4.071965
FG 50	51	0.0058	0.000033				1.988645	2.35041	2.515959	2.884083	3.188913	3.517031
CG 100	50	0.0081	0.000066					1.181915	1.265162	1.450275	1.60356	1.768556
SMA 15	50	0.0088	0.000078						1.070434	1.227055	1.356747	1.496348
SMA 100	50	0.0091	0.000083							1.146315	1.267474	1.397889
FG 15	51	0.0098	0.000096								1.105694	1.219463
SMA 50	50	0.0103	0.000106									1.102893
CG 15	51	0.0108	0.000117									

Compare between lab variances, Corelok

			1	FG 100	CG 50	FG 50	CG 100	SMA 15	FG 15	CG 15	SMA 50	SMA 100
			n	50	50	51	50	50	51	51	50	50
			s	0.0056	0.0066	0.0069	0.0081	0.0094	0.0099	0.0116	0.0120	0.0126
	2n	s	s^2	0.000032	0.000044	0.000048	0.000066	0.000089	0.000097	0.000134	0.000145	0.000158
FG 100	50	0.0056	0.000032		1.380093	1.524979	2.087736	2.815948	3.079777	4.236799	4.590184	5.007952
CG 50	50	0.0066	0.000044			1.104983	1.51275	2.040405	2.231572	3.069937	3.325996	3.628706
FG 50	51	0.0069	0.000048				1.369026	1.846549	2.019554	2.778267	3.009998	3.283948
CG 100	50	0.0081	0.000066					1.348805	1.475175	2.029375	2.198642	2.398747
SMA 15	50	0.0094	0.000089						1.093691	1.504573	1.630067	1.778425
FG 15	51	0.0099	0.000097							1.375684	1.490427	1.626076
CG 15	51	0.0116	0.000134								1.083409	1.182013
SMA 50	50	0.0120	0.000145									1.091013
SMA 100	50	0.0126	0.000158									

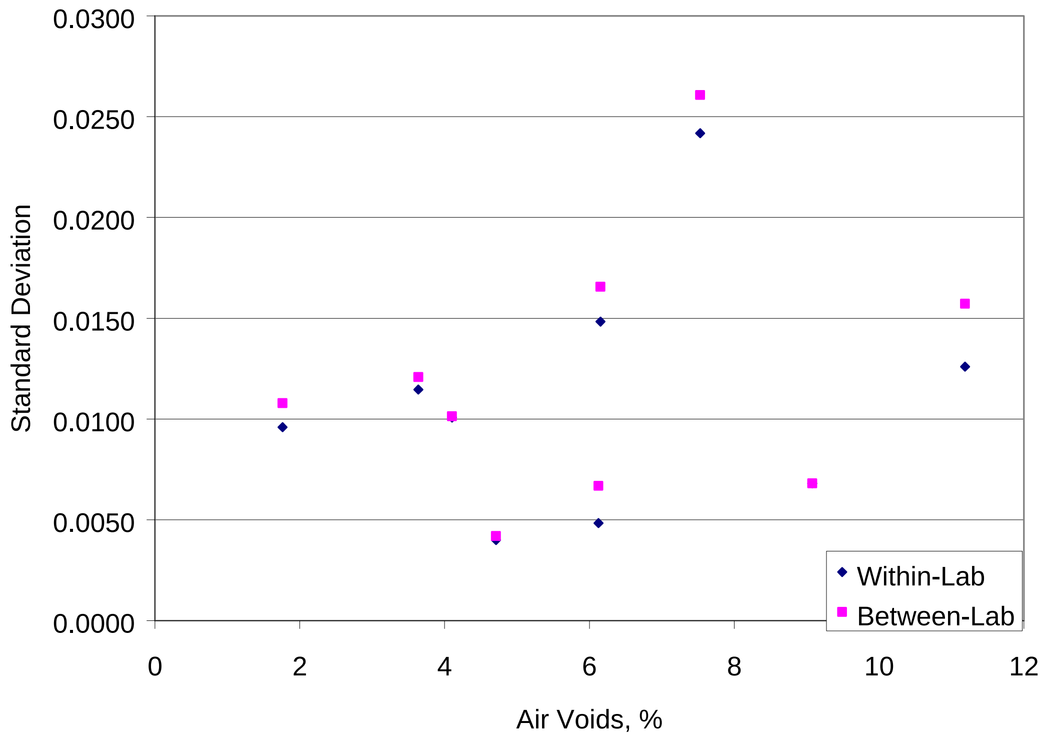

Figure G1. SSD Within and Between Laboratory Standard Deviations with Outliers Versus Air Voids

