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Comparison of methods for determining bulk specific gravity of Hma specimens

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COMPARISON OF METHODS FOR DETERMINING BULK SPECIFIC GRAVITY OF HMA SPECIMENS

by

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ABSTRACT

Comparison of Methods for Determining Bulk Specific Gravity of HMA Specimens

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In this study, bulk specific gravity measurements of coarse graded Hot Mix Asphalt were conducted using two methods, Parafilm™ and Corelok™. The measurements were compared for similarity and repeatability of results. The comparisons were made on two sets of specimens, unrutted and rutted specimens. The unrutted specimens were laboratory prepared beams and cores obtained from the field. The rutted specimens were laboratory prepared beams. Analysis of the data showed (1) based on regression analysis for both rutted and unrutted specimens there is a statistically significant difference between the measurements made by Parafilm™ and Corelok™ methods and (2) based on a one-way analysis of variance Corelok™ measurements are more repeatable for unrutted and rutted specimens than those made by Parafilm™. Additionally, for the rutted specimens, the bulk specific gravities measured by Parafilm™ were significantly

lower than those measured by Corelok™. This is because the self-sealing parafilm bridges over large surface irregularities in contrast to the Corelok™, where the polymer Corelok™ bag follows the contours of the surface irregularities.

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CHAPTER 1

INTRODUCTION

Purpose of the Study

The wide spread acceptance and use of coarse graded Hot Mix Asphalt (HMA) mix designs has brought scrutiny to the testing methods used for determining bulk specific gravity. Asphalt mix design parameters, such as air void content and voids in mineral aggregate (VMA), are dependent on the bulk specific gravity measurements. Presently the Parafilm™ method of bulk specific gravity measurements for coarse graded HMA is widely used. Recently a new method called Corelok™ has been developed. Parafilm™ and Corelok™ bulk specific gravity measurements were made on two sets of specimens, unrutted and rutted specimens. The unrutted specimens were laboratory prepared beams and cores obtained from the field. The rutted specimens were laboratory prepared beams that had been subjected to rutting. The Parafilm™ and Corelok™ measurements were compared for similarity and repeatability of results on the two sets of specimens.

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This thesis is divided into four parts. A background chapter provides information about bulk specific gravity testing methods and literature review. The next chapter, Methodology, details how the data was collected and presents the data that was used for the statistical analysis. Finally, the observations from this study are presented in the Conclusions chapter.

CHAPTER 2

BACKGROUND

Bulk Specific Gravity Measurements

The Bulk Specific Gravity Measurements section describes several methods of determining the bulk specific gravity of HMA specimens. The methods described are the traditional method, the Parafilm™ method and the Corelok™ method. The traditional method is provided as an historical background for the emergence of the Parafilm™ and Corelok™ methods.

Traditional Method

The traditional method for determining the bulk specific gravity of HMA specimens is as follows:

1. Weigh the specimen in air
2. Weigh the specimen submerged in water
3. Weigh the specimen in a saturated surface dry condition.

The following equation is then used to calculate the bulk specific gravity (G_{mb}):

$$\text{Bulk Specific Gravity } (G_{mb}) = \frac{\text{Mass}_{dry}}{\text{Mass}_{SSD} - \text{Mass}_{sub}}$$

where:

$Mass_{dry}$ is the mass of the specimen in air

$Mass_{sub}$ is the mass of the specimen submerged in water and

$Mass_{SSD}$ is the saturated surface dry specimen mass.

This procedure provides an accurate measurement of the bulk specific gravity for conventional dense graded mixes. The increase in the use of coarse and open graded mixes had created a need for more reliable and accurate methods of bulk specific gravity measurements of laboratory and field specimens. Open and coarse graded mixes contain large, interconnected voids that are easily filled with water when the specimens are submerged. However, once the specimens are removed from the submersion tank, the water quickly drains from the voids. The lack of control over the penetration and drainage of water in and out of the HMA specimen creates a fundamental problem with the traditional method for determining bulk specific gravity of coarse graded specimens.

Currently AASHTO T-166 and ASTM D 2726 specifications require that compacted HMA specimens that absorb more than 2 percent water during submersion be tested using either Parafilm™ or other suitable method to coat or seal the surface of the samples to prevent water absorption.

Parafilm Method™

Parafilm™ is a self-sealing flexible film that is 127 μm thick. ASTM D1188 provides the procedure for determining the bulk specific gravity of specimens using the Parafilm™ method.

An unwrapped HMA specimen is weighed in air. The specimen is then wrapped in Parafilm™ and weighed in air. The wrapped specimen is then weighed in water. The bulk specific gravity of the specimen is determined by the following equation:

$$\text{Bulk Specific Gravity} = \frac{A}{\left[B - C - \frac{(B - A)}{D}\right]}$$

where:

A is the weight of the dry specimen in air

B is the weight of the dry specimen plus parafilm in air

C is the weight of the dry specimen plus parafilm in water

D is the specific gravity of the parafilm

Corelok™ Method

The Parafilm™ method is optimized for 100 mm diameter samples and it is difficult to use Parafilm™ for specimens larger than 150 mm diameter. The Corelok™ method does not have size limitations.

