STATE OF FLORIDA

Investigation of the CoreLok for Maximum, Aggregate and Bulk Specific Gravity Tests

Research Report
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STATE MATERIALS OFFICE

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The Florida Department of Transportation uses long established test procedures (very similar to the corresponding AASHTO test procedures) to determine the maximum specific gravity (G_{mm}) and bulk specific gravity (G_{mb}) of asphalt mixtures and bulk specific gravity (G_{sb}) of aggregates. These asphalt mixture and aggregate properties are needed to calculate the volumetric properties (air voids, voids in the mineral aggregate and voids filled with asphalt) used in asphalt mixture design and production. The CoreLok is a vacuum-sealing device that can be used for determining the G_{mm} and G_{mb} of asphalt mixture samples and the G_{sb} of both coarse and fine aggregates. The Department evaluated the CoreLok for these four test procedures. With respect to the G_{mm} test procedure, for mixtures containing non-absorptive granites, the CoreLok determined equivalent results compared to the Department's test procedure. However, for mixtures containing absorptive limestones, the CoreLok determined higher G_{mm} values compared to the Department's test procedure. The apparent reason for the discrepancy is because the CoreLok does not determine a saturated surface-dry condition of the sample. Repeatability of test results was comparable to the Department's test procedure. With respect to the aggregate specific gravity test procedures, the CoreLok provided equivalent test results to the Department's test procedure for the non-absorptive fine aggregates only. For the absorptive fine aggregates and all of the coarse aggregates, the CoreLok determined significantly different G_{sb} test results compared to the Department's test procedures. The CoreLok may be suitable for determining G_{mb} test results for coarse graded compacted specimens with high porosity and air voids. However, there are concerns with the accuracy of the CoreLok results due to the bridging effect of the plastic bag over the large surface voids and due to the CoreLok's significant underestimation of the specific gravity of a solid aluminum cylinder.

INTRODUCTION

The adoption of the Superpave mix design methodology in 1996 by the Florida Department of Transportation, herein referred to as the Department, requires more volumetric mixture testing than the Marshall mix design system used prior to Superpave. Air voids (V_a), voids in the mineral aggregate (VMA) and voids filled with asphalt (VFA) are specification criteria in the Superpave mix design system. To determine these values, the maximum specific gravity of the mixture (G_{mm}), the bulk specific gravity of the compacted mixture (G_{mb}), and the aggregate bulk specific gravity (G_{sb}) are needed. Furthermore, the addition of the fine aggregate angularity test (FAA) by the Superpave mix design system also requires the determination of the fine aggregate specific gravity value in order to calculate the FAA value.

The Department uses long established test procedures (very similar to the corresponding AASHTO test procedures) to determine these mixture and aggregate properties needed to calculate the volumetric properties. However, there are some concerns with these test procedures. The G_{mm} test procedure is more complicated to perform compared to many other laboratory test procedures and requires that the sample be brought to a saturated surface-dry (SSD) condition when using absorptive aggregates, like those commonly encountered in Florida. This “dryback” portion of the test procedure may add one to two hours to the testing time. Two test procedures exist for the determination of the G_{sb} of aggregates, one procedure for coarse aggregates and one procedure for fine aggregates. Both test procedures are very sensitive to operator technique and take nearly a full day to perform when considering the preliminary aggregate soak time required. There are also concerns that the determination of the SSD condition of the fine aggregate by the cone and tamp technique may not be consistent between different aggregates because the amount of slump of the fine aggregate is also dependent on the angularity and texture of the fine aggregate and not just on the quantity of surface moisture present. The determination of G_{mb} for asphalt mixture specimens by the water displacement method is very sound theoretically and is practical to perform. However, the test procedure is not applicable for highly porous mixtures where the water drains out of the pores prior to determining the SSD weight. This condition will result in an inaccurate specimen volume determination and a corresponding inaccuracy in the G_{mb} value.

Due to the previously discussed limitations, there is an interest in new test procedures or equipment that can replace or improve upon the existing Department test procedures. InstroTek, Inc., of Raleigh, NC, developed a new test device in the late 1990’s, termed the CoreLok, with the intention of addressing these limitations. The CoreLok is a vacuum-sealing device (Figure 1) that can be used for determining the G_{mm} and G_{mb} of asphalt mixture samples and the G_{sb} of both coarse and fine aggregates.

Figure 1 – CoreLok Test Device

In order to assess the suitability of this device, the Department acquired a CoreLok and evaluated the device with respect to its ability to determine the G_{mm} of asphalt mixtures, the G_{sb} of both coarse and fine aggregates and the G_{mb} of compacted asphalt mixture specimens.

BACKGROUND AND THEORY OF OPERATION

The CoreLok is a relatively new test device that has gained widespread attention due to its potential to determine multiple asphalt/aggregate properties in a timely and precise manner. The basic function of the CoreLok is to provide a chamber where a vacuum can be applied. The amount of vacuum applied is nearly equal to one atmosphere, resulting in a residual pressure of near zero millimeters of mercury within the chamber.

The general concept of performing a test using the CoreLok is as follows: the asphalt mixture or aggregate samples are placed in a plastic bag, the bag and sample are then placed in the CoreLok chamber, the vacuum is applied, the bag is sealed while in the chamber, atmospheric pressure is slowly applied to the sample and then the sample is removed from the chamber. A G_{mm} sample is shown in Figure 2. The bag/sample is then submerged in a water bath and weighed. Depending on the test procedure, the bag may or may not be cut open while submerged in the water bath. There is additional testing equipment involved (bowls, pycnometers, syringes, etc.) used for some of the tests, which will not be discussed in this report. One can refer to the test procedures from InstroTek for more details. The weights recorded throughout the process are then used to calculate the respective material property in question. InstroTek has provided computer software to perform the required calculations.

Figure 2 – CoreLok G_{mm} Sample

A review of published literature shows that the majority of the research conducted to date with the CoreLok is related to the determination of G_{mb} of compacted asphalt specimens. There is much less published research regarding the G_{mm} and G_{sb} test procedures. Results of the published research will be cited subsequently in this report in the individual sections concerning G_{mm}, G_{sb} and G_{mb}.

OBJECTIVES

The objectives of this study are to evaluate the CoreLok in terms of accuracy, precision, testing time and practicality for the G_{mm}, G_{sb} and G_{mb} test procedures. A variety of mixture and aggregate types will be examined including aggregates with a range of low to high absorption. Current Department test procedures will be used as a reference point to determine accuracy, though the researchers acknowledge that the true value of the test parameter is unknown. Test procedure precision will be estimated based on the variance of the test results, however, the extensive testing necessary to determine accurate within-lab and between-lab precision values will not be performed as part of this research. The results of the research will allow a general determination to be made regarding the suitability of the CoreLok to replace or supplement existing Department test procedures. The research results will be presented in terms of the test parameter being evaluated in the following order: G_{mm}, G_{sb} and G_{mb}.

MAXIMUM SPECIFIC GRAVITY TEST RESULTS

Five different asphalt mixtures and one source of reclaimed asphalt pavement (RAP) were tested using the Department's test procedure, FM 1-T 209, and the CoreLok for determination of the material's G_{mm} value. The mixtures encompassed several aggregate types and gradation ranges. Information regarding the six materials tested is presented in Table 1. All mixtures, excluding the RAP, contained a PG 67-22 asphalt binder. The RAP material contained approximately 85 to 90% by weight of asphalt coated particles.

Table 1 – Information for Materials Tested for G_{mm}

Mixture Designation	Nominal Max Aggregate Size (mm)	Coarse or Fine	Aggregate Type	Aggregate Source	Mine Identification	Degree of Aggregate Water Absorption	% Water Absorption
G-1	9.5	Fine	Granite	Macon, GA	GA-185	Very low	< 1
LS-1	12.5	Fine	Limestone & RAP-1	Miami, FL	87-145, 87-339, 87-090, RAP-1	Medium	2-3
LS-2	12.5	Coarse	Limestone & RAP-1	Miami, FL	87-090, 87-339, 87-145, RAP-1	Medium	2-3
LS-3	12.5	Fine	Limestone	Miami, FL	87-090	Medium	2-3
LS-4	19.0	Coarse	Limestone	Cabbage Grove, FL	38-036, 29-023	High	5-6
RAP-1	9.5	Fine	Limestone	Southeast FL, Various Projects	Pavex, Inc.	Low	1-2

The Department's test procedure for G_{mm} requires that the SSD weight of the uncompacted asphalt mixture sample be determined after the sample is removed from the flask. The Department requires this because a majority of the asphalt mixtures used for State highway construction projects contain some absorptive Florida limestone aggregates. The SSD determination is necessary to obtain an accurate volume determination of the uncompacted mixture sample. All samples tested per the Department's test procedure for this study included the SSD determination.

Ten replicate samples were fabricated in the laboratory for each mixture type and test procedure. Therefore, a total of 120 samples (6 material types x 2 test procedures x 10 samples) were tested for this study. Additional samples were tested in the CoreLok prior to the start of this study so that the operator could become proficient with the test procedure. All ten samples per material type and test procedure were tested by the same operator. The Department's test procedure, FM 1-T 209, requires that two samples be tested and the G_{mm} values for both samples averaged to determine one test result. In order to get a direct comparison of test variability between FM 1-T 209 and the CoreLok test procedures, test results presented for the FM 1-T 209 test procedure are for the individual sample G_{mm} values. Test results are shown in Table 2.

Table 2 – G_{mm} Test Data for the CoreLok and FM 1-T 209

Sample #	Mixture Designation											
	G-1		LS-1		LS-2		LS-3		LS-4		RAP	
	CoreLok	FM 1-T 209	CoreLok	FM 1-T 209	CoreLok	FM 1-T 209	CoreLok	FM 1-T 209	CoreLok	FM 1-T 209	CoreLok	FM 1-T 209
1	2.497	2.495	2.348	2.348	2.332	2.328	2.316	2.311	2.349	2.315	2.441	2.441
2	2.504	2.494	2.358	2.347	2.332	2.329	2.314	2.309	2.347	2.309	2.444	2.447
3	2.492	2.496	2.354	2.349	2.327	2.327	2.310	2.311	2.349	2.314	2.449	2.446
4	2.497	2.500	2.356	2.348	2.326	2.329	2.320	2.313	2.350	2.317	2.451	2.447
5	2.496	2.500	2.352	2.349	2.330	2.326	2.311	2.306	2.348	2.312		2.449
6	2.499	2.496	2.369	2.348	2.332	2.325	2.312	2.302	2.345	2.313	2.451	2.447
7	2.498	2.496	2.361	2.351	2.333	2.326	2.316	2.313	2.349	2.317	2.452	2.447
8	2.499	2.496	2.370	2.349	2.328	2.327	2.322	2.314	2.347	2.314	2.447	2.443
9	2.496	2.497	2.371	2.350	2.324	2.329	2.311	2.311	2.337	2.312	2.450	2.446
10	2.498	2.497	2.361	2.350	2.332	2.327	2.312	2.309	2.348	2.311	2.448	2.444
Average	2.497	2.497	2.360	2.349	2.330	2.327	2.314	2.310	2.347	2.314	2.448	2.446
Difference (Corelok-FM 1-T 209)	0.001		0.011		0.002		0.004		0.033		0.002	
Std. Dev.	0.0031	0.0018	0.0078	0.0011	0.0032	0.0014	0.0040	0.0036	0.0037	0.0025	0.0035	0.0023

Table 2 displays the average and standard deviation of the ten G_{mm} test results for each material type and test procedure combination. The difference between the average CoreLok G_{mm} value and the FM 1-T 209 G_{mm} value is also displayed for each material type and test procedure combination. Examination of the data reveals that the CoreLok average

G_{mm} value was higher than the FM 1-T 209 G_{mm} value for every material tested. In practical terms, the average difference was minimal for the G-1, LS-2 and RAP materials (0.001, 0.002 and 0.002 respectively). The average difference was moderate for the LS-3 material (0.004). The average difference was significant for the LS-1 and LS-4 materials (0.011 and 0.033 respectively). For the range of the G_{mm} differences discussed above, the effect expressed in terms of air voids is shown graphically in Figure 3. For a G_{mm} difference of 0.011, the change in air voids is approximately 0.45% and for a G_{mm} difference of 0.033, the change in air voids is approximately 1.33%.

