STATE OF FLORIDA

ROUND ROBIN STUDY TO DETERMINE THE PRECISION OF THE IGNITION METHOD

Research Report
FL/DOT/SMO/97-413

Bouzid Choubane
James A. Musselman
Gale C. Page

March 1997

STATE MATERIALS OFFICE

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

EXECUTIVE SUMMARY

Laboratory determination or verification of the asphalt content of an asphalt paving mixture is a critical part of both quality control (QC) and quality assurance (QA) of hot mix asphalt production. Traditionally, chlorinated solvents such as carbon tetrachloride, trichloroethylene, or 1-1-1 trichloroethane have been used to dissolve the asphalt. However, the environmental and health concerns associated with the manufacturing and the use of these chemicals compelled the Florida Department of Transportation (FDOT) to look into the use of alternative procedures to solvent extraction of asphalt. One alternative that is rapidly gaining acceptance is the ignition method. It consists of removing the asphalt through ignition in a furnace at 538°C (1000°F). The difference between the initial and the final weights of a hot mix asphalt (HMA) sample is used to measure the asphalt content of the mixture.

In order to implement the ignition method in Florida, the State Materials Office of the FDOT carried out the present round robin study to determine the precision and accuracy of this procedure for local conditions. Twelve materials laboratories, including both public and private sectors throughout Florida, participated in the study. Each of the twelve participant laboratories received a total of thirty-six HMA mixture samples for asphalt content determination and gradation analysis. Samples were prepared in accordance with FDOT specifications using six different types of aggregate and one type of asphalt cement. These materials are commonly used in HMA construction in the state of Florida. Six laboratories used one ignition tester brand and the remainder used a tester from a different manufacturer. Both testers, similar in nature, include an internally mounted load cell and an automated system for data collection and processing. The interlaboratory test data was collected and analyzed at the FDOT State Materials Office.

This report describes the round robin test program and discusses the accuracy and the precision of the ignition method on materials commonly used in HMA construction in the state of Florida.

INTRODUCTION

Laboratory determination or verification of the asphalt content of an asphalt paving mixture is a critical part of both quality control (QC) and quality assurance (QA) of hot mix asphalt production. Traditionally, chlorinated solvents such as carbon tetrachloride, trichloroethylene, or 1-1-1 trichloroethane have been used to dissolve the asphalt. However, the environmental and health concerns associated with the manufacturing and the use of these chemicals, coupled with some general dissatisfaction with terpene solvents, compelled the Florida Department of Transportation (FDOT) to look into the use of alternative procedures to solvent extraction of asphalt. One alternative that is rapidly gaining acceptance is the ignition method. It consists of removing the asphalt through ignition in a furnace at 538°C (1000°F). The difference between the initial and the final weights of a hot mix asphalt (HMA) sample is used to measure the asphalt content of the mixture.

Since the ignition method is newly developed, The National Center for Asphalt Technology (NCAT) conducted a study to determine its precision *(1)*. However, the characteristic precision of the results is a function of a number of factors that include the experience of operators, apparatus, types of materials, and environment *(2)*. As a result, in order to implement the ignition method in Florida, the State Materials Office of the FDOT carried out the present round robin study to verify the precision and accuracy of this procedure to account for local conditions.

OBJECTIVE

The objective of this study was to verify the precision statements of the ignition method as determined in studies elsewhere *(1,3)*, while considering the conditions specific to Florida. Both the asphalt content as determined by the ignition method and the resulting gradation of the recovered aggregate were evaluated for precision and accuracy.

SCOPE

The present round robin study was performed in accordance with ASTM C802 *(4)*. Twelve materials laboratories, including both public and private sectors throughout Florida, participated in the study. Each of the twelve participant laboratories received a total of thirty-six HMA mixture samples, randomly selected, for asphalt content determination and gradation analysis. The laboratories had no knowledge of the asphalt content nor the gradation of the HMA samples. Ignition test and sieve analysis procedures, instructions and summary data worksheets were sent along with the test samples. Six laboratories used one ignition tester brand and the remainder used a tester from a different manufacturer. Both testers, similar in nature, include an internally mounted load cell and an automated system for data collection and processing. The system provides a printout of the initial specimen weight, specimen weight loss, temperature compensation factor, mix calibration factor, calibrated asphalt content (%), test duration time, and furnace set-point temperature. The interlaboratory test data was collected and analyzed at the FDOT State Materials Office. A flow chart summarizing the scope of the investigation is illustrated in Figure 1.

INTERLABORATORY TESTING PROGRAM

Material and Sample Preparation

Samples were prepared in accordance with FDOT specifications using six different types of aggregate and one type of asphalt cement. These materials, commonly used in HMA construction in the state of Florida, are shown in Table 1. Three of the aggregate types were from sources native to Florida and the other three were imported. The native materials included limestone from the oolitic formation in South Florida, limestone from the Brooksville area in Central Florida, and limestone from the Cabbage Grove area of North Florida. These native limestones of Florida are typically white, light gray or light brown in color, and range from hard and compact to soft and chalky, depending on the source. Miami oolite, for instance, is a fairly soft white limestone composed of small, round shaped grains (oolites) with some quartz sand *(5)*. Suwannee limestone, a high calcium aggregate produced in the Brooksville area, generally shows higher specific gravities and lower absorption rates than those of other limestones from the state *(5)*.

The imported materials included limestones from Mexico and Alabama, and granite from Georgia. Limestone imported from Mexico closely resembles Florida limestone, whereas Alabama limestone is relatively denser, with a higher specific gravity, lower porosity, and lower absorption as compared to those of limestone from Florida sources *(5)*. These variations in properties and characteristics of each aggregate is generally due to its source depositional environment, geologic formation process, and erosion.

To reduce the number of variables in this study for ease of data analysis, a silica sand from Ottawa, Illinois, was used for all mixes. Each aggregate type was oven dried and then separated into individual sieve sizes. The aggregate components retained on the individual sieve sizes were then combined to meet the desired gradations. The sieve sizes used for the purpose of this study were those adopted for Superpave, not the FDOT typical asphalt sieve sizes. The individual batch weights were approximately 1200 g. The respective aggregate blend gradations for each mix type are given in Table 2.

After batching the aggregate, the HMA mixtures were prepared by mixing the aggregate batches with a known quantity of asphalt cement. The respective asphalt contents for each sample, per mix type, are summarized in Table 3. For each mix type, samples 1 through 4 were prepared at the design AC content, while samples 5 and 6 were prepared at 0.5% above and 0.5% below the design AC content, respectively. The first three samples were test samples, while the last three were used to establish a mix calibration factor to account for the aggregate weight loss due to burn off.

Each sample mixture was then placed in a cardboard box having a silicone coating on the inside. This type of box can be heated without damage, and the non-stick coating minimized the amount of the sample adhering to the box. The samples were then randomly labeled according to the type of mix and numbered from 1 to 72.

Test Procedure

A test procedure for the interlaboratory test program was provided to each of the laboratory participants (see Appendix B). The procedure was developed specifically for use in this study. The participants were instructed to familiarize themselves with the method and to ensure that the equipment was properly functioning prior to initiating the actual round robin testing (see Appendix A). Each laboratory was provided with a practice sample for that purpose.

Test samples were burned at a temperature of 538 °C (1000 °F) until the measured weight loss did not exceed 0.1 g for three consecutive minutes. Upon completion of ignition testing, a gradation analysis was performed on the recovered aggregate in accordance with the Florida Method of Test FM 1-T 030.

Calibration Factors

In general, most aggregate types will experience some weight loss due to burn off. As such, the measured weight loss of a sample will consist of a combination of the weight loss of asphalt cement and aggregate. Thus, a mix calibration factor for asphalt content has to be established to account for the aggregate weight loss for a particular mixture.

Once the testing of a calibration specimen was completed, the actual weight loss attributed to the aggregate was determined as the difference between the measured asphalt content as given by the furnace print out and the actual asphalt content. The mix calibration factor was taken as the average of the respective weight losses of the three calibration specimens. A calibration factor was established for each mix and for each laboratory. The values of the respective calibration factors, in percent by weight of the mixture, of each mix type per laboratory are summarized in Table 4. These results seem to suggest that the calibration factors depend on the operator proficiency and the ignition tester characteristics.

Determination of Asphalt Content

Each laboratory tested three replicates per mixture for asphalt content determination. These measured asphalt contents were then calibrated by establishing a calibration factor to account for the aggregate weight loss, as previously described. The calibrated asphalt content of each specimen was determined by subtracting the calibration factor from the measured asphalt content of the test sample, respectively. The calibrated asphalt content values for each mix are given in Table 5. These asphalt content values were also averaged for each mix type.

ANALYSIS OF TEST RESULTS

Test results of the round robin study were analyzed for accuracy and precision in accordance with ASTM C802 and ASTM C670 *(4,2)*. These standards are recommended practices to determine the between- and the within-laboratory estimates of the precision of a test method. The between laboratory precision provides an estimate of the difference that may exist between measurements on the same material in two different laboratories. The within laboratory precision provides an estimate of the difference that may exist between duplicate measurements on the same material in the same laboratory by the same operator using the same apparatus. Statistical analyses were performed on the calibrated asphalt content values (based on both the furnace print-out test results as well as results calculated with an external weighing system) and the aggregate gradations.