The Corelok™ system is a vacuum chamber that is used with specially designed polymer bags to completely seal the HMA specimens during the bulk specific gravity measurements. The sample is placed inside a specially designed plastic polymer bag, inserted in the chamber and the door is closed. A switch recognizes the door closure and activates the vacuum pump. The vacuum pump operates for a period of approximately 45 seconds. A pressure gauge monitors the vacuum level and aids the operator in insuring proper vacuum level within the chamber. An automatic sealing strip heat-seals the bag at the open end and air is allowed to enter in the chamber in a controlled manner. Since the bag is sealed and is under vacuum, the increase the increase pressure in the chamber forces the plastic bag around the sample creating a tightly sealed sample. Once the chamber reaches atmospheric pressure, the chamber door automatically opens. The sample can be removed and tested. The calculations are the same as the existing procedure for Parafilm™ method (ASTM D1188). The bag density is known and accounted for in the calculation of the bulk specific gravity.

Literature Review

Several previous studies have compared the results of several different measurement methods to determine the bulk specific gravity of HMA specimens. Buchanan (2000) discussed the comparison of bulk specific gravities determined by water displacement, dimensional analysis, Parafilm™ and vacuum sealing methods. In this study, four mix types (fine and coarse

Superpave, Stone Matrix Asphalt and Open Graded), three compactive efforts (low, medium and high) and two aggregate types (limestone and granite) were used. Specimens were compacted into briquettes (diameter of 150 mm and height of approximately 115 mm), tested, cut into cubes (approximately 75 mm by 75 mm by 75 mm) and retested. The results indicated that the vacuum sealing method provided the most accurate results for all types of specimens. The Parafilm™ method provided similar results as the vacuum sealing method for fine and coarse Superpave mixed, but tended to overestimate the air voids in the Stone Matrix Asphalt and the Open Graded specimens. This overestimation was contributed to the bridging of the Parafilm™ over surface voids.

Hall, Griffith, and Williams (2001) discussed triplicate testing of asphalt specimens by numerous technicians using Saturated Surface Dry, dimensional analysis and vacuum sealing (Corelok™) methods. The testing was performed on 144 field specimens composed of various aggregate and binder types. The specimens were provided to nine different laboratory technicians who performed approximately 1300 tests on the specimens. Their results showed the measurements made using the Corelok™ method had the lowest variability of the three methods examined.

Chehab, O'Quinn, and Kim (2000) compared the air voids within a specimen determined by using SSD, Parafilm™ and vacuum sealing (Corelok™) methods. They found that SSD indicated the lowest air voids, followed by Corelok™ then Parafilm™.

CHAPTER 3

METHODOLOGY AND DATA GATHERING

Two sets of specimens were used for this study. The unrutted specimens were laboratory prepared beams and cores obtained from the field. The beams were prepared using mix design 1 (Table 1) and the cores were obtained from the field having mix design 2 (Table 1). The purpose of this set of specimens was to compare the similarity and repeatability of the bulk specific gravity measurement from Parafilm™ and Corelok™ methods.

The rutted specimens were laboratory prepared beams that had been subjected to rutting. The beams were prepared using mix design 1 (Table 1). The purpose of the second set of specimens was to compare the similarity and repeatability of the bulk specific gravity measurements from Parafilm™ and Corelok™ and to evaluate the effect of rutting.

Specimens

Unrutted Specimens

The set of unrutted specimens was comprised of 29 specimens, 5 beam specimens and 24 core specimens. The beam specimen dimensions were 125 mm by 75 mm by 600 mm. The beam specimens were compacted using a vibratory compactor. The surface roughness was moderate to fine, due to the fineness of the mix. The core specimen dimensions were 152.4 mm diameter by nominal 76.2 mm length. Both the top and the bottom of the cores were saw-cut.

Rutted Specimens

The set of rutted specimens was comprised of 7 beam specimens. The dimensions of the specimens were 125 mm by 75 mm by 600 mm. The specimens were compacted using a vibratory compactor. The surface roughness was moderate to fine, due to the fineness of the mix. These specimens were rutted on their top surface.

Materials

Two mix designs were used in this study. Mix 1 contained 3/8" maximum size basalt aggregate with 15% recycled asphalt pavement (RAP). The asphalt content of Mix 1 was 4.8%. Mix 2 contained 1" maximum size limestone aggregate with 1.5% lime. The asphalt content of Mix 2 was 3.7%. Both mixes used AC-30 as the binder. These are two common mixes that are used in Clark County, Nevada. Table 1 contains the components and the grain size distribution of each mix. Figure 1 contains the grain size distribution curves for each mix.

Table 1. Components and Grain Size Distribution of Asphalt Mixes

COMPONENTS	MIX 1	MIX 2
Aggregate Type	Granite	Limestone
Asphalt Grade	AC-30	AC-30
Asphalt Content	4.8% by weight of mix	3.7% by weight of mix
Lime Content	N/A	1.5% by weight of aggregate
RAP	15%	N/A
Sieve Size	Percent Passing	Percent Passing
1"	100	100
3/4"	100	90
1/2"	100	72
3/8"	95	60
# 4	70	39
# 8	51	25
#50	18	9
#200	6	5.5

Bulk Specific Gravity Measurements

The bulk specific gravity of each specimen was measured by using both Parafilm™ and Corelok™ methods. These measurements were repeated three times for each specimen by the same technician. Using the same technician eliminated variability in measurement methods. The measured bulk specific gravity measurements for the unrutted specimens are presented in Table 2. The database contained 154 bulk specific gravity values. There were 20 "No Value" (N/V) entries in Table 2. The term "No Value" indicates that there was an error when performing the measurements and the measurement was not re-run. The measured bulk specific gravity measurements for the rutted specimens are presented in Table 3. The database contained 42 bulk specific gravity values.