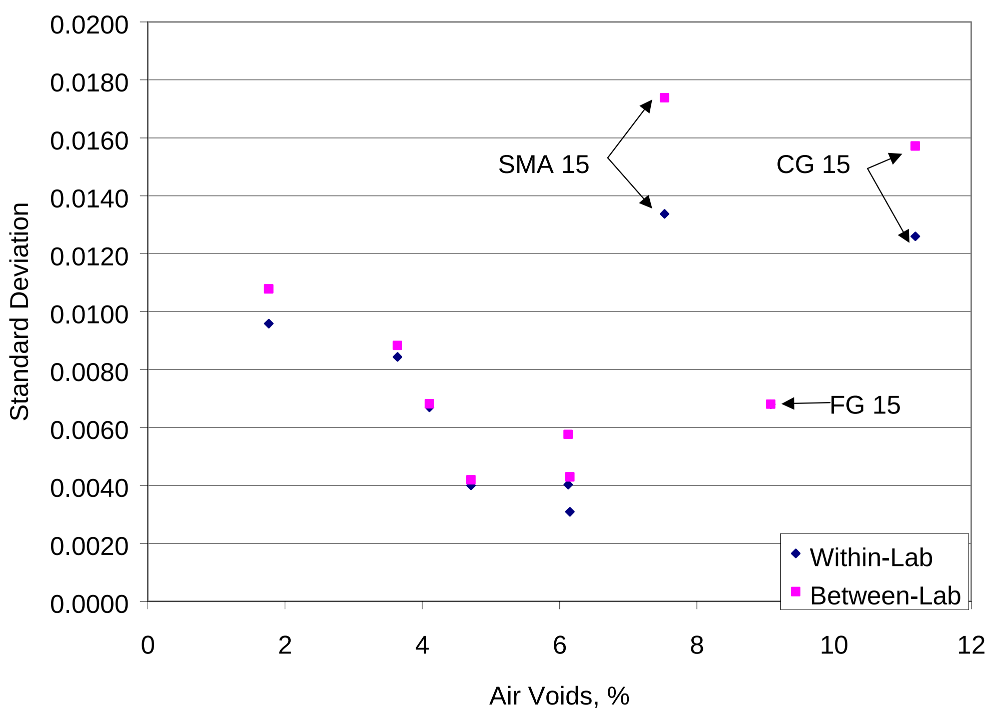

Figure G2. SSD Within and Between Laboratory Standard Deviations with Outliers Removed Versus Air Voids

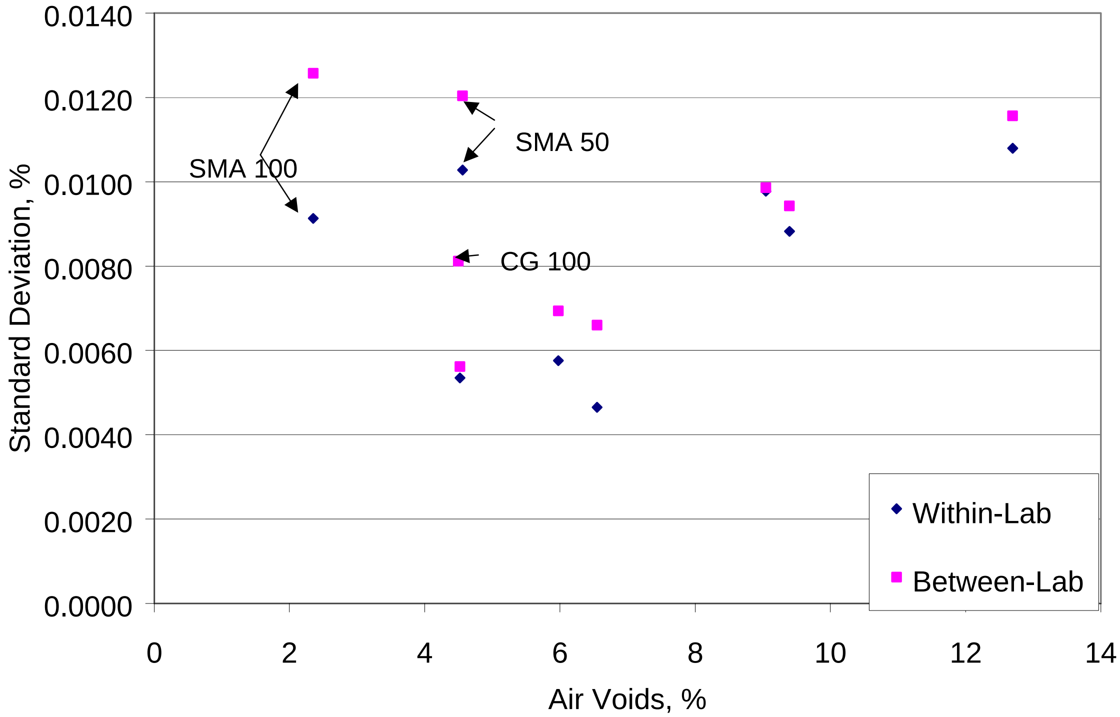

Figure G3. Corelok Within and Between Laboratory Standard Deviations with Outliers Removed Versus Air Voids