Asphalt Content Data Consistency

Since the statistical analysis of the data for accuracy and precision estimates can be invalidated by the presence of severe outliers, the data was first examined for consistency. The results of the between-laboratory, h-, and the within-laboratory, k-, consistency statistics at the 0.5 % significance level are summarized in Table 6. The h-consistency statistic is an indicator of how one laboratory's cell average compares with the average of the other laboratories, for a particular mix. The k-consistency statistic is an indicator of how one laboratory's within variability, under identical conditions, on a particular mix, compares with that of the rest of the laboratories combined.

For a statistical experiment consisting of 12 laboratories and 3 replicates per mix type, the respective critical values of h and k were found to be 2.38 and 2.14 from the Student's t-test and the h-ratio, respectively. Overall, Table 6 indicates a reasonable consistency for variation among laboratories. Only Laboratory 12 stands out with distinctly high h value for mix 1 , and high k values for mixes 1, 3, and 6, respectively. An investigation of Laboratory 12 data showed some discrepancies in the reported sample weights among replicates. This seems to indicate that the operator at Laboratory 12 may not have been weighing or reporting some sample weights correctly. Consequently, this laboratory's data was rejected as an outlier and was not further considered in the analysis. Thus, only data collected from each of the eleven remaining laboratories was used to estimate the precision and accuracy of the ignition method.

Accuracy of Measured AC Content

Not including the data from Laboratory 12, a total of 198 calibrated asphalt content measurements, consisting of 3 replicate samples per mix type per laboratory, were considered in this analysis. An analysis of the paired-difference experiment was, first, performed by comparing the respective asphalt content averages of three replicates per mix type, as produced by the two ignition testers, respectively. The hypothesis concerning their equality (the difference between the respective averages is null) was tested using the Student t-statistic. The t value of the six differences (six mix types) was calculated to be 0.99. The critical value of t based upon $n - 1 = 5$ degrees of freedom and a level of significance $\alpha = 0.05$ is $t_\alpha = 2.776$. Since the critical value, t_α, exceeds the calculated t, it can be stated that, within the test range, both ignition testers determined asphalt content at the same mean level. Thus, the differences between the average values of asphalt content for each mix as measured by both ignition testers, respectively, are not statistically significant within the test range. Consequently, the accuracy of the asphalt content determination was estimated by comparing the average of the calibrated asphalt contents to the actual values for each mix type, regardless of the ignition tester type. As shown in Table 7, the deviation of the measured AC content from the actual AC content ranged from -0.05 to +0.02 percent. The overall average deviation of the measured AC content for the 198 samples was approximately -0.03 percent. These low bias values indicate that the AC content can be determined with a high degree of accuracy by the ignition method.

Precision of Measured AC Content

The results of the within- and the between-laboratory analyses for the various mixes tested for the asphalt content are summarized in Table 8. The within laboratory standard deviations ranged from 0.05 to 0.13 percent with an overall value of 0.09 percent. The between laboratory standard deviations ranged from 0.06 to 0.29 percent with an overall value of 0.13 percent. Lower standard deviation values indicate a higher degree of precision. Furthermore, from Table 8, it is apparent that the standard deviation values may be categorized into three distinct groups by level of magnitude. The first group is composed of mixes 1 and 6 where the standard deviations are relatively constant. The second may consist of mixes 2, 4, and 5 with a relatively higher value of standard deviation. Mix 3 forms the third group with the highest standard deviation value and, thus, has a relatively lower degree of precision among all the mixes. Mix 3 has a between-laboratory standard deviation as well as a coefficient of variance of about twice as large as those of mix 4. These observations may be due to the physical characteristics intrinsic of each of the various types of aggregate used in the mixes.

Aggregate Type Effect on Ignition Method Precision

An F-distribution test was performed to further investigate the statistical level of significance of the effect of these mixes on the ignition method precision. This test consists of comparing the ratio, known as the calculated F-value, of two variances, in this case the variance of Mix 3 to that of each of the other mixes. The calculated F-value is then compared to a critical F-value as given by the F-value table. The results of the analysis are summarized in Table 9. The estimated critical F-values, F_{cr}, based on levels of significance α of 0.05 and 0.10 were 1.797 and 1.5767, respectively. It is clear that, with the exception of two values, the tabulated F-values (Table 9) are sizably greater than the critical F-value at either the $\alpha = 0.05$ or the 0.10 levels. It can therefore be concluded that, within the test range, the data presented sufficient evidence to indicate a significant difference exists between Mix 3 and the other mixes. Consequently, for practical purposes, the data of Mix 3 were not considered in determining the precision statements of the ignition method.

Ignition Tester Type Effect on Ignition Method Precision

The effects of the ignition tester type on the precision of the asphalt content determination was also investigated. It can be observed from Table 10 that, between-laboratory, the average standard deviation value of Tester 2 is more than twice as large as that of Tester 1. Within-laboratory, the average standard deviation value of Tester 2 is about 1.5 times that of Tester 1. These values suggest that a relatively better precision in determining asphalt content may be obtained using Tester 1. Furthermore, an F-distribution test was also done to determine if the data present sufficient evidence to indicate a difference between both testers regarding their precision level in estimating the AC content. The computed F-values are summarized in Table 11. The estimated critical F-values, F_{cr}, based on levels of significance α of 0.05 and 0.10 were 2.332 and 1.927, respectively. The comparison of these critical F-values to the computed ones showed enough evidence, within the test range, to reject the null hypothesis of no difference existed between the two testers at either the $\alpha = 0.05$ or the 0.10 levels. These observations may be related to the differences in the respective internal weighing process of each ignition tester.

Internal vs. External Weighing Systems

As part of this study, it was requested from each participant laboratory to also determine the final weight of each sample after ignition, once it was cooled to room temperature, using an external weighing system (balance used for the initial sample weight). Hence, each ignition tester type was strictly used only as a furnace. This task was initiated with the primary objective of providing information to investigate the causes of any potentially large variability between the test results of the two ignition testers. The calibration factor of each sample was computed using the following equation:

$$CF = \frac{W_I(1 - AC) - W_F}{W_I(1 - AC)} * 100 \qquad (1)$$

where:

CF = calibration factor, % by weight of aggregate;

W_F = weight of the calibration sample after ignition, g;

W_I = weight of the calibration sample before ignition, g; and

AC = percent asphalt in the mix by weight of the total mix, expressed as a fraction.

The mix calibration factor is the average of the respective calibration factors, as determined by Equation 1, of the three calibration specimens. A calibration factor was established for each mix and for each laboratory.

Once the mix calibration factor was established, the asphalt content of each specimen was derived based on the following expression:

(2) $$\%AC = \frac{1 - \dfrac{W_F}{W_I} - CF}{(1 - CF)} * 100$$

where: %AC= asphalt content, percent by weight of the sample;

W_F = weight of the calibration sample after ignition, g;

W_I = weight of the calibration sample before ignition, g; and

CF = calibration factor, as obtained using equation (1), expressed as a fraction.

The results of the analysis on the asphalt data collected through the procedure described above (thus bypassing the internal weighing system of the ignition tester) are summarized in Table 12. As it can be seen, by using an external weighing system, the precision of Tester 1 decreased. Contrastingly, the precision of Tester 2 was greatly improved within the test range. The respective averages of the coefficients of variance as determined for the two types of furnaces are now comparable (a difference of 0.2% within-laboratory and 0.0% between laboratories). These results seem to confirm the previous observation regarding the need for improvement in the internal weighing process of Tester 2. When contacted, the Tester 2 manufacturer suggested that their units used in this study may have been equipped with an older version of the software associated with the asphalt content determination process. The manufacturer also stated that the new furnaces include a newer version of the software developed to improve its precision. For practical purposes, it was deemed necessary to prepare the precision statements based upon the Tester 1 results only.

Even though the average standard deviation value obtained using Tester 2 may be slightly higher as compared to those obtained elsewhere when using the internal weighing system of the furnace *(1,3)*, the precision of the ignition method is still higher than that of the vacuum extraction or nuclear asphalt content gauge methods. The comparison of the respective precision of these methods is illustrated in Table 13.

Precision Statements

For practical purposes, the following precision statements are based on the assumption of constant standard deviations of 0.05 and 0.08% as determined using Tester 1, respectively for within- and between-laboratory results for asphalt content determination.

Within-Laboratory Precision The within-laboratory standard deviation of a single test result consisting of the average of three replicates was determined to be 0.05%. Thus, the results of two properly performed tests by the same operator should not differ by more than 0.13% at 95% confidence level.

Between-Laboratory Precision The between-laboratory standard deviation was found to be 0.08%. Therefore, results of two properly conducted tests in two different laboratories on the same asphalt mixture should not differ by more than 0.21% at 95% level of confidence.

Aggregate Gradation

As stated previously, most aggregate, when tested at high temperatures, will generally experience some weight losses. Table 4 shows the calibration factors for each mix. These values also represent the measured weight losses, in percent of initial weight of mixtures, due to burn off. From this data, it can be seen that with the exception of Mix 3, the ignition did not significantly affect the aggregate initial weights. However, the aggregate did appear to be sensitive to the type of ignition tester used. Ignition Tester 2 seemed to result in higher weight loss values than ignition Tester 1.

In order to evaluate only the effects of the ignition method on aggregate gradations, the changes in gradation due to mixing was first quantified. Three aggregate batches per mix type were mixed with asphalt at their respective optimum asphalt contents. The aggregate was then recovered from each mixture using the reflux extraction procedure. A wash-sieved analysis was performed on each of the recovered aggregate batches in accordance with the Florida Method of Test FM 1-T 030. The respective averages of the resulting after-mixing aggregate gradations as well as the gradations of the aggregate after ignition testing are summarized for each mix type in Table 14. The changes in aggregate gradation due to ignition only were quantified as the respective difference between the after-mixing gradation and the after-ignition gradation for each mix type. These changes, in percent passing each sieve, are given in Table 14 as well. As a convention, the minus sign represents a decrease in the coarseness of the aggregate after ignition or, again, an increase in percent passing a particular sieve size.