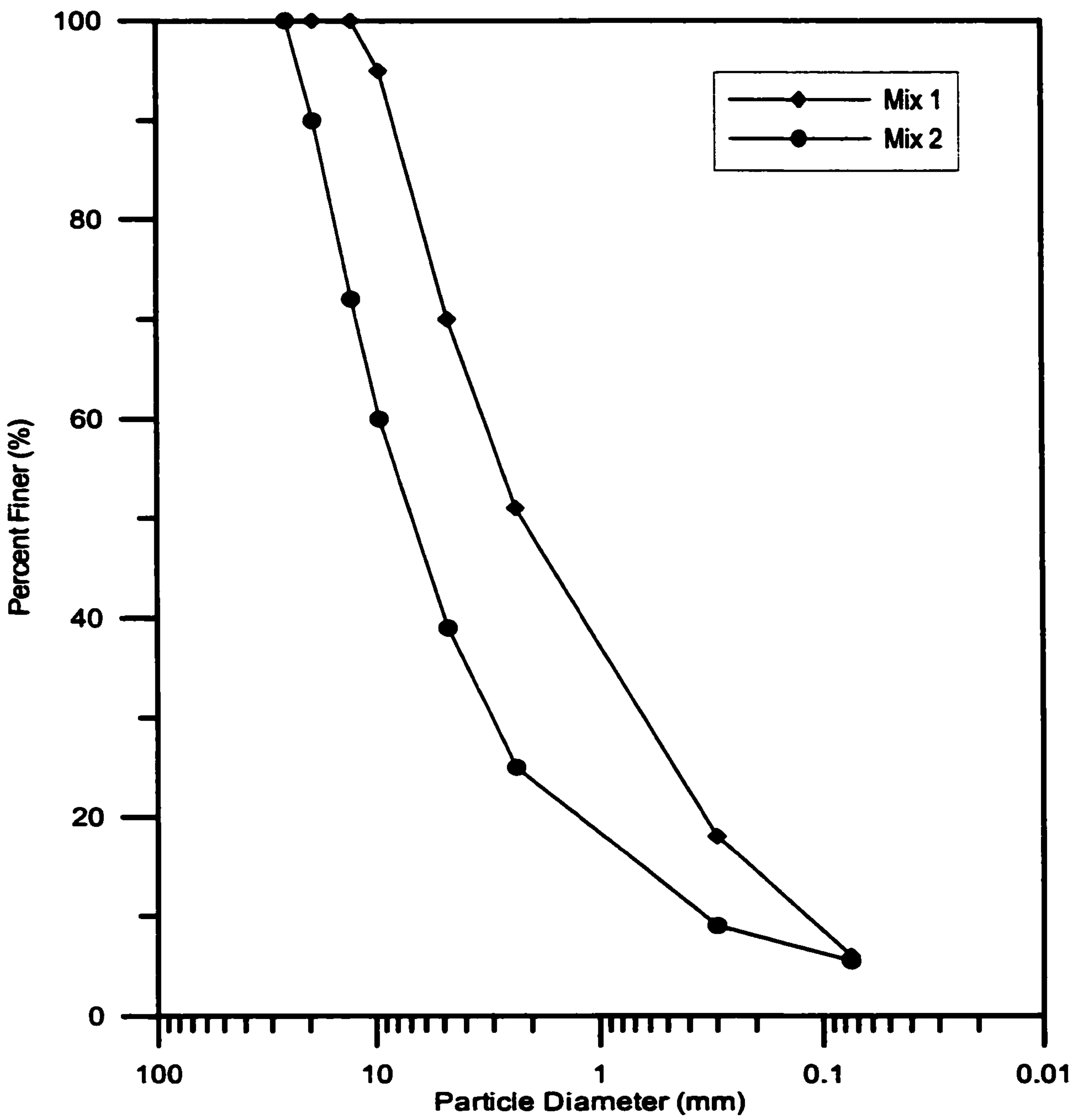

Figure 1. Grain size distribution curves for HMA mixes used in this study.