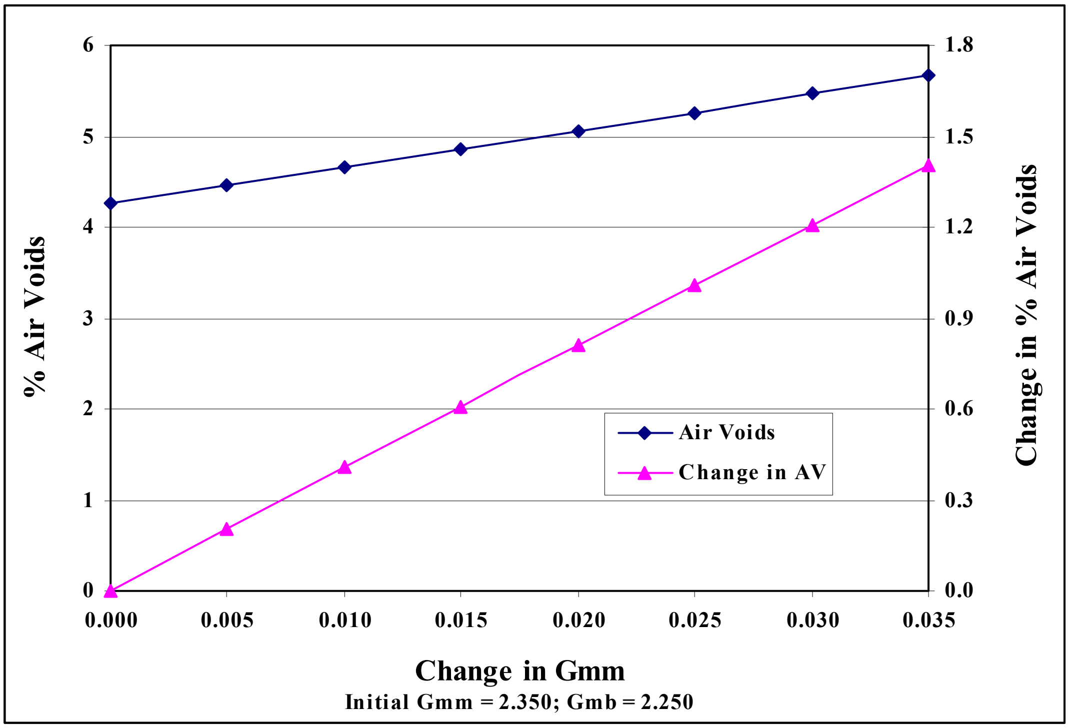


Figure 3 – Effect of G_{mm} on % Air Voids

A statistical t-test analysis was conducted for each material and the results are displayed in Table 3. The null hypothesis is that the difference between the average CoreLok G_{mm} value and the average FM 1-T 209 G_{mm} value for each material is zero. The alternative hypothesis is that the average CoreLok G_{mm} value does not equal the average FM 1-T 209

Table 3 – t-test Results for G_{mm} Test Data for the CoreLok and FM 1-T 209

	Mixture Designation					
	G-1	LS-1	LS-2	LS-3	LS-4	RAP
t-statistic	0.54	4.32	2.01	2.52	23.86	1.80
t-critical	2.10	2.10	2.10	2.10	2.10	2.11
Significantly Different?	No	Yes	No	Yes	Yes	No
p-value	0.59	4.12E-04	0.06	0.02	4.47E-15	0.09

G_{mm} value for each material. The statistical analysis concludes that the mean G_{mm} values for the LS-1, LS-3 and LS-4 materials are statistically different at a significance level of 0.05. Additionally, the t-test for the LS-2 mixture resulted in a p-value of 0.06, which is nearly statistically different for a t-test conducted at a level of significance of 0.05. It is worthy to note that these four materials are all limestone mixtures with medium to high absorption values. The two materials that were not found to be statistically different were the Georgia granite mixture and the RAP material. The Georgia granite is a "very low" absorption (<1%) material and the RAP was a "low" absorption (1 to 2%) material.

With respect to testing variability, examination of the data in Table 2 shows that the CoreLok standard deviations (square root of variance) are greater than the FM 1-T 209 standard deviations for every material tested. A statistical F-test was conducted for each material and the results are displayed in Table 4. The null hypothesis is that the variances are equal. The alternative hypothesis is that the variances are not equal. The statistical analysis concludes that the variance values for the LS-1 and LS-2 materials are statistically different at a significance level of 0.05. Considering that the CoreLok G_{mm} test procedure is new and operator experience was limited, the variability analysis is promising. Testing variance close to that of FM 1-T 209 was achieved with the CoreLok.

Table 4 – F-test Results for G_{mm} Test Data for the CoreLok and FM 1-T 209

	Mixture Designation					
	G-1	LS-1	LS-2	LS-3	LS-4	RAP
F-statistic	2.92	50.10	5.00	1.24	2.14	2.31
F-critical	4.03	4.03	4.03	4.03	4.03	4.10
Significantly Different?	No	Yes	Yes	No	No	No
p-value	0.06	1.28E-06	0.01	0.38	0.14	0.12

Examination of the Effect of the SSD Weight on G_{mm}

The researchers believe that the discrepancy between the CoreLok and FM 1-T 209 G_{mm} test values for the more absorptive materials is because the CoreLok test procedure does not have a "dryback" procedure for the determination of the SSD weight of the material. Using the dry weight of the material instead of the SSD weight of the material in the sample volume determination will result in a smaller sample volume and a higher G_{mm} value. The more absorptive a material is, the greater the difference is between the dry and SSD weights. For example, for a 1000 g sample, the SSD weight for an LS-4 mixture may be up to 8 g higher than the dry weight. To determine the effect of the dryback procedure, the G_{mm} values tested per FM 1-T 209 were recalculated using the dry weight in the volume determination instead of the SSD weight. These recalculated FM 1-T 209 G_{mm} values were then compared to the CoreLok G_{mm} values (see Table 5). For all of the asphalt mixtures tested (excluding loose RAP material), the average difference between test procedures decreased, indicating better agreement between the test procedures. The LS-1 and LS-4 mixtures, which had the greatest average differences when calculated using the SSD weight, improved significantly. For the LS-1 mixture the average difference decreased from 0.011 to 0.006 and for the highly absorptive LS-4 mixture, the average difference decreased from 0.033 to 0.006.

Table 5 – G_{mm} Test Data for the CoreLok and FM 1-T 209 (without SSD weights)

Sample #	Mixture Designation											
	G-1		LS-1		LS-2		LS-3		LS-4		RAP	
	Corelok	FM 1-T 209	Corelok	FM 1-T 209	Corelok	FM 1-T 209	Corelok	FM 1-T 209	Corelok	FM 1-T 209	Corelok	FM 1-T 209
1	2.497	2.496	2.348	2.353	2.332	2.332	2.316	2.322	2.349	2.336	2.441	2.441
2	2.504	2.495	2.358	2.352	2.332	2.332	2.314	2.317	2.347	2.329	2.444	2.447
3	2.492	2.497	2.354	2.351	2.327	2.331	2.310	2.319	2.349	2.355	2.449	2.446
4	2.497	2.501	2.356	2.355	2.326	2.331	2.320	2.321	2.350	2.349	2.451	2.447
5	2.496	2.501	2.352	2.354	2.330	2.329	2.311	2.315	2.348	2.332		2.449
6	2.499	2.498	2.369	2.356	2.332	2.328	2.312	2.306	2.345	2.344	2.451	2.447
7	2.498	2.497	2.361	2.358	2.333	2.330	2.316	2.317	2.349	2.347	2.452	2.447
8	2.499	2.497	2.370	2.356	2.328	2.331	2.322	2.316	2.347	2.344	2.447	2.443
9	2.496	2.498	2.371	2.354	2.324	2.332	2.311	2.321	2.337	2.330	2.450	2.446
10	2.498	2.498	2.361	2.354	2.332	2.332	2.312	2.320	2.348	2.342	2.448	2.444
Average	2.497	2.498	2.360	2.354	2.330	2.331	2.314	2.317	2.347	2.341	2.448	2.446
Difference (Corelok-FM 1-T 209)	0.000		0.006		-0.001		-0.003		0.006		0.002	
Std. Dev.	0.0031	0.0019	0.0078	0.0020	0.0032	0.0015	0.0040	0.0047	0.0037	0.0088	0.0035	0.0023

It should be noted that the G_{mm} values for the RAP-1 material shown in Tables 2 and 5 are the same. The loose RAP material, which contained 10 to 15% uncoated particles, experienced some breakdown in the flask during the agitation process. When decanting the water and RAP material from the flask to the No. 200 sieve, fine material that passes through the No. 200 sieve is not recovered. After performing the dryback procedure, the SSD weight is less than the original dry weight, indicating that more material is lost than water absorbed. If this occurs, the test procedure states to use the original dry weight in the volume calculation instead of the SSD weight. Therefore, all FM 1-T 209 G_{mm} values for the RAP-1 material are calculated using the dry weight instead of the SSD weight in the volume calculation. It was shown previously that the average RAP-1 G_{mm} values for the two test procedures were practically and statistically equivalent.