It can be seen from Table 14 that the recovered aggregate after ignition were somewhat finer, as one would expect. With the exception of Mix 3 data, the changes in the recovered aggregate gradation were not significant. The maximum recorded variation in percent passing of the recovered aggregate gradations for any particular sieve was less than 3 percent. However, the results included in Table 14 suggest that the gradation of Mix 3 aggregate was significantly affected by the ignition test temperature. These aggregate seem to have experienced major fracturing due to ignition. A difference between the initial and the recovered aggregate percent passing of as high as 7 percent was recorded for a particular sieve size. This may be due to the high $CaMg(CO_3)_2$ (dolomite) content of the aggregate used in Mix 3. High temperatures tend to calcine dolomite resulting in its decomposition to magnesium oxide (MgO) and calcium carbonate ($CaCO_3$).

Accuracy of Aggregate Gradation

Table 14 shows the respective average percent passing the various sieve sizes of the recovered aggregate for each mix type. The percent deviation for the six mix types ranged from about -7 to 1.7, depending on the sieve sizes. Apart from mix 3, the respective differences between the actual and the measured percent passing for each sieve are relatively low. Thus, the percent passing each sieve size can be determined with a high degree of accuracy. However, such is not the case for mix 3. Significantly higher differences between the actual and the measured percent passing for each sieve were recorded. The precision statement for aggregate gradations, based on the respective average standard deviations of each sieve size as given in Table 15, are summarized in Table 16. An illustrative comparison of the respective precisions for the percent passing the 4.75 and 0.075 mm sieve sizes as determined in the different studies is shown in Table 17.

CONCLUSIONS

The State Materials Office of the Florida Department of Transportation (FDOT) performed a round robin study to determine the precision of the ignition method for local conditions. Based on the findings of this study, the following conclusions can be drawn:

1. The asphalt content of an asphalt mixture can be determined with a high degree of accuracy by the ignition method.
2. Within the test range, both ignition testers determined the asphalt content at the same mean level. The differences between the average values of asphalt content for each mix as measured by both ignition testers, respectively, were not statistically significant. However, a better precision in determining asphalt content was obtained using ignition Tester 1.
3. The results of two properly performed tests by the same operator should not differ by more than 0.13%.
4. The results of two properly conducted tests in two different laboratories on the same asphalt mixture should not differ by more than 0.21%.
5. The ignition test significantly affected the gradation of the aggregate used in Mix 3.

RECOMMENDATIONS

The following recommendations are based upon the results of the present study:

1. The Department should proceed with the implementation of the ignition method for both QC and Acceptance purposes.
2. Training in the use of the ignition oven and testing procedure should be included in the Asphalt Plant Technician Certification course.
3. Effort to establish a database for aggregate calibration factors should be initiated.

REFERENCES

1. E. R. Brown and S. Mager, “Asphalt Content by Ignition Round Robin Study,” National Center for Asphalt Technology, Auburn University, Auburn, 1995.

2. *Standard Practice for Preparing Precision and Bias Statements for Test Methods for Construction Materials*, American Society of Testing Materials.

3. N. Murphy and R. West, “Precision and Accuracy of Asphalt Content Determination by Ignition Method,” APAC Materials Services, Atlanta, 1996.

4. *Standard Practice for Conducting an Interlaboratory Test Program to Determine the Precision of Test Methods for Construction Materials*, American Society of Testing Materials

5. *Guide to Rocks and Minerals of Florida*, Florida Bureau of Geology, Tallahassee, 1981.

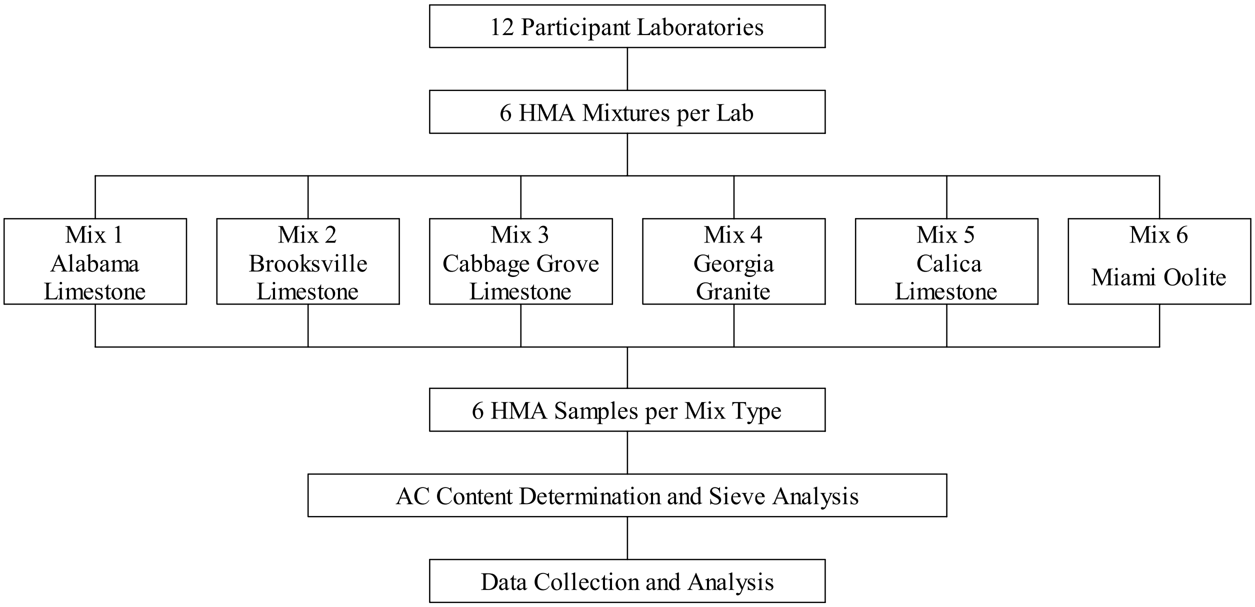

Figure 1 A Flow Chart Summarizing the Scope of the Round Robin Study

Table 1 Materials Used for Preparing Test Samples

Mix	Aggregate Type	Aggregate Source	Sand Type	AC Grade
1	Limestone	Calera, AL	Silica Sand	AC-30
2	Limestone	Brooksville, FL	Silica Sand	AC-30
3	Limestone	Cabbage Grove, FL	Silica Sand	AC-30
4	Granite	Ruby, GA	Silica Sand	AC-30
5	Limestone	Calica, Mexico	Silica Sand	AC-30
6	Oolite	Miami, FL	Silica Sand	AC-30

Table 2 Average of Aggregate Blend Gradations for Each Mix Type

Mix	1	2	3	4	5	6
Sieve Size (mm)	Percent Passing					
25.0	100.0	100.0	100.0	100.0	100.0	100.0
19.0	100.0	100.0	96.8	96.8	100.0	100.0
12.5	97.5	95.4	91.1	87.4	94.8	97.8
9.5	94.1	89.3	79.9	70.5	88.0	91.5
4.75	71.5	61.3	59.0	55.8	70.0	67.9
2.36	52.8	48.2	26.1	48.4	53.3	54.2
1.18	38.8	40.4	23.4	40.1	40.5	42.7
0.600	30.8	32.5	22.7	33.5	33.6	34.3
0.300	11.5	12.2	8.2	14.7	14.7	4.7
0.150	4.7	4.8	2.9	5.5	6.3	2.4
0.075	3.7	4.0	2.2	3.2	3.5	2.4

Table 3 Respective Asphalt Contents of Test Samples

Sample	1	2	3	4	5	6
Mix	% AC by Weight of Total Mix					
1	5.7	5.7	5.7	5.7	6.2	5.2
2	6.5	6.5	6.5	6.5	7.0	6.0
3	6.8	6.8	6.8	6.8	7.3	6.3
4	5.5	5.5	5.5	5.5	6.0	5.0
5	6.3	6.3	6.3	6.3	6.8	5.8
6	6.5	6.5	6.5	6.5	7.0	6.0

Table 4 Calibration Factors for Asphalt Content, Percent by Weight of Mixture

Lab	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
	Ignition Tester 1					
1	0.000	0.173	0.517	0.167	0.173	0.077
2	-0.023	0.277	0.793	0.340	0.100	0.057
3	-0.023	0.007	0.673	0.077	0.060	-0.033
4	0.030	0.153	0.553	0.117	0.127	0.043
5	-0.003	0.090	0.445	0.157	0.157	0.080
6	0.030	0.183	0.523	0.227	0.110	0.030
Average	0.002	0.147	0.584	0.181	0.121	0.042
	Ignition Tester 2					
7	0.107	0.273	1.037	0.257	0.213	0.183
8	0.147	0.253	1.387	0.227	0.247	0.103
9	0.213	0.197	1.293	0.343	0.337	0.307
10	-0.067	0.107	0.673	0.057	0.070	-0.010
11	0.007	0.207	0.357	0.140	0.087	-0.067
12	0.240	0.353	1.237	0.387	0.383	0.303
Average	0.108	0.232	0.997	0.235	0.223	0.137

Table 5 Respective Calibrated Asphalt Contents of Test Samples, Percent by Weight of Mixture