Table 2. Unrutted Specimen Type and Bulk Specific Gravity Measurements

Specimen	Specimen Type	Corelok™ Bulk Specific Gravity			Parafilm™ Bulk Specific Gravity		
		Measurement 1	Measurement 2	Measurement 3	Measurement 1	Measurement 2	Measurement 3
1	Beam	2.240	2.242	2.242	2.226	2.250	2.229
2	Beam	2.253	2.255	2.255	2.231	2.264	N/V*
3	Beam	2.206	2.206	2.208	2.208	2.219	N/V*
4	Beam	2.210	2.211	2.211	2.208	2.215	2.195
5	Beam	2.221	2.222	2.223	2.228	2.233	2.211
6	Field Core	2.326	2.324	2.324	2.364	2.332	N/V*
7	Field Core	2.310	2.308	2.308	2.351	2.312	2.306
8	Field Core	2.334	2.330	2.330	2.355	2.341	2.341
9	Field Core	2.338	2.335	2.334	2.351	2.346	2.349
10	Field Core	N/V*	2.312	2.311	2.324	2.323	2.395
11	Field Core	2.319	2.332	2.332	2.343	N/V*	2.338
12	Field Core	2.340	2.337	2.338	2.349	2.343	2.344
13	Field Core	2.320	2.318	2.319	2.326	2.325	2.334
14	Field Core	2.328	2.324	2.324	2.334	2.331	2.327
15	Field Core	2.322	2.318	2.318	2.331	2.326	2.322
16	Field Core	N/V*	2.243	2.243	2.231	N/V*	N/V*
17	Field Core	N/V*	2.287	2.287	2.304	2.298	2.303
18	Field Core	2.275	2.269	2.269	2.276	N/V*	2.257
19	Field Core	2.300	N/V*	2.293	N/V*	2.298	2.291
20	Field Core	2.336	2.334	2.333	2.345	2.339	2.335
21	Field Core	2.287	2.285	2.284	2.294	2.291	2.285
22	Field Core	2.339	2.335	2.335	2.339	2.341	2.331
23	Field Core	2.305	N/V*	2.307	N/V*	2.312	2.312
24	Field Core	2.308	2.302	2.302	2.308	2.300	2.300
25	Field Core	2.265	N/V*	2.260	N/V*	2.269	N/V*
26	Field Core	2.308	2.302	2.303	2.311	N/V*	N/V*
27	Field Core	2.261	2.256	2.256	2.264	2.264	N/V*
28	Field Core	2.546	2.546	2.546	2.560	2.559	2.557
29	Field Core	2.334	2.327	2.329	2.344	2.339	2.329

*N/V indicates No Value

Table 3. Bulk Specific Gravity Measurements Made on Rutted Specimens (Beam Specimens)

Specimen	Corelok™ Bulk Specific Gravity			Parafilm™ Bulk Specific Gravity		
	Measurement 1	Measurement 2	Measurement 3	Measurement 1	Measurement 2	Measurement 3
1	2.298	2.282	2.267	2.281	2.280	2.249
2	2.252	2.253	2.200	2.239	2.233	2.269
3	2.306	2.306	2.279	2.303	2.249	2.286
4	2.378	2.328	2.343	2.338	2.282	2.297
5	2.236	2.286	2.268	2.185	2.218	2.228
6	2.321	2.314	2.292	2.292	2.276	2.254
7	2.280	2.280	2.301	2.248	2.246	2.297

CHAPTER 4

DATA ANALYSIS

Statistical analyses were performed on both data sets (unrutted and rutted). The analyses included descriptive statistics, regression analyses, one-way ANOVA analyses and two-way ANOVA analyses. The statistical analyses are presented below.

Descriptive Statistics

The following table presents the descriptive statistics from the unrutted and rutted data sets. The descriptive statistics include the number of specimens, the number of tests performed, the mean of the bulk specific gravity measurements and the standard deviation of the bulk specific gravity sets. Scatter plots of the bulk specific gravity data are provided in Figure 4.1 and 4.2.

Table 4. Descriptive Statistics for Unrutted and Rutted Specimens

Statistic	**Unrutted**		**Rutted**	
	Corelok™	**Parafilm™**	**Corelok™**	**Parafilm™**
Number of Specimens	29	29	7	7
Number of Measurements	81	73	21	21
Mean	2.31798	2.32365	2.2891	2.2642
Standard Deviation	0.063	0.069	0.038	0.035