A statistical t-test analysis was performed again for each material comparing the CoreLok procedure to the FM 1-T 209 procedure without using the dryback procedure. The results are displayed in Table 6. The LS-1 material is the only mix that was determined to be statistically different at a significance level of 0.05. The p-value for the LS-1 mixture was 0.04. In summary, when the SSD weight is not used in the FM 1-T 209 G_{mm} calculations, the

Table 6 – t-test Results for G_{mm} Test Data for the CoreLok and FM 1-T 209 (without SSD weights)

	Mixture Designation					
	G-1	LS-1	LS-2	LS-3	LS-4	RAP
t-statistic	-0.31	2.16	-1.03	-1.58	2.06	1.80
t-critical	2.10	2.10	2.10	2.10	2.10	2.11
Significantly Different?	No	Yes	No	No	No	No
p-value	0.76	0.04	0.31	0.13	0.05	0.09

test procedures compare very well. However, the researchers are not advocating calculating the G_{mm} values using the dry weight instead of the SSD weight. It is essential to use the SSD weight in the calculations to obtain an accurate sample volume. One option is to add a dryback procedure to the CoreLok procedure.

Other researchers have found mixed results using the CoreLok to determine G_{mm}. Lynn (1) concluded that the CoreLok compared favorably with AASHTO T 209 when considering all of the mixture types examined (granite, limestone and slag). However, when considering the limestone mixture independently, the average difference in G_{mm} values between the two test procedures was 0.008, which is significant. With respect to testing variability, Lynn found that the CoreLok had comparable standard deviations to the AASHTO T 209 test procedure for both the laboratory-fabricated and plant-produced mixtures that were tested. Hall and Fernandez (2) tested laboratory-fabricated and plant-produced mixtures and found that a majority of the mixture types were found to be practically and statistically different. Additionally, the researchers concluded that the CoreLok test procedure was more variable than the AASHTO T 209 test procedure. The researchers subsequently experimented with additional plant-produced mixtures using AASHTO T 209 and a modified CoreLok test procedure. They found that the difference in

G_{mm} between the two test procedures narrowed compared to the previous tests. However, in practical terms, the difference between test procedures was still very large, with nine out of twelve tests having a difference in $G_{mm} \geq 0.017$. It should be noted that neither Lynn or Hall and Fernandez used a dryback procedure when performing AASHTO T 209 G_{mm} tests.

AGGREGATE SPECIFIC GRAVITY TEST RESULTS

The CoreLok can be used to determine the aggregate specific gravity of both coarse and fine aggregates using separate test procedures. Both test procedures use the vacuum chamber to vacuum seal an aggregate sample, however, each procedure uses different external equipment accessories (Figure 4).

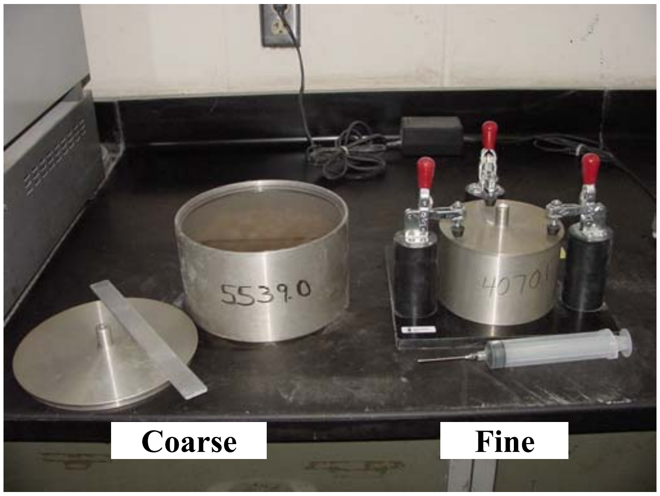


Figure 4 – Accessories for Coarse and Fine G_{sb} Test Procedures

Coarse Aggregate Specific Gravity

The Department's test procedure for coarse aggregate specific gravity is FM 1-T 085 and is similar to AASHTO T 85. Both the FM 1-T 085 and CoreLok test procedures determine the coarse aggregate specific gravity for the aggregate material retained on the 4.75 mm sieve. For this evaluation, six aggregate types were evaluated, including granite aggregates from

Nova Scotia and Georgia and four different limestone aggregates from various locations within Florida. Additionally, for several of the aggregate types, different gradations were tested to see if gradation had an effect on the G_{sb} values obtained. Therefore, a total of eleven aggregates were tested. The aggregate types and gradations are provided in Table 7. Two test results were determined for each test procedure and aggregate type. Therefore, a total of 44 test results (11 material types x 2 test procedures x 2 samples) were obtained for this study. The same operator tested all of the samples for both test methods. Additional samples were tested in the CoreLok prior to the start of this study so that the operator could become proficient with the test procedure. In addition to the G_{sb} value, the absorption and apparent specific gravity (G_{sa}) values were calculated from the test data for each material and test procedure. Test results are presented in Table 8. Figures 5-7 display graphs of G_{sb}, % absorption and G_{sa} respectively, comparing the FM 1-T 085 and CoreLok test procedures.

Table 7 – Coarse Aggregate Type and Gradation

Aggregate Type and Mine Number	Sieve Size and Percent Passing (Average of Two Tests)									
	19.0 mm	12.5 mm	9.5 mm	4.75 mm	2.36 mm	1.18 mm	600 um	300 um	150 um	75 um
Nova Scotia Granite, #67, NS-315	100	62	43	11	4	3	2	2	1	0.9
Nova Scotia Granite, #7, NS-315	100	95	44	2	1	1	1	1	1	0.4
Nova Scotia Granite, #89, NS-315	100	100	93	36	11	4	2	1	1	0.6
Georgia Granite, #7, GA-185	100	96	57	1	1	1	0	0	0	0.4
FL Limestone, Miami, #67, 87-090	99	64	37	4	2	2	2	2	1	1.0
FL Limestone, Miami, FC-3, 87-090	100	99	84	36	4	2	2	1	1	1.0
FL Limestone, Miami, FC-2, 87-090	100	100	100	78	13	3	1	1	1	0.7
FL Limestone, Miami, S-1-B, 87-339	100	100	95	36	6	2	2	1	1	0.8
FL Limestone, Cabbage Grove, S-1-B, 38-036	100	100	80	7	6	6	5	5	4	2.9
FL Limestone, Brooksville, S-1-A, 08-005	99	57	21	4	3	3	3	3	3	2.2
FL Limestone, Brooksville, #67, 08-012	100	66	23	5	4	4	4	4	4	3.0

Examination of Figure 5 shows that the CoreLok determines higher values of G_{sb} than FM 1-T 085. Absorptive aggregates result in a greater difference in G_{sb} test values between the two test procedures than do low absorptive aggregates. The difference is approximately 0.033 for the granite aggregates and 0.165 on average for the limestone aggregates.

Table 8 – Coarse Aggregate G_{sb}, Absorption and G_{sa} Test Results

Aggregate Description	Test Number	Bulk Specific Gravity (Gsb)		Water Absorption (%)		Apparent Specific Gravity (Gsa)	
		CoreLok	FM 1-T 085	CoreLok	FM 1-T 085	CoreLok	FM 1-T 085
Nova Scotia Granite, #67, NS-315	1	2.644	2.608	0.24	0.72	2.662	2.658
	2	2.642	2.610	0.26	0.71	2.660	2.659
	Avg.	2.643	2.609	0.25	0.72	2.661	2.659
	Abs. Diff.	0.002	0.002	0.02	0.01	0.002	0.001
Nova Scotia Granite, #7, NS-315	1	2.647	2.608	0.16	0.70	2.658	2.657
	2	2.645	2.608	0.20	0.73	2.659	2.658
	Avg.	2.646	2.608	0.18	0.72	2.659	2.658
	Abs. Diff.	0.002	0.000	0.04	0.03	0.001	0.001
Nova Scotia Granite, #89, NS-315	1	2.640	2.597	0.23	0.84	2.656	2.656
	2	2.640	2.600	0.22	0.82	2.656	2.656
	Avg.	2.640	2.599	0.23	0.83	2.656	2.656
	Abs. Diff.	0.000	0.003	0.01	0.02	0.000	0.000
Georgia Granite, #7, GA-185	1	2.728	2.715	0.23	0.46	2.745	2.750
	2	2.727	2.703	0.29	0.50	2.749	2.740
	Avg.	2.728	2.709	0.26	0.48	2.747	2.745
	Abs. Diff.	0.001	0.012	0.06	0.04	0.004	0.010
Florida Limestone, Miami, #67, 87-090	1	2.498	2.368	2.34	3.02	2.653	2.551
	2	2.503	2.367	2.29	3.06	2.655	2.552
	Avg.	2.501	2.368	2.32	3.04	2.654	2.552
	Abs. Diff.	0.005	0.001	0.05	0.04	0.002	0.001
Florida Limestone, Miami, FC-3, 87-090	1	2.544	2.372	1.97	3.50	2.679	2.587
	2	2.547	2.378	1.97	3.38	2.682	2.585
	Avg.	2.546	2.375	1.97	3.44	2.681	2.586
	Abs. Diff.	0.003	0.006	0.00	0.12	0.003	0.002
Florida Limestone, Miami, FC-2, 87-090	1	2.554	2.368	2.01	3.77	2.692	2.600
	2	2.553	2.367	2.08	3.80	2.696	2.601
	Avg.	2.554	2.368	2.05	3.79	2.694	2.601
	Abs. Diff.	0.001	0.001	0.07	0.03	0.004	0.001
Florida Limestone, Miami, S-1-B, 87-339	1	2.578	2.446	1.53	2.69	2.684	2.619
	2		2.444		2.74		2.619
	Avg.	2.578	2.445	1.53	2.72	2.684	2.619
	Abs. Diff.	NA	0.002	NA	0.05	NA	0.000
Florida Limestone, Cabbage Grove, S-1-B, 38-036	1	2.591	2.397	2.79	3.79	2.793	2.636
	2	2.594	2.401	2.73	3.80	2.791	2.643
	Avg.	2.593	2.399	2.76	3.80	2.792	2.640
	Abs. Diff.	0.003	0.004	0.06	0.01	0.002	0.007
Florida Limestone, Brooksville, S-1-A, 08-005	1	2.530	2.372	2.33	3.46	2.689	2.584
	2	2.528	2.372	2.42	3.45	2.693	2.583
	Avg.	2.529	2.372	2.38	3.46	2.691	2.584
	Abs. Diff.	0.002	0.000	0.09	0.01	0.004	0.001
Florida Limestone, Brooksville, #67, 08-012	1	2.520	2.336	2.54	4.11	2.692	2.584
	2	2.520	2.336	2.53	4.07	2.692	2.582
	Avg.	2.520	2.336	2.54	4.09	2.692	2.583
	Abs. Diff.	0.000	0.000	0.01	0.04	0.000	0.002
Average of Absolute Difference		0.002	0.003	0.04	0.04	0.002	0.002