Lab	Replicate	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
		Ignition Tester 1					
1	1	5.72	6.42	6.73	5.47	6.24	6.43
	2	5.78	6.53	6.76	5.49	6.28	6.45
	3	5.76	6.50	6.82	5.49	6.27	6.44
2	1	5.80	6.46	6.87	5.33	6.33	6.51
	2	5.76	6.47	6.88	5.31	6.36	6.47
	3	5.75	6.45	6.98	5.33	6.37	6.50
3	1	5.60	6.49	6.26	5.55	6.27	6.57
	2	5.76	6.46	5.91	5.46	6.32	6.54
	3	5.72	6.54	6.40	5.50	6.11	6.64
4	1	5.74	6.54	6.85	5.52	6.36	6.49
	2	5.74	6.41	6.90	5.54	6.29	6.44
	3	5.72	6.50	6.95	5.50	6.28	6.47
5	1	5.74	6.49	6.95	5.45	6.06	6.43
	2	5.79	6.54	7.04	5.50	6.27	6.46
	3	5.71	6.47	6.85	5.51	6.31	6.49
6	1	5.69	6.41	6.16	5.32	6.25	6.40
	2	5.71	6.40	6.32	5.25	6.29	6.35
	3	5.71	6.24	6.25	5.26	6.22	6.40
Average		5.73	6.46	6.66	5.43	6.27	6.47
		Ignition Tester 2					
7	1	5.64	6.41	6.92	5.46	6.30	6.49
	2	5.70	6.34	6.92	5.51	6.27	6.36
	3	5.72	6.46	6.79	5.46	6.39	6.43
8	1	5.65	6.67	6.75	5.44	6.32	6.58
	2	5.70	6.68	6.83	5.58	6.27	6.56
	3	5.58	6.38	6.95	5.71	6.39	6.53
9	1	5.72	6.53	6.84	5.41	5.81	6.42
	2	5.91	6.73	6.86	4.93	6.32	6.54
	3	5.66	6.48	6.85	5.47	6.17	6.45
10	1	5.75	6.41	6.64	5.50	6.31	6.44
	2	5.75	6.49	6.83	5.47	6.35	6.45
	3	5.78	6.38	6.64	5.56	6.28	6.42
11	1	5.72	6.52	6.57	5.30	6.10	6.45
	2	5.64	6.46	7.08	5.59	6.32	6.34
	3	5.70	6.45	6.97	5.62	6.34	6.27
12	1	5.59	6.52	7.30	5.44	6.09	6.23
	2	5.12	6.45	6.53	5.49	6.21	6.53
	3	5.66	6.60	6.55	5.46	6.10	6.67
Average		5.67	6.50	6.82	5.47	6.24	6.45

Table 6 Results of the Asphalt Content Data Consistency Analysis

Lab	Mean	h	k	Mean	h	k
	Mix 1			Mix 2		
1	5.75	0.61	0.30	6.48	0.00	0.69
2	5.77	0.85	0.26	6.46	-0.25	0.12
3	5.69	-0.08	0.83	6.50	0.28	0.50
4	5.73	0.38	0.11	6.48	0.00	0.81
5	5.75	0.58	0.40	6.50	0.30	0.44
6	5.70	0.03	0.11	6.35	-1.97	1.20
7	5.69	-0.12	0.41	6.40	-1.21	0.73
8	5.65	-0.63	0.60	6.57	1.42	2.08
9	5.76	0.69	1.30	6.58	1.57	1.61
10	5.76	0.65	0.17	6.43	-0.76	0.69
11	5.69	-0.12	0.41	6.48	0.00	0.46
12	5.46	-2.84	2.92	6.52	0.61	0.91
	Mix 3			Mix 4		
1	6.77	0.13	0.26	5.49	0.35	0.10
2	6.91	0.65	0.34	5.32	-1.25	0.10
3	6.19	-2.17	1.41	5.50	0.49	0.41
4	6.90	0.61	0.28	5.52	0.71	0.18
5	6.94	0.79	0.53	5.49	0.38	0.29
6	6.24	-1.96	0.45	5.28	-1.69	0.32
7	6.88	0.55	0.42	5.48	0.28	0.26
8	6.85	0.41	0.57	5.58	1.26	1.23
9	6.85	0.41	0.06	5.27	-1.80	2.69
10	6.70	-0.16	0.62	5.51	0.61	0.42
11	6.88	0.53	1.51	5.50	0.51	1.60
12	6.80	0.22	2.47	5.47	0.15	0.23
	Mix 5			Mix 6		
1	6.26	0.04	0.20	6.44	-0.28	0.13
2	6.35	1.24	0.20	6.50	0.55	0.27
3	6.23	-0.32	1.03	6.58	1.87	0.68
4	6.31	0.73	0.41	6.46	0.03	0.32
5	6.22	-0.51	1.27	6.46	-0.02	0.38
6	6.26	-0.02	0.32	6.38	-1.21	0.32
7	6.32	0.77	0.59	6.42	-0.60	0.83
8	6.33	0.94	0.57	6.55	1.43	0.32
9	6.10	-1.97	2.49	6.47	0.18	0.80
10	6.31	0.73	0.33	6.44	-0.39	0.20
11	6.26	0.00	1.26	6.35	-1.74	1.16
12	6.13	-1.63	0.63	6.47	0.18	2.88

Table 7 Accuracy of Ignition Test Method for Asphalt Content Determination

Mix	Actual AC, %	Avg. Measured AC, %	Bias, %
1	5.70	5.72	0.02
2	6.50	6.48	-0.02
3	6.80	6.74	-0.06
4	5.50	5.45	-0.05
5	6.30	6.27	-0.03
6	6.50	6.46	-0.04
Average			-0.03

Table 8 Components of Variance, Variances, Standard Deviations, and Coefficients of Variations for Asphalt Contents

Mix	Average	Component of Variance		Variance		Std. Deviation		Coef of Variation	
		W/L	B/L	W/L	B/L	W/L	B/L	W/L	B/L
1	5.72	0.0032	0.0005	0.0032	0.0037	0.0564	0.0610	1.0	1.1
2	6.48	0.0068	0.0023	0.0068	0.0092	0.0827	0.0957	1.3	1.5
3	6.74	0.0169	0.0649	0.0169	0.0819	0.1301	0.2861	1.9	4.2
4	5.45	0.0132	0.0071	0.0132	0.0203	0.1148	0.1424	2.1	2.6
5	6.27	0.0117	0.0010	0.0117	0.0127	0.1083	0.1128	1.7	1.8
6	6.46	0.0021	0.0038	0.0021	0.0059	0.0455	0.0767	0.7	1.2
Average						0.0896	0.1291	1.5	2.1

Table 9 Results of the F-Distribution Test on Mixes

Variance, s^2			F-static		
Mix	W/L	B/L	Variance Ratio	W/L	B/L
1	0.0032	0.0037	s_3^2/s_1^2	5.3295	22.0125
2	0.0068	0.0092	s_3^2/s_2^2	2.4744	8.9448
3	0.0169	0.0819	s_3^2/s_3^2	1.0000	1.0000
4	0.0132	0.0203	s_3^2/s_4^2	1.2841	4.0352
5	0.0117	0.0127	s_3^2/s_5^2	1.4434	6.4346
6	0.0021	0.0059	s_3^2/s_6^2	8.1773	13.9015

Table 10 Components of Variance, Variances, Standard Deviations, and Coefficients of Variations for Asphalt Contents per Ignition Tester Type

Mix	Average	Component of Variance		Variance		Std. Deviation		Coef of Variance	
		W/L	B/L	W/L	B/L	W/L	B/L	W/L	B/L
Ignition Tester 1									
1	5.73	0.0018	0.0004	0.0018	0.0021	0.0418	0.0459	0.7	0.8
2	6.46	0.0034	0.0020	0.0034	0.0054	0.0583	0.0737	0.9	1.1
4	5.43	0.0008	0.0107	0.0008	0.0116	0.0288	0.1076	0.5	2.0
5	6.27	0.0056	0.0008	0.0056	0.0064	0.0750	0.0803	1.2	1.3
6	6.47	0.0009	0.0040	0.0009	0.0049	0.0304	0.0700	0.5	1.1
Average						0.0469	0.0755	0.8	1.3
Ignition Tester 2									
1	5.71	0.0049	0.0007	0.0049	0.0056	0.0699	0.0750	1.2	1.3
2	6.49	0.0110	0.0032	0.0110	0.0142	0.1047	0.1190	1.6	1.8
4	5.47	0.0280	0.0048	0.0280	0.0328	0.1673	0.1811	3.1	3.3
5	6.26	0.0190	0.0025	0.0190	0.0216	0.1380	0.1468	2.2	2.3
6	6.45	0.0034	0.0044	0.0034	0.0078	0.0587	0.0884	0.9	1.4
Average						0.1077	0.1221	1.8	2.0

Table 11 Results of the F-Distribution Test on Ignition Tester Types

Mix	Tester 1		Tester 2		F-static	
	Variance		Variance			
	W/L	B/L	W/L	B/L	W/L	B/L
1	0.0018	0.0021	0.0049	0.0056	2.7927	2.6708
2	0.0034	0.0054	0.0110	0.0142	3.2248	2.6043
4	0.0008	0.0116	0.0280	0.0328	33.7193	2.8325
5	0.0056	0.0064	0.0190	0.0216	3.3814	3.3447
6	0.0009	0.0049	0.0034	0.0078	3.7372	1.5950

Table 12 Components of Variance, Variances, Standard Deviations, and Coefficients of Variations for Asphalt Contents per Ignition Tester Type (Using External Weighing System)