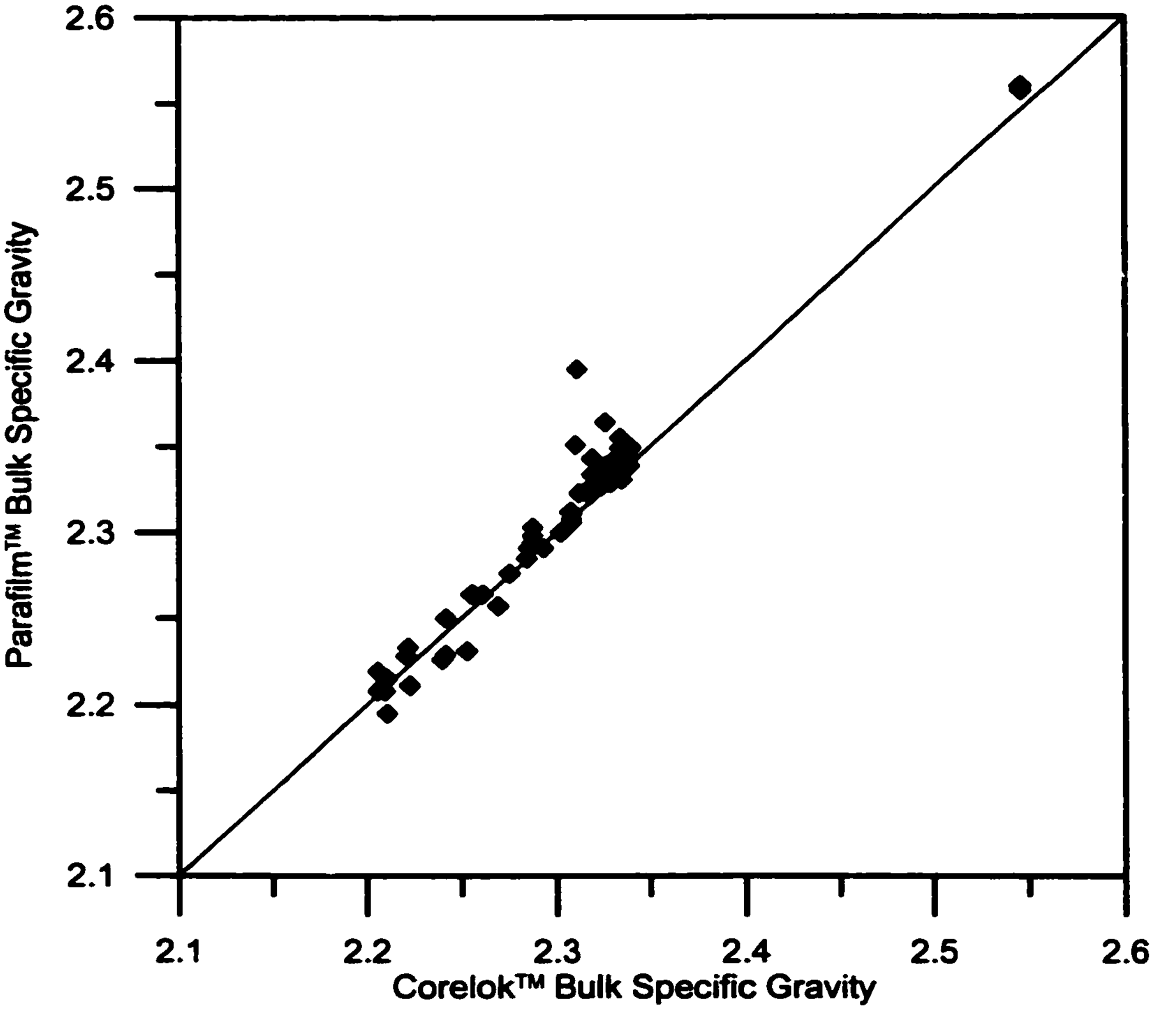

Figure 2. Scatter plot of Corelok™ bulk specific gravity versus Parafilm™ bulk specific gravity for the unrutted specimens.

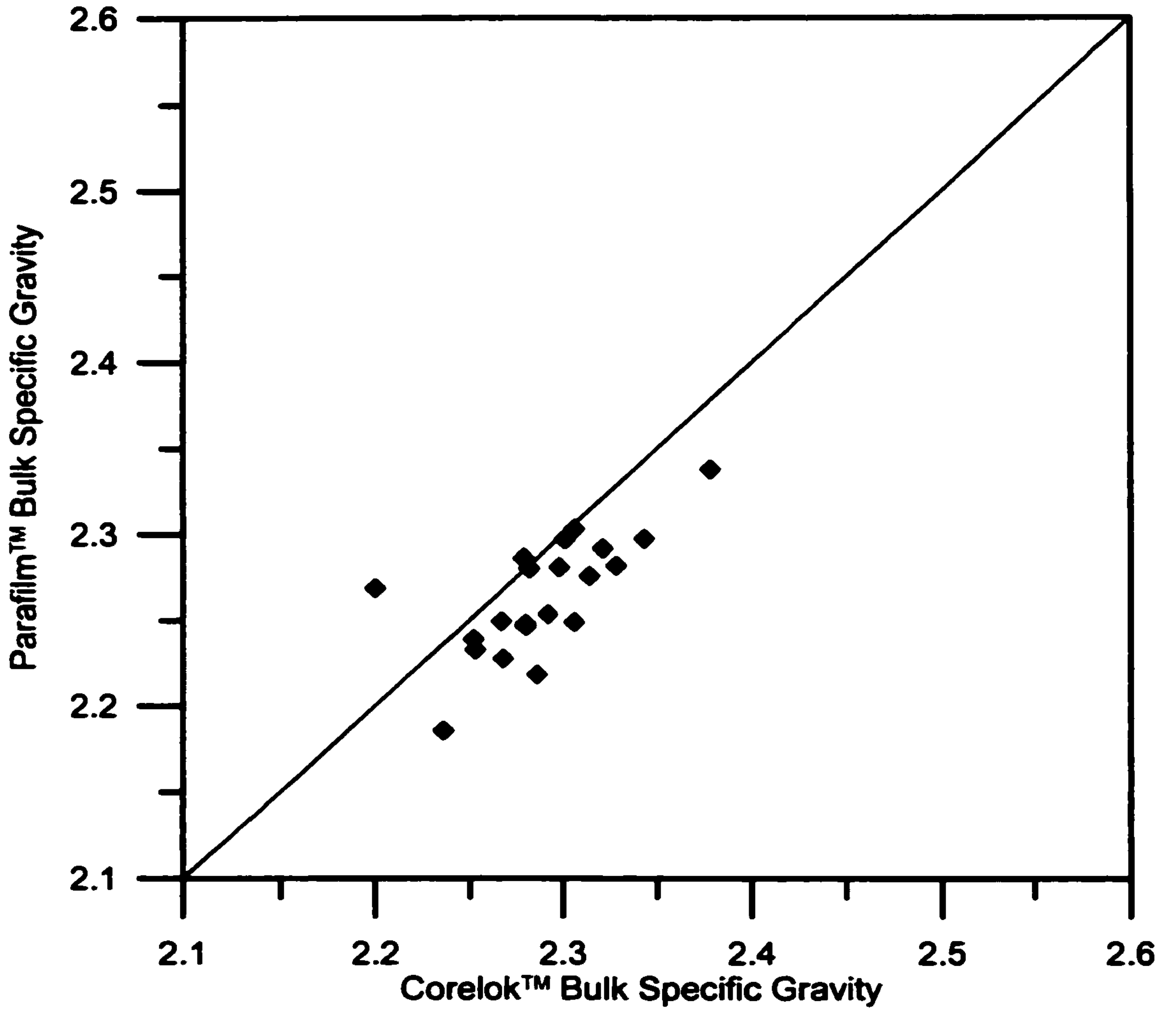

Figure 3. Scatter plot of Corelok™ bulk specific gravity versus Parafilm™ bulk specific gravity for the rutted specimens.