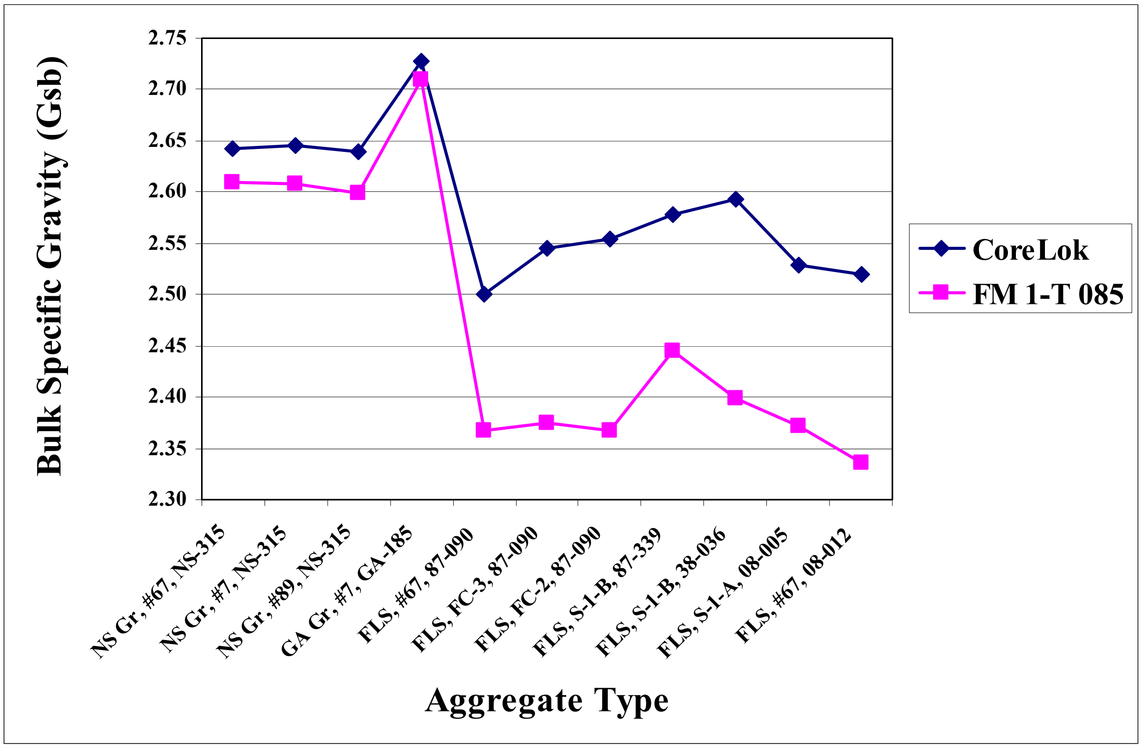


Figure 5 – G_{sb} Results for FM 1-T 085 and CoreLok Coarse Aggregate Test Procedures

Figure 6 shows that the CoreLok determines lower % water absorption values than FM 1-T 085. Absorptive aggregates result in a greater difference in % absorption between the two test procedures than do low absorptive aggregates. The difference is approximately 0.5% for the granite aggregates and 1.3% for the limestone aggregates.

Figure 7 shows that the CoreLok and FM 1-T 085 determined nearly equivalent values of G_{sa} for the granite aggregates, but for the limestone aggregates, the CoreLok determined greater G_{sa} values than FM 1-T 085. Again, absorptive aggregates result in a greater difference in G_{sa} test values between the two test procedures than do low absorptive aggregates. The difference in G_{sa} was 0.104 greater on average for the CoreLok as compared to FM 1-T 085 for the limestone aggregates.

For a particular aggregate source, there appeared to be no influence of gradation on the aggregate properties determined.

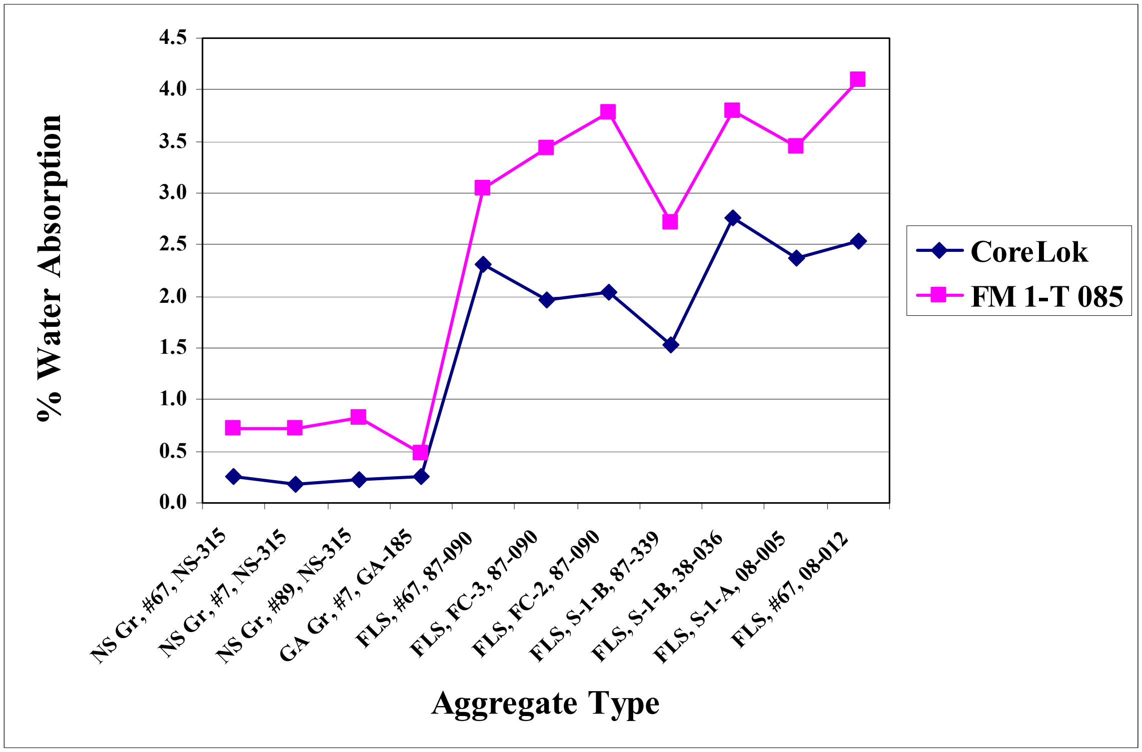


Figure 6 – % Water Absorption Results for FM 1-T 085 and CoreLok Coarse Aggregate Test Procedures

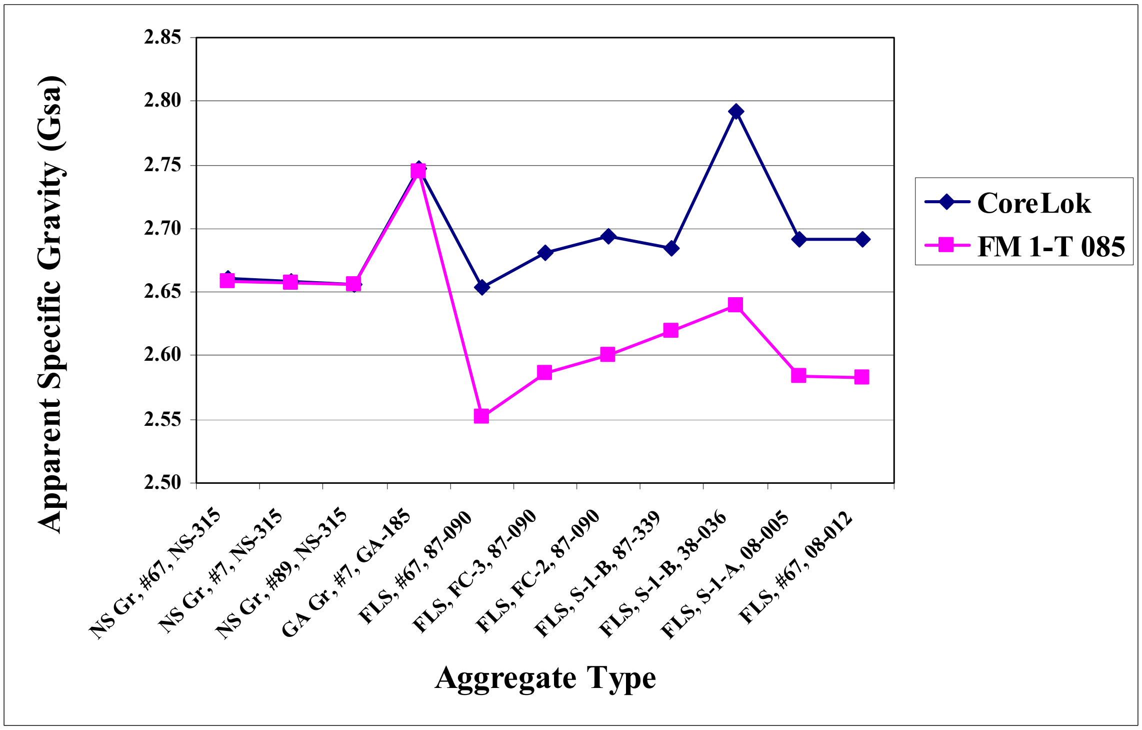
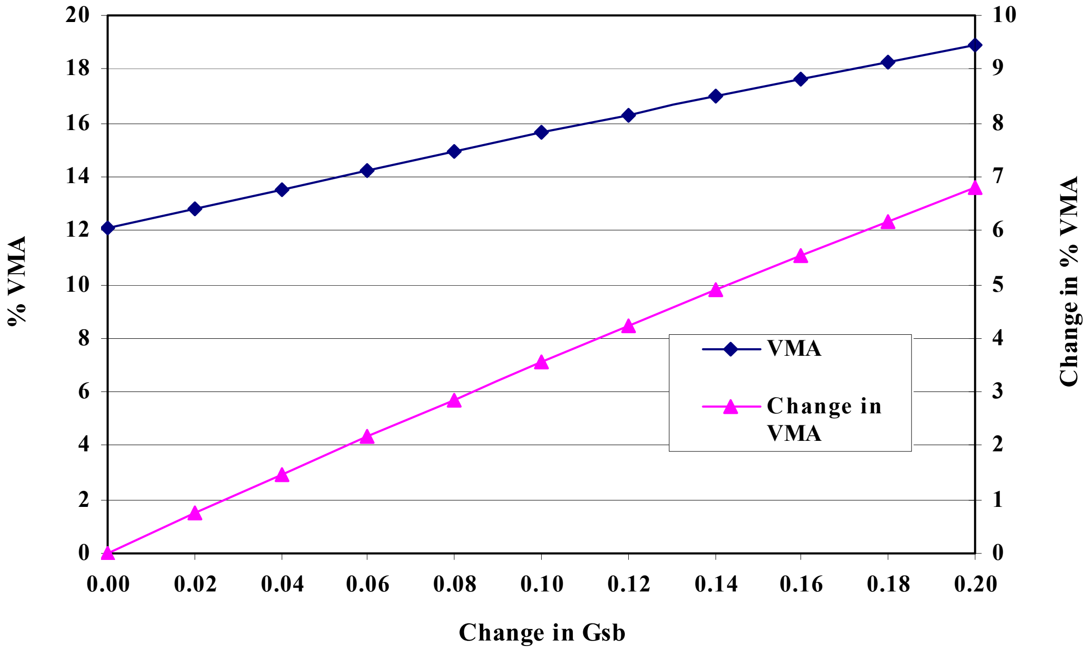


Figure 7 – G_{sa} Results for FM 1-T 085 and CoreLok Coarse Aggregate Test Procedures

The researchers believe that the discrepancy between the CoreLok and FM 1-T 085 coarse aggregate test results is for the same reason as the maximum specific gravity test. The CoreLok test procedure does not include the determination of the SSD weight of the aggregate. The more absorptive an aggregate is, the more critical it is to determine the SSD weight of the aggregate so that the proper volume of the aggregate can be calculated.