Mix	Average	Component of Variance		Variance		Std. Deviations		Coef of Variation	
		W/L	B/L	W/L	B/L	W/L	B/L	W/L	B/L
Ignition Tester 1									
1	5.73	0.0049	0.0010	0.0049	0.0059	0.0699	0.0768	1.2	1.3
2	6.53	0.0030	0.0019	0.0030	0.0049	0.0550	0.0699	0.8	1.1
4	5.52	0.0025	0.0046	0.0025	0.0071	0.0499	0.0841	0.9	1.5
5	6.31	0.0051	0.0002	0.0051	0.0053	0.0716	0.0729	1.1	1.2
6	6.44	0.0035	0.0133	0.0035	0.0168	0.0592	0.1296	0.9	2.0
Average						0.0611	0.0866	1.0	1.4
Ignition Tester 2									
1	5.72	0.0028	-0.0002	0.0028	0.0026	0.0524	0.0506	0.9	0.9
2	6.50	0.0027	0.0039	0.0027	0.0066	0.0520	0.0813	0.8	1.3
4	5.55	0.0068	0.0030	0.0068	0.0099	0.0826	0.0992	1.5	1.8
5	6.29	0.0043	0.0015	0.0043	0.0059	0.0659	0.0767	1.0	1.2
6	6.50	0.0145	-0.0026	0.0145	0.0118	0.1202	0.1088	1.8	1.7
Average						0.0746	0.0833	1.2	1.4

Table 13 Respective Precision for Asphalt Content Determination Methods

Method			Standard Deviation, (1S)		Acceptable Range of Two Test Results, (D2S)	
			W/L	B/L	W/L	B/L
Ignition	FDOT	Tester 1	0.05	0.08	0.13	0.21
		Tester 2	0.11	0.12	0.30	0.34
	NCAT		0.04	0.06	0.11	0.17
	APAC		0.04	0.05	0.11	0.14
NAC Gauge			0.16(1)	0.23(1)	0.45	0.65
Vacuum Extraction			0.21(2)	0.22(2)	0.59	0.62

(1) *Precision of Methods for Determining Asphalt Cement Content*, National Asphalt Pavement Association.

(2) *Standard Test Methods for Quantitative Extraction of Bitumen from Bituminous Paving Mixture*, American Society of Testing Materials.

Table 14 Respective Aggregate Gradations

Sieve Size (mm)		25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
		Mix 1 Aggregate Gradation, % Passing										
Control	Avg.	100.0	100.0	97.5	94.1	71.5	52.8	38.8	30.8	11.5	4.7	3.7
After Mixing	Avg.	100.0	100.0	97.9	94.0	71.9	52.8	38.7	31.0	11.7	4.8	3.8
After Ignition	Lab 1	100.0	100.0	97.5	93.9	71.2	52.3	39.1	31.4	12.7	5.1	3.8
	Lab 2	100.0	100.0	97.5	93.6	71.8	52.9	39.1	31.1	12.2	4.8	3.5
	Lab3	100.0	100.0	97.3	94.1	71.7	52.3	39.2	31.7	12.5	5.0	3.6
	Lab4	100.0	100.0	97.8	94.2	71.7	52.4	38.9	31.2	12.8	5.2	3.9
	Lab 5	100.0	100.0	97.6	94.3	70.9	52.9	39.7	31.9	13.6	7.4	4.0
	Lab 6	100.0	100.0	97.7	94.3	72.2	52.5	39.0	31.5	13.1	5.1	4.0
	Lab 7	100.0	100.0	97.3	93.9	71.3	52.2	38.9	31.2	12.6	5.2	3.9
	Lab 8	100.0	100.0	97.4	93.6	70.8	51.8	38.8	30.8	12.2	4.8	3.7
	Lab 8	100.0	100.0	97.2	94.0	71.6	52.5	39.2	31.2	12.5	5.2	3.9
	Lab 10	100.0	100.0	97.8	93.7	71.6	52.6	39.6	31.2	11.5	5.0	3.9
	Lab 11	100.0	100.0	97.7	93.9	70.9	53.5	39.1	31.0	11.9	5.0	3.9
Difference Between the After Mixing and After Ignition Gradations, %	Lab 1	0.0	0.0	0.4	0.1	0.8	0.5	-0.4	-0.4	-1.0	-0.3	0.0
	Lab 2	0.0	0.0	0.4	0.5	0.1	-0.1	-0.4	-0.1	-0.5	0.0	0.4
	Lab3	0.0	0.0	0.6	-0.1	0.2	0.5	-0.5	-0.7	-0.8	-0.2	0.2
	Lab4	0.0	0.0	0.1	-0.2	0.2	0.4	-0.2	-0.2	-1.1	-0.4	-0.1
	Lab 5	0.0	0.0	0.3	-0.3	1.0	-0.1	-1.0	-0.9	-1.9	-2.6	-0.2
	Lab 6	0.0	0.0	0.2	-0.3	-0.3	0.3	-0.3	-0.5	-1.4	-0.3	-0.2
	Lab 7	0.0	0.0	0.6	0.1	0.7	0.6	-0.2	-0.2	-0.9	-0.4	-0.1
	Lab 8	0.0	0.0	0.5	0.4	1.1	1.0	-0.1	0.2	-0.5	0.0	0.1
	Lab 8	0.0	0.0	0.7	0.0	0.4	0.3	-0.5	-0.2	-0.8	-0.4	-0.1
	Lab 10	0.0	0.0	0.1	0.3	0.3	0.2	-0.9	-0.2	0.2	-0.2	-0.1
	Lab 11	0.0	0.0	0.2	0.1	1.0	-0.7	-0.4	0.0	-0.2	-0.2	-0.1
	Avg.	0.0	0.0	0.4	0.1	0.5	0.3	-0.4	-0.3	-0.8	-0.4	0.0

Table 14 - Continued

Sieve Size		25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
		Mix 2 Aggregate Gradation, % passing										
Control	Avg.	100.0	100.0	95.4	89.3	61.3	48.2	40.4	32.5	12.2	4.8	4.0
After Mixing	Avg.	100.0	100.0	95.2	89.8	61.2	48.1	40.5	32.8	12.4	4.8	3.9
After Ignition	Lab 1	100.0	100.0	95.1	89.4	61.5	48.2	40.7	33.8	12.5	4.8	3.7
	Lab 2	100.0	100.0	95.1	88.5	61.2	48.2	40.6	33.3	11.7	4.4	3.4
	Lab3	100.0	100.0	95.2	89.4	61.4	47.8	40.4	33.3	11.8	4.3	3.3
	Lab4	100.0	100.0	95.9	89.8	62.4	48.6	41.6	35.4	14.4	6.3	4.9
	Lab 5	100.0	100.0	95.4	89.5	61.5	49.0	42.1	35.6	15.0	6.1	4.7
	Lab 6	100.0	100.0	96.1	90.2	62.9	49.2	41.5	34.2	13.6	5.3	4.1
	Lab 7	100.0	100.0	94.8	88.5	61.1	48.1	40.9	33.8	13.0	5.1	4.0
	Lab 8	100.0	100.0	95.2	88.7	60.6	47.3	40.1	32.5	11.8	4.1	3.2
	Lab 8	100.0	100.0	95.1	88.6	61.3	48.4	40.8	33.0	12.2	4.7	3.7
	Lab 10	100.0	100.0	96.2	88.3	61.5	48.3	41.2	33.5	11.7	4.6	3.7
	Lab 11	100.0	100.0	95.6	89.1	61.4	49.1	40.9	33.1	12.1	4.8	3.8
Difference Between the After Mixing and After Ignition Gradations, %	Lab 1	0.0	0.0	0.1	0.4	-0.3	-0.1	-0.2	-1.0	-0.1	0.0	0.2
	Lab 2	0.0	0.0	0.1	1.3	0.1	-0.1	-0.1	-0.5	0.7	0.4	0.6
	Lab3	0.0	0.0	0.0	0.4	-0.2	0.3	0.1	-0.5	0.7	0.6	0.7
	Lab4	0.0	0.0	-0.7	0.0	-1.2	-0.5	-1.1	-2.6	-2.0	-1.5	-1.0
	Lab 5	0.0	0.0	-0.2	0.3	-0.3	-0.9	-1.6	-2.8	-2.6	-1.3	-0.8
	Lab 6	0.0	0.0	-0.9	-0.4	-1.7	-1.1	-1.0	-1.4	-1.2	-0.5	-0.2
	Lab 7	0.0	0.0	0.4	1.3	0.1	0.0	-0.4	-1.0	-0.6	-0.3	-0.1
	Lab 8	0.0	0.0	0.1	1.1	0.6	0.9	0.5	0.4	0.6	0.7	0.7
	Lab 8	0.0	0.0	0.1	1.2	-0.1	-0.3	-0.3	-0.2	0.3	0.1	0.2
	Lab 10	0.0	0.0	-1.0	1.5	-0.3	-0.2	-0.7	-0.7	0.7	0.2	0.3
	Lab 11	0.0	0.0	-0.4	0.7	-0.2	-1.0	-0.4	-0.3	0.3	0.0	0.1
	Avg.	0.0	0.0	-0.2	0.7	-0.3	-0.3	-0.5	-1.0	-0.3	-0.1	0.1