When comparing the values in Table 4 and visually inspecting the data in Figures 2 and 3, there is a noticeable difference between the Parafilm™ and Corelok™ bulk specific gravities for both unrutted and rutted data. For unrutted specimen data, there were significantly more bulk specific gravity measurements made using Corelok™ than Parafilm™. Since only one operator was performing the tests, it is possible to conclude there is a higher probability that an error will occur in the Parafilm™ method as compared to the Corelok™ method. The tabulated mean bulk specific gravity values of the Corelok™ and Parafilm™ are very similar, 2.31798 and 2.32365 respectively. This is also indicated in Figure 2. All the bulk specific gravity values fall close to the 45-degree line indicating that the measurements are very similar. The standard deviations of the bulk specific gravity measurements are also very similar. The Corelok™ method has a slightly lower standard deviation than the Parafilm™ method.

For the rutted specimen data, there were the same number of Corelok™ and Parafilm™ measurements. The mean bulk specific gravity values are not similar. The mean Corelok™ bulk specific gravity is 2.2891 whereas the mean Parafilm™ bulk specific gravity is 2.2642, significantly less than the Corelok™ measurement. This contradicts the tendency observed in the unrutted specimen data. Figure 3 shows the data is very disperse along the 45-degree line indicating the values are significantly different. The standard deviations of the rutted specimen measurements are significantly lower than the standard deviations of the unrutted specimen measurements. The rutted specimen

Parafilm™ standard deviation is less than the rutted specimen Corelok™ standard deviation. The opposite is true for the unrutted specimen data.

A possible explanation for the Parafilm™ average bulk specific gravity being higher for the unrutted specimens than for the rutted specimens is bridging of the parafilm over the rutted segment of the specimens. The Corelok™ bag is applied to the specimen using a vacuum so that the bag is held tightly against the specimen. The surface of the specimen through the bag looks pockmarked or pitted. The bag also follows the contour of the surface rut (Figure 4).

The parafilm™ is placed on the specimen so that the parafilm does not follow the surface of the specimen as closely. This may cause bridging of the parafilm over large surface voids and in this study, the rutted segment of the specimen (Figure 5). This means the Parafilm™ specimen erroneously occupies a larger volume and the bulk specific gravity will be less than the true value.

Regression Analysis

In order to compare the two measurement methods, a linear regression analysis was used. Details of this analysis can be found in Walpole and Meyers (1989). The linear regression analysis used:

Y = average of Corelok™ measurements for each specimen

on

X = average of Parafilm™ measurements for each specimen.