The G_{sb} aggregate property is used in the calculation of the VMA of an asphalt mixture. The other properties used to calculate VMA are the G_{mb} and percent asphalt binder of the mixture. For the range of the G_{sb} differences discussed above, the effect expressed in terms of VMA is shown graphically in Figure 8. The average difference in G_{sb} between the two test methods for the limestone aggregates was 0.165. From Figure 8, this would equate to a difference in VMA of approximately 5.5%.



Assumptions: Initial Gsb = 2.380; Gmb = 2.250; %AC = 7.0%

Figure 8 – Effect of G_{sb} on % VMA

G_{sb} test results in Table 8 show that replicate tests for the CoreLok test procedure were repeatable to 0.002 on average and the FM 1-T 085 test procedure was repeatable to 0.003 on average. Repeatability for the % water absorption and G_{sa} aggregate parameters were equal between the two test procedures. Multiple tests were not conducted for each material/test procedure combination, as was conducted with the G_{mm} test procedure. Therefore, it is not possible to determine an estimate of the variability of the CoreLok test procedure at this time. Due to the wide discrepancies in test values between the two test methods, the CoreLok test procedure will need to be modified (possibly to contain an aggregate SSD determination) to determine test values that more closely match the values obtained with FM 1-T 085. At that time, it would be more appropriate to determine the variability of the CoreLok test procedure.

Fine Aggregate Specific Gravity

The Department's test procedure for fine aggregate specific gravity is FM 1-T 084 and is similar to AASHTO T 84. Both the FM 1-T 084 and CoreLok test procedures determine the fine aggregate specific gravity for the aggregate material passing the 4.75 mm sieve. For this evaluation, six aggregate types were evaluated, including granite aggregates from Nova Scotia, New Brunswick and Georgia and three different limestone aggregates from various locations within Florida. Additionally, for one of the Florida limestone aggregates, two different gradations were tested, therefore, a total of seven aggregates were tested. The aggregate types and gradations are provided in Table 9. Two test results were determined for each test procedure and aggregate type. Therefore, a total of 28 test results (7 material types x 2 test procedures x 2 samples) were obtained for this study. The same operator tested all of

Table 9 – Fine Aggregate Type and Gradation

Aggregate Type and Mine Number	Sieve Size and Percent Passing (Average of Two Tests)							
	9.5 mm	4.75 mm	2.36 mm	1.18 mm	600 um	300 um	150 um	75 um
Nova Scotia Granite, Screenings, NS-315	100	90	59	35	21	12	6	3.2
New Brunswick Granite, Screenings, NB-509	100	91	67	47	34	24	17	11.4
Georgia Granite, Screenings, GA-178	100	100	71	44	30	21	11	3.9
FL Limestone, Miami, Screenings, 87-090	100	100	94	76	59	41	17	4.9
FL Limestone, Miami, Screenings (1), 87-339	100	100	85	60	44	28	9	2.7
FL Limestone, Miami, Screenings (2), 87-339	100	100	83	54	35	19	5	1.7
FL Limestone, Cabbage Grove, Screenings, 38-036	100	99	57	31	17	10	7	4.1

the samples for both test methods. Additional samples were tested in the CoreLok prior to the start of this study so that the operator could become proficient with the test procedure. In addition to the G_{sb}, the absorption and apparent specific gravity (G_{sa}) values were calculated from the test data for each material and test procedure. Test results are presented in Table 10. Figures 9-11 display graphs of G_{sb}, % absorption and G_{sa} respectively, comparing the FM 1-T 084 and CoreLok test procedures.

Table 10 – Fine Aggregate G_{sb}, Absorption and G_{sa} Test Results

Aggregate Description	Test Number	Bulk Specific Gravity (Gsb)		Water Absorption (%)		Apparent Specific Gravity (Gsa)	
		CoreLok	FM 1-T 084	CoreLok	FM 1-T 084	CoreLok	FM 1-T 084
Nova Scotia Granite, Screenings, NS-315	1	2.611	2.611	0.81	0.62	2.668	2.654
	2	2.608	2.599	0.83	0.60	2.666	2.641
	Avg.	2.610	2.605	0.82	0.61	2.667	2.648
	Abs. Diff.	0.003	0.012	0.02	0.02	0.002	0.013
New Brunswick Granite, Screenings, NB-509	1	2.679	2.668	0.2	0.54	2.694	2.707
	2	2.678	2.679	0.18	0.50	2.691	2.716
	Avg.	2.679	2.674	0.19	0.52	2.693	2.712
	Abs. Diff.	0.001	0.011	0.02	0.04	0.003	0.009
Georgia Granite, Screenings, GA-178	1	2.731	2.721	0.24	0.46	2.749	2.756
	2	2.731	2.716	0.2	0.44	2.746	2.749
	Avg.	2.731	2.719	0.22	0.45	2.748	2.753
	Abs. Diff.	0.000	0.005	0.04	0.02	0.003	0.007
Florida Limestone, Miami, Screenings, 87-090	1	2.483	2.542	3.07	1.79	2.688	2.664
	2	2.481	2.547	3.18	1.75	2.694	2.666
	Avg.	2.482	2.545	3.13	1.77	2.691	2.665
	Abs. Diff.	0.002	0.005	0.11	0.04	0.006	0.002
Florida Limestone, Miami, Screenings (1), 87-339	1	2.547	2.572	2.13	1.46	2.693	2.673
	2	2.544	2.569	2.22	1.48	2.696	2.671
	Avg.	2.546	2.571	2.18	1.47	2.695	2.672
	Abs. Diff.	0.003	0.003	0.09	0.02	0.003	0.002
Florida Limestone, Miami, Screenings (2), 87-339	1	2.498	2.551	2.96	1.92	2.697	2.682
	2		2.549		1.85		2.675
	Avg.	2.498	2.550	2.96	1.89	2.697	2.679
	Abs. Diff.	NA	0.002	NA	0.07	NA	0.007
Florida Limestone, Cabbage Grove, Screenings, 38-036	1	2.499	2.523	4.35	3.91	2.803	2.799
	2	2.503	2.521	4.37	3.95	2.810	2.800
	Avg.	2.501	2.522	4.36	3.93	2.807	2.800
	Abs. Diff.	0.004	0.002	0.02	0.04	0.007	0.001
Average of Absolute Difference		0.002	0.006	0.05	0.04	0.004	0.006

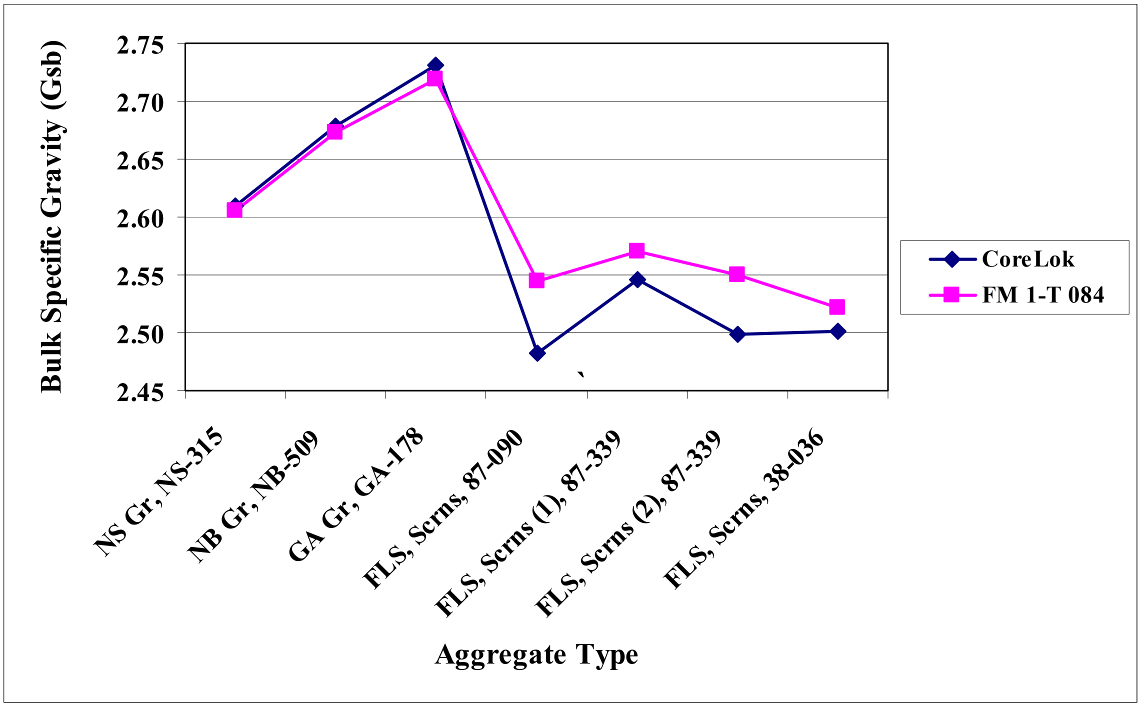


Figure 9 – G_{sb} Results for FM 1-T 084 and CoreLok Fine Aggregate Test Procedures