Table 14 - Continued

Sieve Size		25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
		Mix 3 Aggregate Gradation, % Passing										
Control	Avg.	100.0	96.8	91.1	79.9	59.0	26.1	23.4	22.7	8.2	2.9	2.2
After Mixing	Avg.	100.0	96.2	91.1	80.4	60.2	28.9	25.0	24.0	9.3	4.0	3.0
After Ignition	Lab 1	100.0	96.4	91.2	79.7	60.9	31.7	28.1	27.0	12.2	5.9	3.5
	Lab 2	100.0	96.6	91.5	79.6	61.2	32.4	28.2	27.0	11.7	5.9	3.4
	Lab3	100.0	96.3	91.1	80.4	60.3	29.7	26.5	25.6	11.2	4.9	2.8
	Lab4	99.5	96.4	92.2	83.0	62.5	34.2	30.4	29.2	14.3	7.7	4.7
	Lab 5	100.0	95.6	91.2	80.0	61.1	34.2	30.3	29.0	14.6	7.6	4.3
	Lab 6	100.0	96.8	92.6	83.6	63.9	36.2	32.2	30.5	15.5	8.4	4.8
	Lab 7	100.0	96.2	90.8	78.6	59.8	31.1	27.7	26.5	12.2	5.7	3.4
	Lab 8	100.0	96.6	91.1	78.7	58.6	28.9	25.5	24.5	10.1	3.8	2.0
	Lab 8	100.0	96.8	91.1	80.5	61.3	32.9	29.1	27.9	13.3	6.6	3.9
	Lab 10	100.0	95.9	91.7	78.6	58.9	32.1	27.9	26.7	11.7	5.7	3.3
	Lab 11	100.0	96.9	91.5	80.8	60.8	33.4	28.8	27.6	13.6	6.6	4.0
Difference Between the After Mixing and After Ignition Gradations, %	Lab 1	0.0	-0.2	-0.1	0.8	-0.7	-2.8	-3.1	-3.0	-2.9	-1.9	-0.5
	Lab 2	0.0	-0.4	-0.4	0.8	-1.0	-3.5	-3.2	-3.0	-2.4	-1.9	-0.4
	Lab3	0.0	-0.1	0.0	0.0	-0.1	-0.8	-1.5	-1.6	-1.9	-0.9	0.2
	Lab4	0.5	-0.2	-1.1	-2.6	-2.3	-5.3	-5.4	-5.2	-5.0	-3.7	-1.7
	Lab 5	0.0	0.6	-0.1	0.4	-0.9	-5.3	-5.3	-5.0	-5.3	-3.6	-1.3
	Lab 6	0.0	-0.6	-1.5	-3.2	-3.7	-7.3	-7.2	-6.5	-6.2	-4.4	-1.8
	Lab 7	0.0	0.0	0.4	1.8	0.4	-2.2	-2.7	-2.5	-2.9	-1.7	-0.4
	Lab 8	0.0	-0.4	0.0	1.8	1.6	0.1	-0.5	-0.5	-0.8	0.3	1.0
	Lab 8	0.0	-0.6	0.0	-0.1	-1.1	-4.0	-4.1	-3.9	-4.0	-2.6	-0.9
	Lab 10	0.0	0.3	-0.6	1.8	1.4	-3.2	-2.9	-2.7	-2.4	-1.7	-0.3
	Lab 11	0.0	-0.7	-0.4	-0.4	-0.6	-4.5	-3.8	-3.6	-4.3	-2.6	-1.0
	Avg.	0.0	-0.2	-0.3	0.1	-0.6	-3.5	-3.6	-3.4	-3.4	-2.2	-0.6

Table 14 - Continued

Sieve Size (mm)		25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
		Mix 4 Aggregate Gradation, % Passing										
Control	Avg.	100.0	96.8	87.4	70.5	55.8	48.4	40.1	33.5	14.7	5.5	3.2
After Mixing	Avg.	100.0	97.1	86.8	70.3	55.7	48.5	40.3	33.9	15.1	5.8	3.3
After Ignition	Lab 1	100.0	96.6	86.6	70.2	56.0	48.2	39.9	34.3	15.5	6.0	3.4
	Lab 2	100.0	97.3	87.4	70.1	56.0	48.5	40.3	34.4	15.6	6.1	3.3
	Lab3	100.0	96.5	87.3	70.5	55.9	48.1	40.0	34.5	15.6	6.0	3.2
	Lab4	100.0	96.4	87.8	72.1	56.0	48.4	40.2	34.7	15.8	6.1	3.4
	Lab 5	99.5	96.8	87.1	70.6	55.7	48.3	40.3	34.4	16.0	5.9	3.3
	Lab 6	99.5	95.9	87.9	72.0	56.6	48.7	40.4	34.7	16.6	6.2	3.4
	Lab 7	100.0	96.5	86.1	69.6	56.0	48.3	40.4	34.4	15.8	6.2	3.5
	Lab 8	100.0	96.7	86.2	68.7	55.5	47.8	40.0	33.8	15.1	5.4	2.8
	Lab 8	100.0	96.3	86.8	69.8	56.0	48.4	40.4	34.4	15.6	6.3	3.5
	Lab 10	100.0	96.8	90.1	69.7	55.7	48.6	41.0	34.4	14.9	5.9	3.4
	Lab 11	100.0	97.1	87.4	70.7	56.0	49.1	40.8	34.4	16.4	6.1	3.5
Difference Between the After Mixing and After Ignition Gradations, %	Lab 1	0.0	0.5	0.2	0.1	-0.3	0.3	0.4	-0.4	-0.4	-0.2	-0.1
	Lab 2	0.0	-0.2	-0.6	0.2	-0.3	0.0	0.0	-0.5	-0.5	-0.3	0.0
	Lab3	0.0	0.6	-0.5	-0.2	-0.2	0.4	0.3	-0.6	-0.5	-0.2	0.2
	Lab4	0.0	0.7	-1.0	-1.8	-0.3	0.1	0.1	-0.8	-0.7	-0.3	-0.1
	Lab 5	0.5	0.3	-0.3	-0.3	0.0	0.2	0.0	-0.5	-0.9	-0.1	0.1
	Lab 6	0.5	1.2	-1.1	-1.7	-0.9	-0.2	-0.1	-0.8	-1.5	-0.4	-0.1
	Lab 7	0.0	0.6	0.7	0.8	-0.3	0.3	-0.1	-0.5	-0.7	-0.4	-0.2
	Lab 8	0.0	0.4	0.6	1.6	0.2	0.7	0.3	0.1	0.1	0.4	0.6
	Lab 8	0.0	0.8	0.0	0.5	-0.3	0.1	-0.1	-0.5	-0.5	-0.5	-0.2
	Lab 10	0.0	0.3	-3.3	0.7	0.0	-0.1	-0.7	-0.5	0.2	-0.1	-0.1
	Lab 11	0.0	0.0	-0.6	-0.4	-0.3	-0.6	-0.5	-0.5	-1.3	-0.3	-0.2
	Avg.	0.1	0.5	-0.5	-0.1	-0.2	0.1	0.0	-0.5	-0.6	-0.2	0.0

Table 14 - Continued

Sieve Size (mm)		25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
		Mix 5 Aggregate Gradation, % Passing										
Control	Avg.	100.0	100.0	94.8	88.0	70.0	53.3	40.5	33.6	14.7	6.3	3.5
After Mixing	Avg.	100.0	100.0	94.5	88.1	69.9	53.3	40.4	33.5	14.6	6.3	3.6
After Ignition	Lab 1	100.0	99.8	94.8	87.5	69.7	52.6	40.4	33.6	14.4	6.3	3.7
	Lab 2	100.0	100.0	94.5	87.0	70.0	53.3	40.3	33.1	13.8	5.6	3.1
	Lab3	100.0	100.0	94.5	88.3	70.5	52.5	40.3	33.6	14.1	6.1	3.5
	Lab4	100.0	100.0	95.1	88.7	70.1	52.7	40.5	33.7	14.6	6.5	4.0
	Lab 5	100.0	100.0	94.7	87.8	69.5	53.2	40.6	33.7	15.2	6.3	3.6
	Lab 6	100.0	100.0	95.6	88.8	70.4	53.1	40.7	33.9	14.9	6.5	3.9
	Lab 7	100.0	100.0	94.3	87.6	69.6	52.3	40.3	33.3	14.2	6.1	3.5
	Lab 8	100.0	100.0	94.6	87.2	69.3	52.1	40.3	33.0	14.2	5.8	3.3
	Lab 8	100.0	99.8	94.5	87.5	69.8	52.7	40.5	33.3	14.4	6.2	3.6
	Lab 10	100.0	99.8	95.6	87.1	69.8	53.2	41.2	33.6	13.7	6.1	3.6
	Lab 11	100.0	99.8	95.0	87.8	69.7	54.2	40.8	33.4	15.1	6.2	3.7
Difference Between the After Mixing and After Ignition Gradations, %	Lab 1	0.0	0.2	-0.3	0.6	0.3	0.7	0.0	-0.1	0.2	0.0	-0.1
	Lab 2	0.0	0.0	0.0	1.1	-0.1	0.0	0.1	0.4	0.8	0.7	0.6
	Lab3	0.0	0.0	0.0	-0.2	-0.6	0.8	0.2	-0.1	0.5	0.2	0.1
	Lab4	0.0	0.0	-0.6	-0.6	-0.2	0.6	-0.1	-0.2	0.1	-0.2	-0.4
	Lab 5	0.0	0.0	-0.2	0.3	0.4	0.1	-0.2	-0.2	-0.6	0.1	0.0
	Lab 6	0.0	0.0	-1.1	-0.7	-0.5	0.3	-0.3	-0.4	-0.3	-0.2	-0.3
	Lab 7	0.0	0.0	0.2	0.5	0.4	1.0	0.2	0.3	0.5	0.2	0.2
	Lab 8	0.0	0.0	-0.1	1.0	0.6	1.2	0.2	0.5	0.4	0.5	0.4
	Lab 8	0.0	0.2	0.0	0.6	0.1	0.7	-0.1	0.3	0.2	0.1	0.0
	Lab 10	0.0	0.2	-1.1	1.0	0.1	0.1	-0.8	-0.1	0.9	0.2	0.0
	Lab 11	0.0	0.2	-0.5	0.3	0.2	-0.9	-0.4	0.2	-0.5	0.1	-0.1
	Avg.	0.0	0.1	-0.3	0.4	0.1	0.4	-0.1	0.0	0.2	0.2	0.0