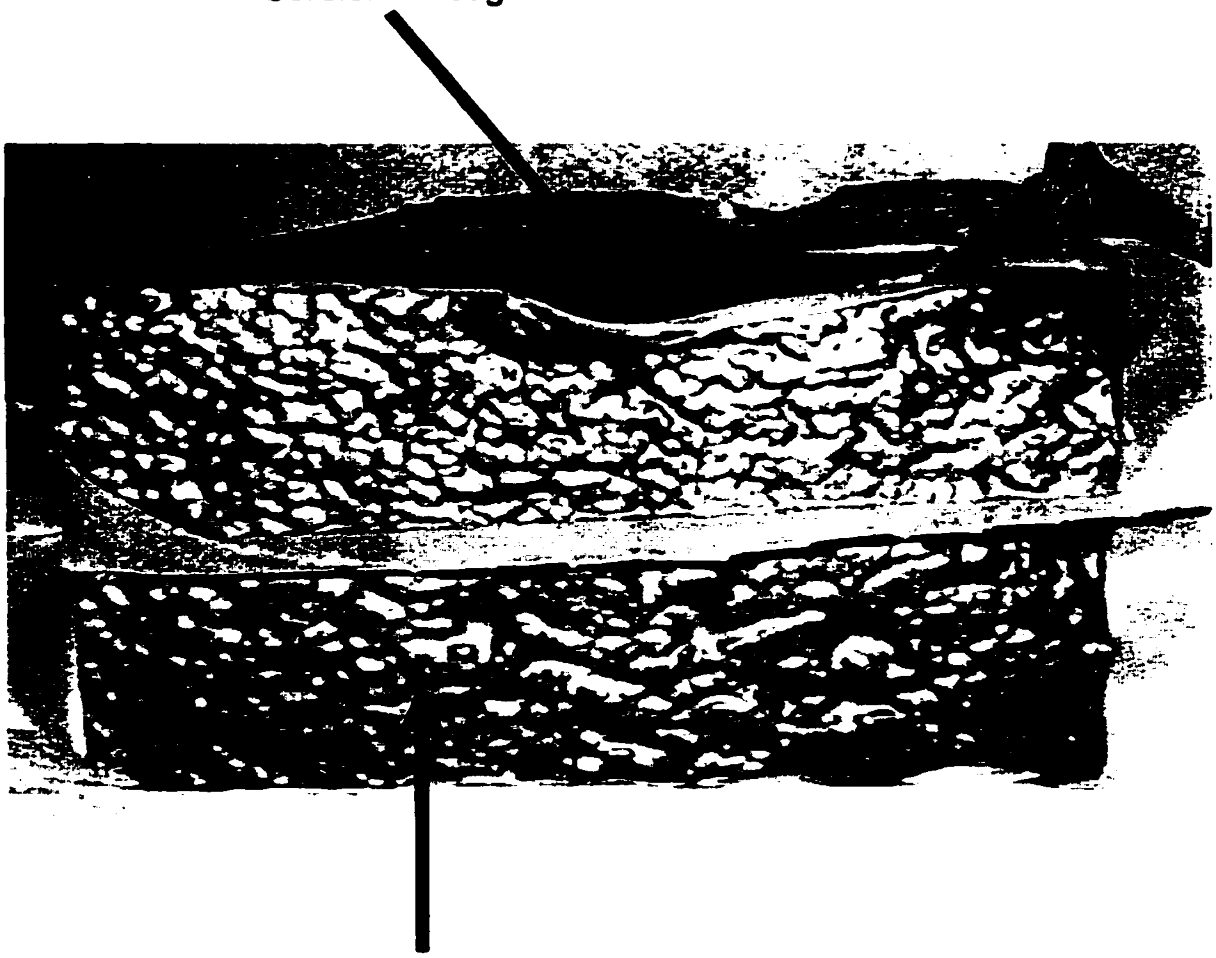

Figure 4. Pitted surface of Corelok^{TM} specimen

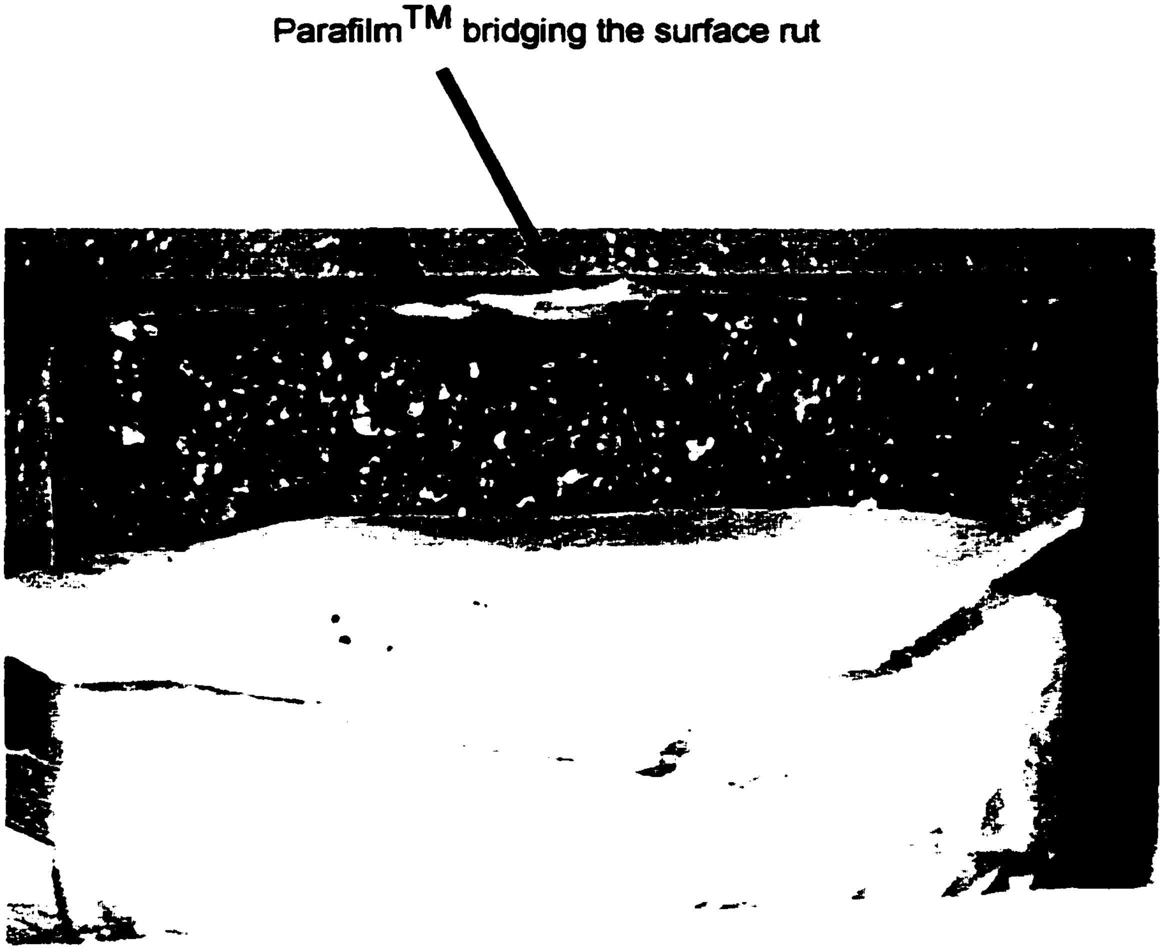

Figure 5. Bridging of Parafilm™ over rutted specimen.

If the two measurements are equivalent, the relationship between Y and X will be:

$$Y = X \text{ (linear with intercept = 0, slope = 1)}$$

Unrutted Data

Using the statistical software MINITAB, the estimated regression line is:

$$Y = -0.14 + 1.06 X$$

The ANOVA table from the MINITAB procedure REGRESSION shows P values for the null hypotheses that

$$\text{Intercept} = 0 \quad \text{versus} \quad \text{Intercept} \neq 0$$

and

$$\text{Slope} = 1 \quad \text{versus} \quad \text{Slope} \neq 1$$

The estimated P-value for the intercept term is 0.032, which implies that at test size $\alpha = 0.05$, the intercept term is significantly different from 0.