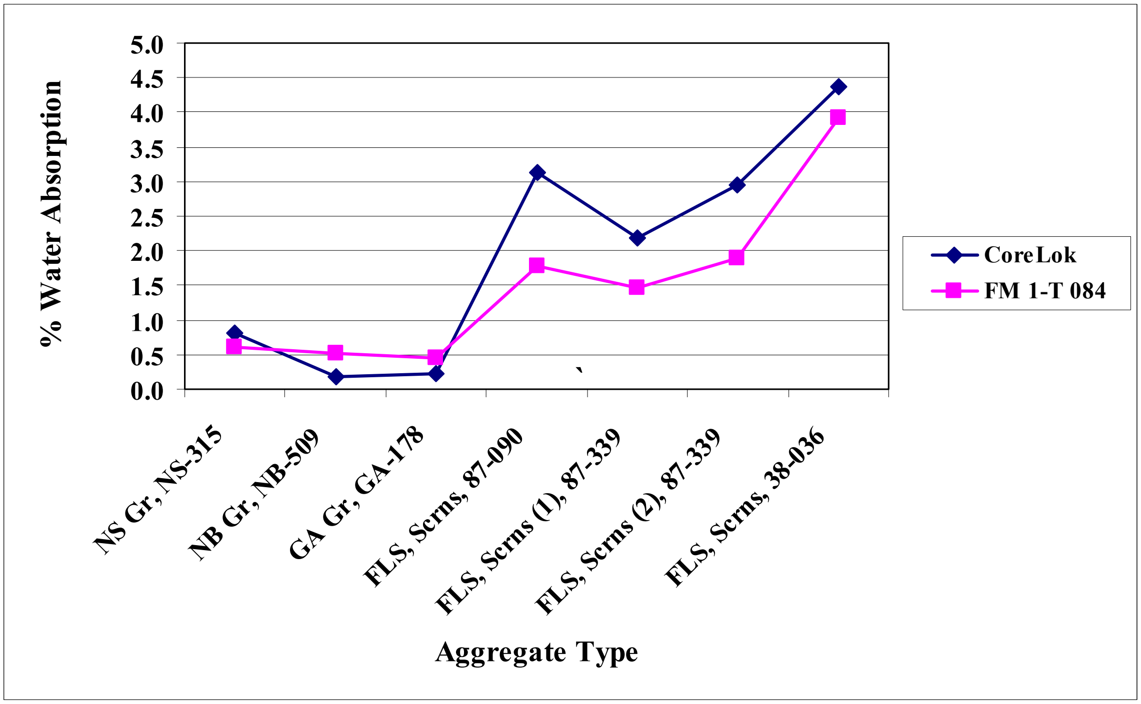


Figure 10 – % Water Absorption Results for FM 1-T 084 and CoreLok Fine Aggregate Test Procedures

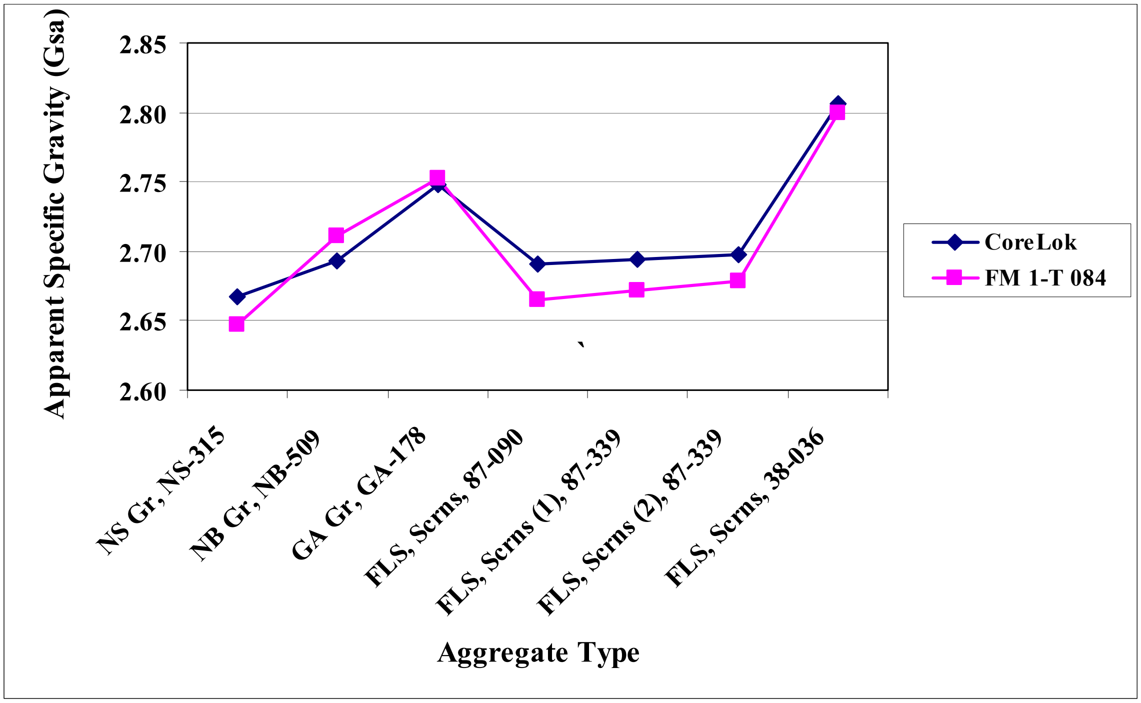


Figure 11 – G_{sa} Results for FM 1-T 084 and CoreLok Fine Aggregate Test Procedures

Examination of Figure 9 shows that the CoreLok measures G_{sb} at approximately the same level as FM 1-T 084 for the three granite aggregates but measures G_{sb} at a lower level for the four limestone aggregates. Absorptive aggregates result in a greater difference in G_{sb} test values between the two test procedures than do low absorptive aggregates. The average difference for the granite aggregates is 0.007 higher for the CoreLok and the average difference for the limestone aggregates is 0.040 lower for the CoreLok compared to FM 1-T 084. This is in contrast to the coarse aggregate test procedure, in which the CoreLok measured G_{sb} at a higher level than FM 1-T 085 for the limestone aggregates.

Four of the same aggregate sources were evaluated using the coarse and fine aggregate test procedures. The four aggregate sources were Nova Scotia granite, Miami, Florida limestone (87-090), Miami, Florida limestone (87-339) and Florida limestone from Cabbage Grove (38-036). Typically, the fine aggregate specific gravity is greater than or equal to the coarse aggregate specific gravity for a particular source of aggregate. However, for the four aggregates tested, the CoreLok determined higher coarse aggregate specific gravities than the corresponding fine aggregate specific gravities. The Department's test procedures determined higher specific gravities for the limestone fine aggregates compared to the limestone coarse aggregates and equivalent coarse and fine aggregate specific gravities for the granite aggregate.

Figure 10 shows that the CoreLok determines % water absorption at approximately the same level as FM 1-T 084 for the three granite aggregates but measures % water absorption at a higher level for the four limestone aggregates. Absorptive aggregates result in a greater difference in % absorption between the two test procedures than do low absorptive aggregates. The average difference for the granite aggregates is 0.12% lower for the CoreLok and the average difference for the limestone aggregates is 0.89% higher for the CoreLok compared to FM 1-T 084.

Figure 11 shows that the CoreLok determines G_{sa} at approximately the same level as FM 1-T 084 for the three granite aggregates but determines G_{sa} at a higher level for the three limestone aggregates. Again, absorptive aggregates result in a greater difference in G_{sa} test values between the two test procedures than do low absorptive aggregates. The average difference for the granite aggregates is 0.002 lower for the CoreLok and the average difference for the limestone aggregates is 0.019 higher for the CoreLok compared to FM 1-T 084.

The researchers are uncertain of the reason for the difference between the CoreLok and FM 1-T 084 limestone fine aggregate test results. The CoreLok fine aggregate test procedure does not include the determination of the SSD weight of the aggregate, however, the CoreLok G_{sb} results for the absorptive limestones were still lower than the results obtained with FM 1-T 084.

The effect of the difference in G_{sb} determined from both test procedures on the calculation of VMA is shown graphically in Figure 8. The average difference in G_{sb} between the two test methods for the limestone aggregates was 0.040. From Figure 8, this would equate to a difference in VMA of approximately 1.4%.

G_{sb} test results in Table 10 show that replicate tests for the CoreLok test procedure were repeatable to within approximately 0.002 on average compared to 0.006 for FM 1-T 084. Repeatability for the % water absorption parameter was approximately equal between the two test procedures. Repeatability for the G_{sa} parameter was 0.004 on average for the CoreLok compared to 0.006 for FM 1-T 084.

Hall (3) conducted research comparing the CoreLok fine aggregate procedure to AASHTO T 84 for six fine aggregates of varying mineralogy. For three of the six aggregates, G_{sb} and % water absorption test values were determined to be statistically different between the two test methods. No statistical differences were determined for the G_{sa} parameter. Hall did not observe any trends with respect to the difference in G_{sb} values obtained and the relationship to the absorption of the fine aggregates. With respect to test result variability, the CoreLok was equivalent to AASHTO T 84 in the determination of G_{sb}, was more variable than AASHTO T 84 in the determination of % water absorption and was less variable than AASHTO T 84 in the determination of G_{sa}.

BULK SPECIFIC GRAVITY TEST RESULTS

The CoreLok was initially developed for the purpose of determining the bulk specific gravity (G_{mb}) of compacted hot-mix asphalt specimens. The intent was to develop a device that would provide accurate G_{mb} determinations for both non-porous and porous specimens and to reduce testing variability. Most asphalt testing personnel use AASHTO T 166 or another similar water submersion testing procedure for determining G_{mb}. AASHTO T 166 requires the determination of the SSD weight of the specimen to be used as part of the calculation of the bulk volume of the specimen. The determination of the SSD weight is believed to be the major source of variability for AASHTO T 166. Furthermore, it is believed that inaccurate test results may be obtained for very porous mixtures because some water will drain out of the specimen's pores prior to determining the SSD weight. This condition will result in an inaccurate (smaller) specimen volume determination. For an asphalt specimen that absorbs >2% water by volume, AASHTO T 166 states that an alternative method shall be used, in which a paraffin coating is applied to the specimen to prevent water intrusion into the pores.

The Department's test procedure for the determination of G_{mb} (FM 1-T 166) is essentially identical to AASHTO T 166. The Department believes that the FM 1-T 166 test procedure is theoretically and practically sound and has confidence in the test results for the types of specimens tested by the Department. The Department rarely tests specimens with more than 2% water absorption. However, since the CoreLok test equipment was available, the researchers decided to conduct a limited study comparing the CoreLok and FM 1-T 166 test methods.

Nine gyratory compacted specimens and one aluminum cylinder were tested. Of the nine gyratory compacted specimens, six were 150 mm diameter specimens and three were

100 mm diameter specimens. Mixture gradations varied from 9.5 mm fine graded mixtures to 19.0 mm coarse graded mixtures. The solid aluminum cylinder measured 150 mm in diameter and 165 mm tall and had smooth sides with no voids. Two operators conducted CoreLok tests on the same ten specimens. In addition, one operator tested all ten specimens using the FM 1-T 166 test procedure. Results are tabulated in Table 11.