Table 14 - Continued

Sieve Size (mm)		25	19	12.5	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
		Mix 6 Aggregate Gradation, % Passing										
Control	Avg.	100.0	100.0	97.8	91.5	67.9	54.2	42.7	34.3	15.4	4.7	2.4
After Mixing	Avg.	100.0	100.0	98.0	91.3	67.6	54.2	42.8	34.4	15.6	5.0	2.6
After Ignition	Lab 1	100.0	100.0	97.8	91.3	68.0	54.3	42.9	35.1	15.4	5.0	2.6
	Lab 2	100.0	100.0	97.9	90.6	68.3	54.4	42.8	34.5	15.3	4.5	2.3
	Lab3	100.0	100.0	97.9	91.7	68.7	54.0	42.7	35.1	15.2	4.8	2.4
	Lab4	100.0	100.0	98.3	92.4	68.6	54.6	43.5	35.6	15.7	5.3	2.9
	Lab 5	100.0	100.0	98.3	91.5	68.2	54.8	43.8	35.9	17.1	5.5	2.9
	Lab 6	100.0	100.0	98.8	92.5	69.7	55.4	43.6	35.8	16.5	5.3	2.8
	Lab 7	100.0	100.0	97.6	90.9	68.1	54.1	42.9	34.9	15.6	5.1	2.7
	Lab 8	100.0	100.0	98.5	90.8	67.3	53.7	42.8	34.3	15.4	4.5	2.3
	Lab 8	100.0	100.0	97.9	90.9	68.0	54.7	43.2	34.9	15.8	5.1	2.6
	Lab 10	100.0	100.0	99.1	90.9	67.3	54.4	43.6	35.1	14.8	4.7	2.5
	Lab 11	100.0	100.0	97.9	91.6	68.1	55.6	43.8	35.2	16.5	5.1	2.8
Difference Between the After Mixing and After Ignition Gradations, %	Lab 1	0.0	0.0	0.2	0.0	-0.4	-0.1	-0.1	-0.7	0.2	0.0	0.0
	Lab 2	0.0	0.0	0.2	0.7	-0.7	-0.2	0.0	-0.1	0.3	0.5	0.4
	Lab3	0.0	0.0	0.2	-0.4	-1.1	0.3	0.1	-0.7	0.4	0.2	0.3
	Lab4	0.0	0.0	-0.3	-1.1	-1.0	-0.4	-0.7	-1.2	-0.1	-0.3	-0.3
	Lab 5	0.0	0.0	-0.3	-0.2	-0.6	-0.6	-1.0	-1.5	-1.5	-0.5	-0.3
	Lab 6	0.0	0.0	-0.8	-1.2	-2.1	-1.2	-0.8	-1.4	-0.9	-0.3	-0.2
	Lab 7	0.0	0.0	0.4	0.4	-0.5	0.1	-0.1	-0.5	0.0	-0.1	-0.1
	Lab 8	0.0	0.0	-0.5	0.5	0.4	0.5	0.0	0.1	0.3	0.5	0.3
	Lab 8	0.0	0.0	0.1	0.4	-0.4	-0.5	-0.4	-0.5	-0.2	-0.1	0.0
	Lab 10	0.0	0.0	-1.1	0.4	0.3	-0.2	-0.8	-0.7	0.8	0.3	0.1
	Lab 11	0.0	0.0	0.1	-0.3	-0.5	-1.4	-1.0	-0.8	-0.9	-0.1	-0.2
	Avg.	0.0	0.0	-0.2	-0.1	-0.6	-0.3	-0.4	-0.7	-0.1	0.0	0.0

Table 15 Components of Variance, Variances, Standard Deviations, and Coefficients of Variation for the Recovered Aggregate Gradation after Ignition

Mix	Average	Component of Variance		Variance		Standard Deviations		Coefficient of Variation	
		W/L	B/L	W/L	B/L	W/L	B/L	W/L	B/L
		25 mm Sieve Size							
1	100.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0	0.0
2	100.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0	0.0
3	99.9	0.1094	0.0000	0.1094	0.1094	0.3307	0.3307	0.3	0.3
4	99.9	0.2306	-0.0077	0.2306	0.2229	0.4802	0.4722	0.5	0.5
5	100.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0	0.0
6	100.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0	0.0
Average						0.1352	0.1338	0.1	0.1
		19 mm Sieve Size							
1	100.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0	0.0
2	100.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0	0.0
3	97.0	0.5121	-0.0013	0.5121	0.5108	0.7156	0.7147	0.7	0.7
4	96.2	0.8619	-0.0708	0.8619	0.7911	0.9284	0.8894	1.0	0.9
5	99.9	0.0479	-0.0010	0.0479	0.0469	0.2188	0.2165	0.2	0.2
6	100.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0	0.0
Average						0.3105	0.3034	0.3	0.3
		12.5 mm Sieve Size							
1	97.1	0.1173	0.0105	0.1173	0.1278	0.3425	0.3575	0.4	0.4
2	95.5	0.1433	0.1625	0.1433	0.3058	0.3786	0.5530	0.4	0.6
3	91.4	0.1742	0.1731	0.1742	0.3474	0.4174	0.5894	0.5	0.6
4	87.7	0.7606	0.6411	0.7606	1.4018	0.8721	1.1840	1.0	1.4
5	95.0	0.0713	0.1315	0.0713	0.2027	0.2670	0.4503	0.3	0.5
6	98.1	0.2393	0.0510	0.2393	0.2903	0.4892	0.5388	0.5	0.5
Average						0.4611	0.6122	0.5	0.7
		9.5 mm Sieve Size							
1	94.1	0.0574	0.0479	0.0574	0.1053	0.2396	0.3244	0.3	0.3
2	88.6	0.2045	0.3855	0.2045	0.5900	0.4523	0.7681	0.5	0.9
3	79.7	0.6518	2.5230	0.6518	3.1748	0.8074	1.7818	1.0	2.2
4	70.4	0.4605	0.9916	0.4605	1.4521	0.6786	1.2050	1.0	1.7
5	87.6	0.1337	0.3584	0.1337	0.4921	0.3657	0.7015	0.4	0.8
6	91.5	0.2259	0.2685	0.2259	0.4944	0.4753	0.7032	0.5	0.8
Average						0.5031	0.9140	0.6	1.1

Table 15 - Continued

Mix	Average	Component of Variance		Variance		Standard Deviations		Coefficient of Variation	
		W/L	B/L	W/L	B/L	W/L	B/L	W/L	B/L
		4.75 mm Sieve Size							
1	71.0	0.2738	0.0992	0.2738	0.3730	0.5232	0.6107	0.7	0.9
2	61.6	0.1803	0.3842	0.1803	0.5645	0.4246	0.7513	0.7	1.2
3	59.6	0.8252	2.0362	0.8252	2.8613	0.9084	1.6915	1.5	2.8
4	56.0	0.0762	0.0756	0.0762	0.1517	0.2760	0.3895	0.5	0.7
5	69.9	0.0982	0.1092	0.0982	0.2075	0.3134	0.4555	0.4	0.7
6	68.5	0.2170	0.3486	0.2170	0.5657	0.4659	0.7521	0.7	1.1
Average						0.4853	0.7751	0.8	1.2
		2.36 mm Sieve Size							
1	52.5	0.0763	0.1417	0.0763	0.2180	0.2762	0.4669	0.5	0.9
2	48.4	0.0785	0.3146	0.0785	0.3931	0.2802	0.6270	0.6	1.3
3	29.5	1.4870	4.1244	1.4870	5.6113	1.2194	2.3688	4.1	8.0
4	48.2	0.1269	0.0899	0.1269	0.2168	0.3562	0.4656	0.7	1.0
5	52.7	0.0666	0.1870	0.0666	0.2536	0.2581	0.5036	0.5	1.0
6	54.4	0.1452	0.1518	0.1452	0.2970	0.3811	0.5450	0.7	1.0
Average						0.4619	0.8295	1.2	2.2
		1.18 mm Sieve Size							
1	39.2	0.0407	0.0519	0.0407	0.0926	0.2017	0.3042	0.5	0.8
2	40.8	0.0718	0.3964	0.0718	0.4682	0.2680	0.6842	0.7	1.7
3	27.0	1.1512	3.2812	1.1512	4.4324	1.0729	2.1053	4.0	7.8
4	40.0	0.2794	0.0532	0.2794	0.3326	0.5286	0.5767	1.3	1.4
5	40.5	0.0393	0.0596	0.0393	0.0990	0.1983	0.3146	0.5	0.8
6	43.1	0.1157	0.1215	0.1157	0.2372	0.3401	0.4870	0.8	1.1
Average						0.4350	0.7454	1.3	2.3
		0.600 mm Sieve Size							
1	31.1	0.0275	0.0817	0.0275	0.1092	0.1659	0.3305	0.5	1.1
2	33.4	0.1588	1.0482	0.1588	1.2070	0.3985	1.0986	1.2	3.3
3	26.1	0.9906	2.8032	0.9906	3.7938	0.9953	1.9478	3.8	7.5
4	33.9	0.2174	0.0522	0.2174	0.2696	0.4662	0.5192	1.4	1.5
5	33.5	0.0136	0.0808	0.0136	0.0944	0.1165	0.3073	0.3	0.9
6	35.0	0.0773	0.1993	0.0773	0.2766	0.2780	0.5259	0.8	1.5
Average						0.4034	0.7882	1.3	2.6
		0.300 mm Sieve							
1	12.3	0.1135	0.2251	0.1135	0.3386	0.3368	0.5819	2.7	4.7
2	12.4	0.2591	1.3921	0.2591	1.6512	0.5090	1.2850	4.1	10.3
3	11.6	0.7924	2.5804	0.7924	3.3728	0.8902	1.8365	7.7	15.9
4	15.2	0.3953	0.1402	0.3953	0.5355	0.6287	0.7318	4.1	4.8
5	14.5	0.1588	0.0825	0.1588	0.2413	0.3984	0.4912	2.8	3.4
6	15.4	0.3362	0.2080	0.3362	0.5442	0.5799	0.7377	3.8	4.8
Average						0.5572	0.9440	4.2	7.3