For the slope term, the correct hypothesis to be tested is

$$\text{Slope} = 1 \quad \text{versus} \quad \text{Slope} \neq 1$$

The correct value of the t-statistics for the above hypothesis is calculated as

$$t = \frac{(1.06 - 1)}{0.02719} = 2.36$$

The P-value for the null hypothesis:

$$\text{Slope} = 1 \quad \text{versus} \quad \text{Slope} \neq 1$$

is

$$P = 2P(t_{27} > 2.36) = 0.0258$$

Since P = 0.0258 is less than α = 0.05, the slope is said to be significantly different from 1. It is important to realize that in the absence of measurements taken on known standards, it is impossible to determine which of the two methods is better.

Rutted Data

Using the statistical software MINITAB, the estimated regression line is:

$$Y = 0.096 + 0.969\,X$$

The ANOVA table from the MINITAB procedure REGRESSION shows P values for the null hypotheses that

$$\text{Intercept} = 0 \quad \text{versus} \quad \text{Intercept} \neq 0$$

and

$$\text{Slope} = 1 \quad \text{versus} \quad \text{Slope} \neq 1$$

The estimated P-value for the intercept term is 0.032. Since P=0.032 is less than the test size α = 0.05, the intercept term is significantly different from 0.

For the slope term, the correct hypothesis to be tested is

$$\text{Slope} = 1 \quad \text{versus} \quad \text{Slope} \neq 1$$

The correct value of the t-statistics for the above hypothesis is calculated as

$$t = \frac{(0.9686 - 1)}{0.3259} = -0.0963$$

The P-value for the null hypothesis:

$$\text{Slope} = 1 \quad \text{versus} \quad \text{Slope} \neq 1$$

is

$$P = 2P(t_5 < -0.0963) = 0.927$$

Comparing P = 0.927 to α = 0.05, it can be concluded that the slope is not different than 1. It is important to realize that in the absence of measurements taken on known standards, it is impossible to determine which of the two methods is better.

Comparison of Means

A two-way analysis of variance (ANOVA) procedure was used to compare the means of the two measurements. Details of this procedure can be found in Walpole and Meyers (1989). In the two-way ANOVA, measurement V is modeled as a sum of effect of the measurement method i, the specimen j, and a normally distributed random experimental error. This case is modeled as a randomized complete block design with the specimens acting as blocks. We used the software package MINITAB to run two-way ANOVA on V.

Unrutted Data

The results from two-way ANOVA show that the mean of measurements using Corelok™ is 2.31798, and the mean of measurements using Parafilm™ is 2.32365; the P-value for the source method is 0.000. Since $P = 0.000$ is less than $\alpha = 0.05$, the difference in the two means is statistically significant.

Rutted Data

The results from two-way ANOVA show that the mean of measurements using Corelok™ is 2.2891, and the mean of measurements using Parafilm™ is 2.2642; the P-value for testing the equality of the two means equals 0.001.

Since P = 0.01 is less than α = 0.05, the difference in the two means is statistically significant.

Repeatability Analysis

A one-way ANOVA procedure was used to investigate the repeatability of the measurements. Details of this procedure can be found in Walpole and Meyers (1989). Let V1 and V2 denote the measurements taken by Corelok™ and Parafilm™, respectively. One-way ANOVA models each measurement Vi (i=1, 2) as a sum of effect of specimen and a normally distributed random experimental error. The software package MINITAB was used to run one-way ANOVA on V1 and V2 separately.

Unrutted Data

The mean sum of squares from one-way ANOVA gives an unbiased estimate of the experimental error variances associated with the two measurement methods. The pooled standard deviation of V1 from one-way ANOVA is 0.00258, and that for V2 is 0.0129, showing the Corelok™ measurements are more repeatable than the Parafilm™ measurements.

Rutted Data

The mean sum of squares from one-way ANOVA gives an unbiased estimate of the experimental error variances associated with the two measurement methods. The pooled standard deviation of V1 from one-way

ANOVA is 0.021, and that for V2 is 0.024, showing the Corelok™ measurements are more repeatable than the Parafilm™ measurements.

CHAPTER 5

CONCLUSIONS

In this study, bulk specific gravity measurements of coarse graded Hot Mix Asphalt (HMA) were conducted using two methods, Parafilm™ and Corelok™. The measurements were compared for similarity and repeatability of results. The comparisons were made on two sets of specimens, unrutted and rutted specimens. The unrutted of specimens were laboratory prepared beams and cores obtained from the field. The rutted specimens were laboratory prepared beams. Analysis of the data showed (1) based on regression analysis for both rutted and unrutted specimens there is a statistically significant difference between the measurements made by Parafilm™ and Corelok™ methods and (2) based on a one-way ANOVA analysis the Corelok™ measurements are more repeatable for unrutted and rutted specimens than those made by Parafilm™. Additionally, for the rutted specimens, the bulk specific gravities measured by Parafilm™ were significantly lower than those measured by Corelok™. This is because the self-sealing parafilm bridges over the large surface irregularities in contrast to the Corelok™, where the polymer bag follows the contours of the surface irregularities.

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