Table 11 – G_{mb} and % Air Void Results for FM 1-T 166 and CoreLok Test Procedures (Uncut Gyratory Specimens)

Core ID	CoreLok Gmb		CoreLok Air Voids		FM 1-T 166 Gmb	FM 1-T 166 Air Voids	FM 1-T 166 % Water Absorption
(diameter - #)	Operator 1	Operator 2	Operator 1	Operator 2	Operator 1	Operator 1	Operator 1
150-1	2.432	2.427	5.83	6.06	2.466	4.52	0.37
150-2	2.106	2.105	10.06	10.11	2.129	9.10	3.33
150-3	2.238	2.250	4.46	3.92	2.254	3.75	0.22
150-4	2.449	2.457	5.21	4.87	2.479	4.01	0.10
150-5	2.427	2.437	6.04	5.66	2.459	4.81	0.22
150-6	2.450	2.458	5.16	4.85	2.481	3.95	0.17
100-1	2.295	2.301	7.03	6.82	2.305	6.64	0.40
100-2	2.136	2.152	7.41	6.71	2.171	5.88	1.03
100-3	2.264	2.270	7.95	7.72	2.304	6.35	1.26
Alum.	2.680	2.689			2.714		

Figure 12 is an equality graph displaying the CoreLok air voids for each operator versus the air voids determined with FM 1-T 166. Air voids were calculated for both test procedures using the G_{mm} value as determined by FM 1-T 209 so as not to introduce bias as a result of differences in G_{mm} values obtained by using two different test procedures. The CoreLok measured air voids at approximately 1% higher than FM 1-T 166. This occurred for the range of air voids tested. CoreLok test results were fairly repeatable with Operator #2 results slightly less than Operator #1 for most of the specimens tested. Only one specimen (150-2), which was compacted with 30 gyrations, had a water absorption value higher than 2%. The CoreLok also measured the G_{mb} of the aluminum cylinder at a significantly lower G_{mb} value than FM 1-T 166. Since the aluminum cylinder was smooth and absorbed no

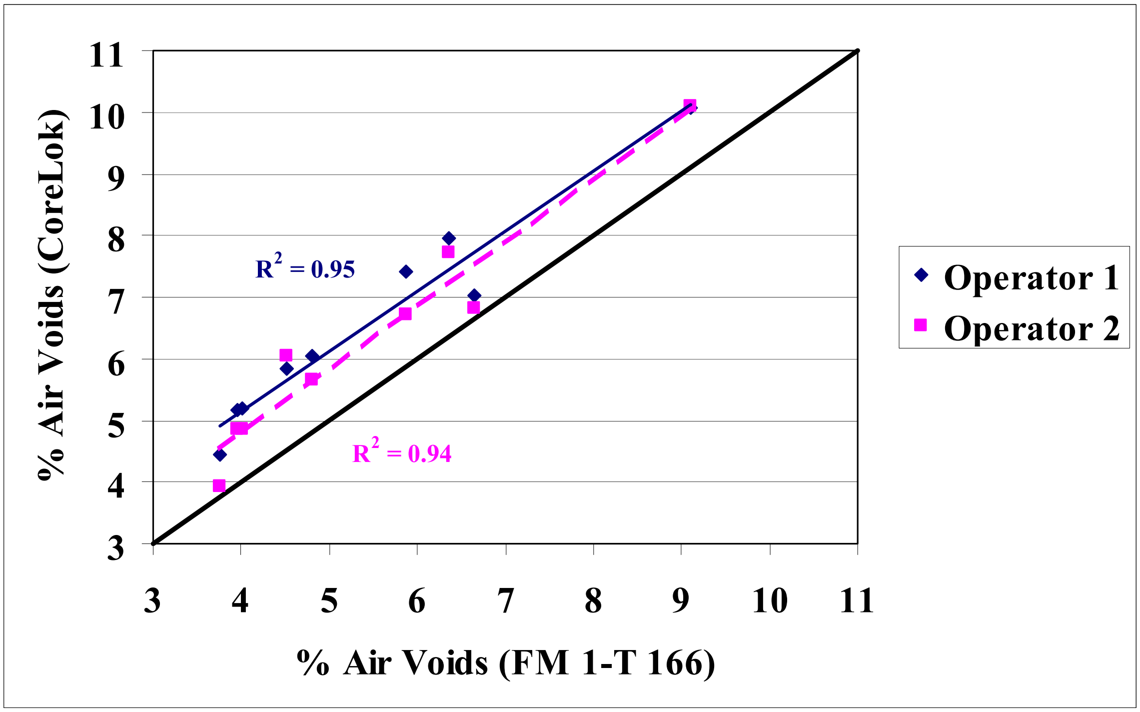


Figure 12 – % Air Void Results for FM 1-T 166 and CoreLok Test Procedures (Uncut Gyratory Specimens)

water, FM 1-T 166 is a suitable test procedure for the determination of the aluminum cylinder's G_{mb}.

A visual examination of the vacuum-sealed gyratory specimens revealed that the plastic bags were not able to completely conform to the rough surface texture of the top and bottom surfaces of the gyratory specimens. The plastic bags were bridging over the depressions. Consequently, these artificial voids, formed by the bridging effect of the bag, were included as actual specimen air voids in the CoreLok test procedure. To quantify this effect, approximately 5 - 15 mm was trimmed off of the top and bottom surface of three 150 mm diameter and three 100 mm diameter specimens with a wet saw. The depth trimmed off of each specimen was just enough to remove the unrepresentative large-void portion of the asphalt mixture contained on the surfaces of the specimens. Both operators then tested each of the six specimens with both test procedures. The results are presented in Table 12.

Table 12 – G_{mb} and % Air Void Results for FM 1-T 166 and CoreLok Test Procedures (Cut Gyratory Specimens)

Core ID	CoreLok Gmb		CoreLok Air Voids		FM 1-T 166 Gmb		FM 1-T 166 Air Voids		FM 1-T 166 % Water Absorption	
(diameter - #)	Operator 1	Operator 2	Operator 1	Operator 2	Operator 1	Operator 2	Operator 1	Operator 2	Operator 1	Operator 2
150-1	2.504	2.482	3.05	3.93	2.493	2.493	3.47	3.47	0.05	0.06
150-2	2.135	2.137	8.83	8.75	2.138	2.134	8.71	8.89	2.38	1.85
150-3	2.280	2.275	2.66	2.87	2.268	2.269	3.17	3.13	0.23	0.19
100-1	2.322	2.317	5.95	6.15	2.315	2.314	6.23	6.28	0.19	0.08
100-2	2.180	2.174	5.50	5.76	2.182	2.183	5.42	5.37	0.80	0.48
100-3	2.296	2.302	6.67	6.41	2.308	2.308	6.19	6.19	0.66	0.60

Figure 13 is an equality graph displaying the CoreLok air voids of the sawed specimens versus the FM 1-T 166 air voids for each operator. For both operators, the CoreLok air voids nearly matched the FM 1-T 166 air voids, as evidenced by the data points and best-fit lines being very close to the equality line. This occurred throughout the range of air voids tested (3 to 9%). Therefore, the difference between the test results obtained from the CoreLok and FM 1-T 166 for the uncut specimens appears to be primarily related to the top and bottom surfaces of the gyratory specimens.

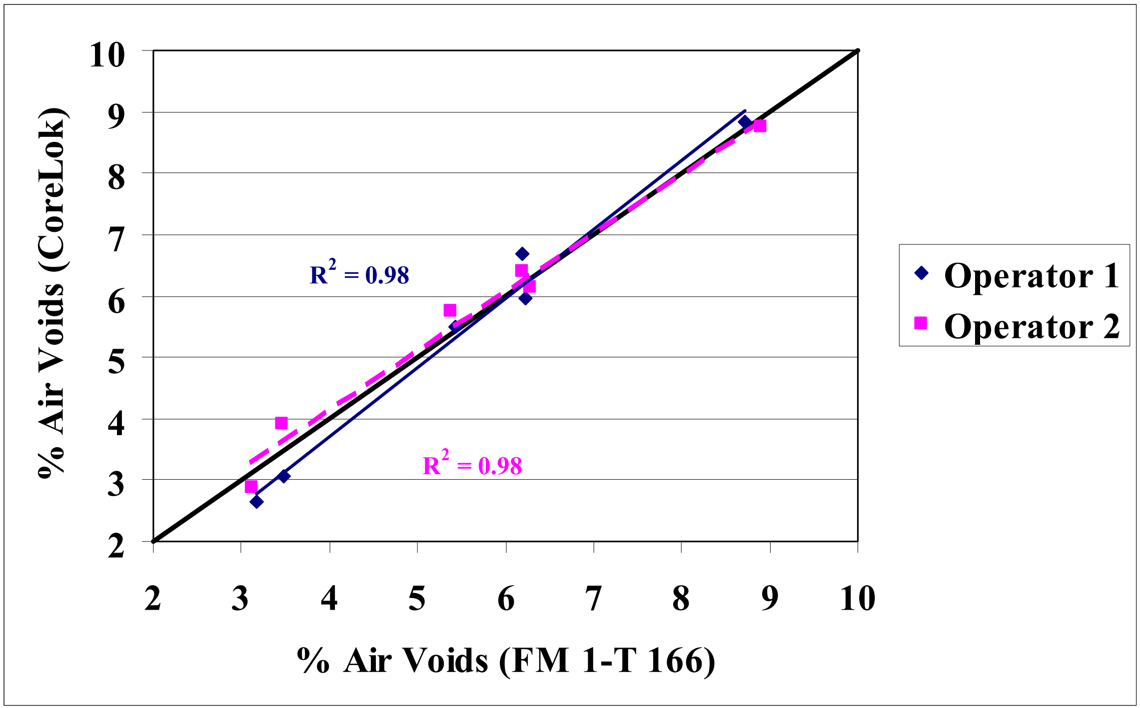


Figure 13 – % Air Void Results for FM 1-T 166 and CoreLok Test Procedures (Cut Gyratory Specimens)

The between operator repeatability for the uncut and cut specimens using the CoreLok test procedure is shown graphically in Figure 14. The between operator repeatability for the cut specimens using the FM 1-T 166 test procedure is shown graphically in Figure 15. FM 1-T 166 had better repeatability than the CoreLok procedure for the cut specimens tested in this study.