Table 15 - Continued

Mix	Average	Component of Variance		Variance		Standard Deviations		Coefficient of Variation	
		W/L	B/L	W/L	B/L	W/L	B/L	W/L	B/L
		0.150 mm Sieve Size							
1	5.2	2.0792	0.1383	2.0792	2.2175	1.4419	1.4891	27.8	28.8
2	4.9	0.1418	0.5077	0.1418	0.6495	0.3766	0.8059	7.7	16.5
3	5.1	0.6018	1.7231	0.6018	2.3249	0.7758	1.5248	15.2	29.9
4	5.6	0.2858	0.0330	0.2858	0.3188	0.5346	0.5646	9.5	10.1
5	6.1	0.0133	0.0634	0.0133	0.0767	0.1155	0.2769	1.9	4.5
6	4.6	0.0819	0.0623	0.0819	0.1443	0.2863	0.3798	6.2	8.2
Average						0.5884	0.8402	11.4	16.3
		0.075 mm Sieve Size							
1	3.7	0.0131	0.0214	0.0131	0.0345	0.1143	0.1858	3.1	5.0
2	3.9	0.0985	0.3108	0.0985	0.4093	0.3138	0.6397	8.1	16.5
3	2.8	0.1782	0.6463	0.1782	0.8245	0.4221	0.9080	15.1	32.5
4	3.1	0.2329	0.0221	0.2329	0.2550	0.4826	0.5050	15.5	16.2
5	3.4	0.0138	0.0661	0.0138	0.0800	0.1176	0.2828	3.4	8.3
6	2.4	0.0378	0.0357	0.0378	0.0735	0.1945	0.2712	8.2	11.4
Average						0.2741	0.4654	8.9	15.0

Table 16 Precision Statement for Recovered Aggregate Gradation (Not Including Mix 3 Data)

Sieve Size (mm)	Standard Deviation (1S)		Acceptable Range of Two Test Results (D2S)	
	W/L	B/L	W/L	B/L
25	0.0960	0.0944	0.3	0.3
19	0.2294	0.2212	0.6	0.6
12.5	0.4699	0.6167	1.3	1.7
9.5	0.4423	0.7405	1.3	2.1
4.75	0.4006	0.5918	1.1	1.7
2.36	0.3103	0.5216	0.9	1.5
1.18	0.3074	0.4734	0.9	1.3
0.6	0.2850	0.5563	0.8	1.6
0.3	0.4906	0.7655	1.4	2.2
0.15	0.5510	0.7033	1.6	2.0
0.075	0.2445	0.3769	0.7	1.1

Table 17 Illustrative Comparison of Respective Precision Statements for Percent Passing 4.75 and 0.075 mm Sieve Sizes

Study	Std Deviation, (1S)		Acceptable Range, (D2S)	
	W/L	B/L	W/L	B/L
	4.75 mm Sieve Size			
FDOT	0.40	0.59	1.1	1.7
NCAT	0.28	0.37	0.8	1.1
APAC	0.26	0.38	0.7	1.1
	0.075 mm Sieve Size			
FDOT	0.24	0.38	0.7	1.1
NCAT	0.47	0.65	1.3	1.8
APAC	0.17	0.26	0.5	0.7

APPENDIX A

INSTRUCTIONS

September 3, 1996

To: Round Robin Study Participants.

Subject: Ignition Method Round Robin Study.

Thank you for your willingness to participate in the ignition method round robin study. Please find attached the respective testing procedures for asphalt content determination and gradation analysis. In order to establish single and multi-operator variability, it is essential that **one and only one** technician be designated to perform these tests. The designated technician for the subject study must follow these test methods when testing the samples. If the technician is not familiar enough with the procedures, he/she should be given the opportunity to acquaint himself/herself with the methods. To verify that the procedures are properly followed, it is requested that, prior to testing the round robin samples, the designated technician test the provided "practice sample" and have the results faxed to my attention at (352) 334-1649. **Please do not start testing the round robin samples until you are notified to do so**.

For the purpose of the subject study, your laboratory will be receiving thirty-six samples of hot mix asphalt concrete mixtures and a "practice sample". Each box containing the round robin sample has an identification label. A sample worksheet is attached to illustrate how the test results should be reported. A blank worksheet is also provided to record all test results. Please make copies of the blank worksheet as necessary.

Please attempt to complete the round robin testing by October 15, 1996. Upon completion of the testing, return all data sheets to my attention at the address below:

Bituminous Research Laboratory
Florida Department of Transportation
2006 N.E. Waldo Road
Gainesville, FL 32609

If you have any questions, please call Toby Dillow at (352) 337-3189 (SC 642-3189) or myself at (352) 337-3167 (SC 642-3167).

Sincerely,

Bouzid Choubane
Bituminous Research Engineer

Enclosures: Test Procedures.
Sample Worksheet.
Blank Worksheet.

APPENDIX B

TEST PROCEDURE

IGNITION METHOD ROUND ROBIN STUDY
TEST PROCEDURE

1 Obtain the box containing the test sample and record the sample number on the attached data sheet.

2 Preheat the mixture sample in the box to a temperature of 115°C (239°F) in an oven for 20 minutes or until the mixture can be easily crumbled with a spatula.

3 Preheat the ignition furnace to 538°C (1000°F).

4 Enter a correction factor of 0.00 in the ignition furnace.

5 Weigh and record the weight of the sample baskets and catch pan (with guards in place), (A).

6 Place the bottom sample basket in the catch pan. Evenly distribute approximately one half of the mixture sample specimen in the lower basket, keeping the material approximately 25 mm (1 in) away from the edges of the basket.

7 Place the upper sample basket on the bottom basket assembly. Evenly distribute the remaining specimen in the top basket as in 6.

NOTE: If the basket assembly contains more than two baskets, divide the sample into equal proportions accordingly.

8 Weigh the sample and the sample basket assembly and record, (B). Subtract from this weight the weight measured in 5, (C = B - A), and record. This is the actual weight, (C), of the sample specimen.

9 Input the actual weight, (C), of the sample specimen, rounded to the nearest gram, into the ignition furnace controller. Verify that the correct weight has been entered.

10 Using protective equipment, open the chamber door and place the sample basket assembly in the furnace. Close the chamber door and initiate the test by pressing the start/stop button.

11 Allow the test to continue until the stable light and audible stable alarm indicate that the test is complete. Press the start/stop button. This will also initiate the print out of the test results.

12 Using protective equipment, open the chamber door, remove the sample baskets, place on an insulated heat resistant surface and cover the basket assembly with the protective cage. Allow to cool to room temperature, then weigh the sample and the sample basket assembly, (D). Determine the final weight of the sample specimen, (E = D - A).

13 Perform a gradation analysis on the residual aggregate according to FM 1-T 030 attached herewith. Please note the sieves to be used are the 1", ¾ ", ½ ", d ", #4, 8, 16, 30, 50, 100, and 200.

APPENDIX C

WORKSHEET SUMMARY

WORKSHEET SUMMARY

General Information		*Washed Sieve Analysis*			
Lab. Name:		Tare Weight of pan, g			
Lab Location:		Initial weight of aggregate sample, g			
		Weight of sample after washing & drying, g			
Technician(s):		Wash Loss, g			
Date:		-200 from Sieve Analysis, g			
Sample I.D.:		Total -200, g			
Ignition Test Data		Sieve	Weight Retained (g)	Percent Retained (%)	Percent Passing (%)
Chamber Temperature Setting, Deg. C		1" (25.0mm)			
Basket Assembly Weight, g - (A)		3/4" (19.0mm)			
Basket Assembly + Sample Wt before Test, g -(B)		1/2" (12.5mm)			
Initial Sample Weight, g - (C) = (B - A)		3/8" (9.5mm)			
Basket Assembly + Sample Wt. after Test, g - (D)		No. 4 (4.75mm)			
Final Sample Weight, g - (E) = (D - A)		No. 8 (2.36mm)			
Temperature Compensation, %		No. 16 (1.18mm)			
Loss of Material, % of Mix - (C - E)*100/C		No. 30 (600um)			
A.C. Content, %		No. 50 (300um)			
Elapsed Time to Test Completion		No. 100 (150um)			
Note: Please attach furnace controller print out.		No. 200 (75um)			
		Pan			
		Total			

Comments: ______________________________