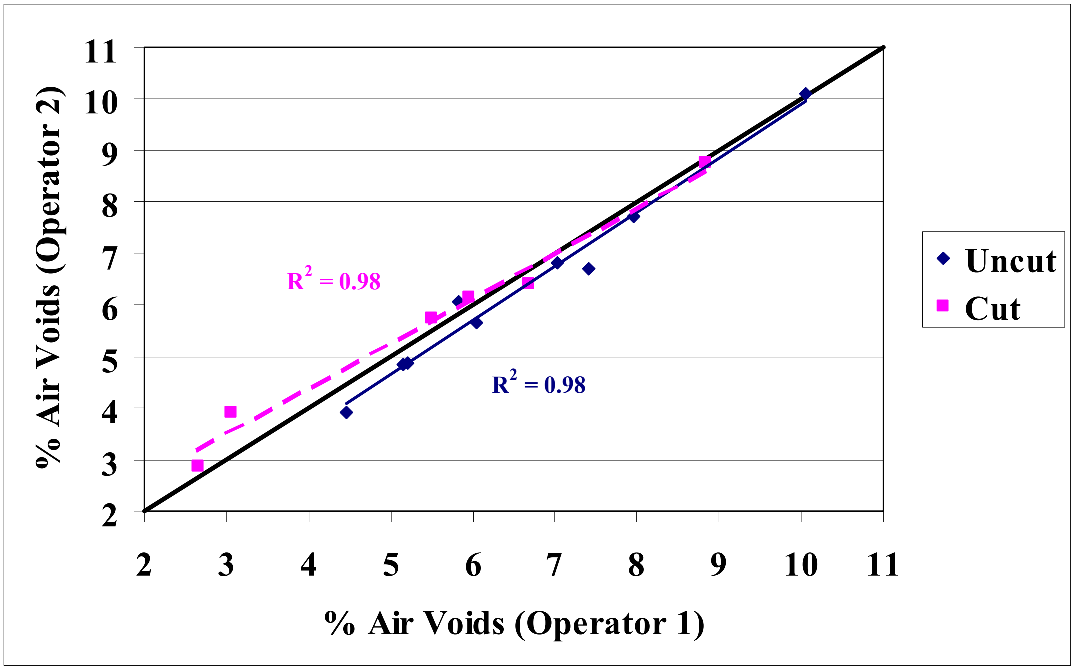


Figure 14 – Between Operator Repeatability for CoreLok Test Procedure for Uncut and Cut Specimens

Considerable research has been conducted by other researchers using the CoreLok for the determination of G_{mb}. Cooley et al. (4) of NCAT conducted a comprehensive round-robin study with the CoreLok to determine the repeatability of the test procedure and also to investigate the reasons for the differences between the CoreLok and AASHTO T 166 G_{mb} test results. Results of the round-robin study show that the repeatability of AASHTO T 166 is slightly better than the CoreLok. The CoreLok and AASHTO T 166 test procedures measured G_{mb} at the same level for fine graded mixtures and either method could be used for

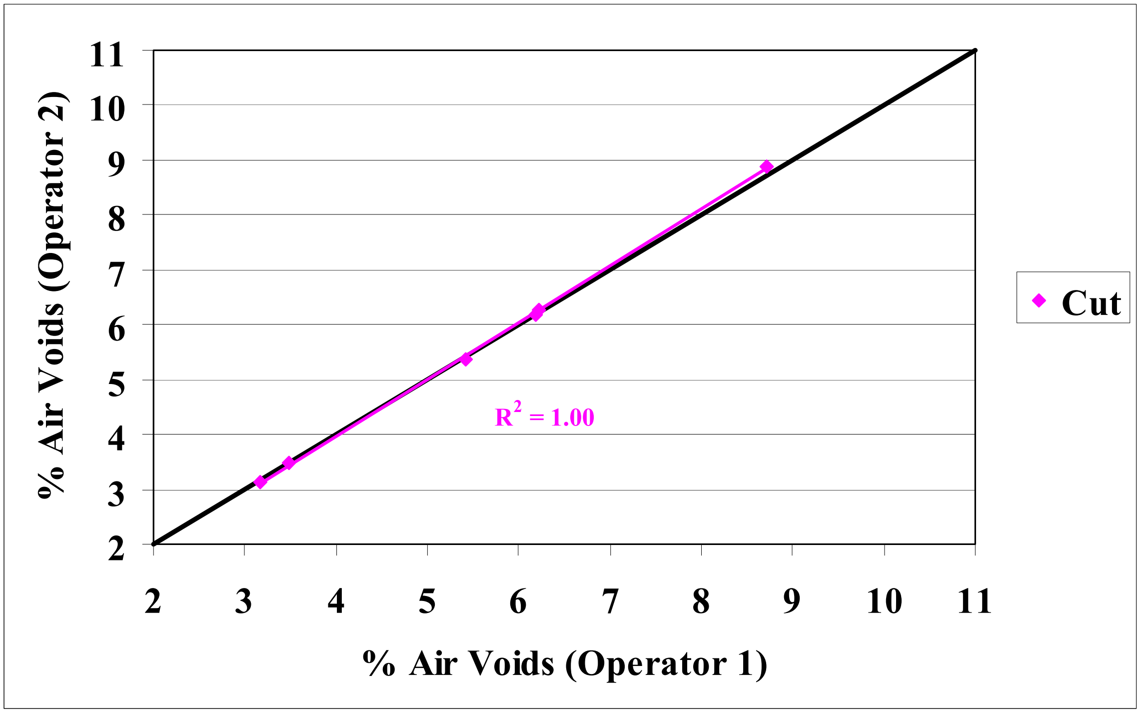


Figure 15 – Between Operator Repeatability for FM 1-T 166 Test Procedure for Cut Specimens

specimens with water absorption less than 2%. However, with coarse graded mixtures, the test methods did not measure G_{mb} at the same level for specimens with high air voids and water absorption. Using a statistical 95% confidence level, the researchers concluded that for laboratory compacted coarse graded specimens (Superpave and SMA), the two test methods' G_{mb} results diverged when the water absorption exceeded 0.4%, which occurred at approximately 4% air voids. The researchers recommend that the CoreLok be used for the determination of G_{mb} when testing coarse graded mixtures.

Buchanan (5) compared four methods of G_{mb} measurement: water displacement (AASHTO T 166), vacuum sealing (CoreLok), parafilm and dimensional analysis. G_{mb} measurements were obtained for each test procedure on 150 mm diameter gyratory samples for various mixture types compacted to multiple levels of gyration. Additionally, the samples were then saw cut into 75 mm cubes to eliminate surface texture effects and then retested. Buchanan concluded that the vacuum sealing and water displacement methods provided similar results for fine graded Superpave mixtures at all gyration levels. For coarse graded Superpave mixtures, as air void and % water absorption levels increased, it was observed that significant differences appeared between the vacuum sealing and water displacement methods. However, for the cut cubical shaped specimens, the vacuum sealing and water displacement methods provided similar results in nearly every case.

Other researchers, Hall et al. (6) and Crouch et al. (7) performed similar studies as Buchanan, with the exception of saw cutting the specimens. Both researchers concluded that the CoreLok has variability comparable to AASHTO T 166. Additionally, the CoreLok tends to measure lower G_{mb} values (resulting in higher air voids) than AASHTO T 166 for the range of mixtures tested. Crouch also tested a solid aluminum cylinder and obtained a significantly lower G_{mb} value with the CoreLok compared to AASHTO T 166. This matches the result obtained in this FDOT study.

CONCLUSIONS

1. With respect to the G_{mm} test procedure, the CoreLok produces test results equivalent to FM 1-T 209 for mixtures containing low absorptive aggregates (granites). As the % water absorption of the aggregate source increases, the differences between the test procedures increase, with the CoreLok resulting in higher G_{mm} values compared to FM 1-T 209. Using the CoreLok G_{mm} test results would result in an increase in calculated air voids. The reason for the discrepancy is primarily due to the CoreLok test procedure not having a dryback procedure to determine the SSD weight of the mixture sample. Test variability for the CoreLok test procedure was slightly greater than FM 1-T 209, but would likely decrease with more testing experience.

2. With respect to the coarse aggregate G_{sb} test procedure, the CoreLok produces test results that are significantly greater than FM 1-T 085 for mixtures containing low absorptive or high absorptive aggregates. Using the CoreLok G_{sb} test results would result in an increase in calculated VMA. As the % water absorption of the aggregate source increases, the differences between the test procedures increase. The CoreLok test procedure does not include a dryback procedure to determine the SSD weight of the aggregate sample.

3. With respect to the fine aggregate G_{sb} test procedure, the CoreLok produces test results equivalent to FM 1-T 084 for mixtures containing low absorptive aggregates (granites). For the higher absorption limestone aggregates tested, the CoreLok determined lower G_{sb} values than FM 1-T 084. Typically, the fine aggregate specific gravity is greater than or equal to the coarse aggregate specific gravity for a particular source of aggregate. However, for the four aggregates tested with both the coarse and fine aggregate test procedures, the CoreLok determined higher coarse aggregate specific gravities than the corresponding fine aggregate specific gravities. The Department's test procedures determined higher specific gravities for the limestone fine aggregates compared to the limestone coarse aggregates and equivalent coarse and fine aggregate specific gravities for the granite aggregate.

4. The CoreLok test procedure for G_{mb} has received positive reviews by researchers, primarily for its use with coarse graded mixtures containing high air voids and high % water absorption. In general, the CoreLok tends to determine G_{mb} at an equivalent or lower level than water submersion methods (FM 1-T 166 and AASHTO T 166). Results of this research and that of Buchanan (5) indicate that much of the difference between test procedures is a

result of the surface texture of the gyratory compacted specimen and not due to the internal void structure of the specimen. When the surface texture is removed by wet sawing, the test procedures provide equivalent results. This indicates that the plastic liner used in the CoreLok procedure is partially bridging over the large, mostly unrepresentative voids on the surface of the specimen and including a portion of them as true specimen air voids. This results in a higher than true air void content. Additionally, the water submersion test procedure (FM 1-T 166) may be underestimating air voids for specimens with high air void contents and high water absorption as a result of water draining from the interconnected surface voids, of which a portion of the voids are probably true air voids. Therefore, the true air void content is most likely a value in between the values determined by the CoreLok and water submersion test procedures. This research and that by Crouch (7) have measured significantly lower G_{mb} results of a solid aluminum cylinder using the CoreLok test procedure compared to the water submersion procedure. Since the water submersion procedure is ideally suited for the determination of G_{mb} of a solid aluminum cylinder, this sheds some doubt on the ability of the CoreLok to accurately measure G_{mb}.

RECOMMENDATIONS

1. The Department should not approve the CoreLok for use as a test procedure for the determination of G_{mm} without the addition of a dryback portion to the test procedure. However, the addition of a dryback portion to the CoreLok procedure would nearly eliminate any advantage in terms of testing time that the CoreLok has over FM 1-T 209. Due to the cost of the CoreLok equipment it would not be advantageous for the Department to adopt the CoreLok test procedure.

2. Based on the results of this study, the CoreLok test procedures for coarse and fine aggregate specific gravity do not produce results consistent with accepted Department and AASHTO test procedures. Therefore, these CoreLok test procedures should not be allowed for the determination of G_{sb}, G_{sa} and % water absorption of aggregates.

3. The CoreLok procedure for the determination of G_{mb} for high air void coarse graded and SMA specimens may be warranted based on research conducted by others. However, since the Department does not construct SMA mixtures and the maximum nominal size Superpave mixture is 19.0 mm, there may not be a need to utilize the CoreLok test procedure. Furthermore, gyratory specimens are compacted to approximately 4% air voids at design and during production, making the concern about the applicability of water submersion test procedures for porous mixtures less applicable. Roadway cores at higher air void levels will have smooth sides and a smooth bottom due to sawing. Differences between the CoreLok and FM 1-T 166 test procedures have been shown to be minor when testing saw cut specimens, therefore there would be no need to adopt the CoreLok for G_{mb} determination.

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