EVALUATION OF TEST METHODS FOR DETERMINATION OF AGGREGATE SPECIFIC GRAVITY

Final Report

by

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A Report on Research Sponsored by

THE OKLAHOMA DEPARTMENT OF TRANSPORTATION

FHWA-OK-05-02
ODOT Item Number 2169
OSU: AA-5-81504

COLLEGE OF ENGINEERING ARCHITECTURE and TECHNOLOGY
STILLWATER, OKLAHOMA

April 2005

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FHWA-OK-05-02	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Evaluation of Test methods for Determination of Aggregate Specific Gravity		5. Report Date April 2005 6. Performing Organization Code
7. Authors Stephen A. Cross and Msengi K. Mgonella		8. Performing Organization Report No. AA-5-81504
9. Performing Organization Name and Address Oklahoma State University Civil & Environmental Engineering 207 Engineering South Stillwater, OK 74078		10. Work Unit No. 11. Contract or Grant No. Item 2169
12. Sponsoring Agency Name and Address Oklahoma Department of Transportation Planning & Research Division 200 N.E. 21st Street, Room 3A7 Oklahoma City, OK 73105		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

The current AASHTO procedures for determination of specific gravity and absorption of coarse and fine aggregates are time consuming and the repeatability is less than generally desired. This is especially true for angular fine aggregates with high absorption and rough surface textures.

There are two new methods currently available for determining bulk specific gravity and absorption of coarse and fine aggregates, the AggPlus^tm system using the CoreLok device and the SSDetect system. The AggPlus^tm system applicable to both coarse and fine aggregates, and blended aggregate gradations. The SSDetect system is applicable to fine aggregates only.

The objectives of this study were to determine if either the AggPlus^tm system or the SSDetect system could produce statistically similar results to the current AASHTO procedures. A total of eight coarse aggregate sources and 15 fine aggregate sources were selected for evaluation in this study and the specific gravity and absorption determined using each procedure.

The CoreLok procedure for fine aggregate was the only procedure that produced statistically similar results to the AASHTO procedures. There was a high correlation between the CoreLok procedures for bulk specific gravity and AASHTO T-84 and T-85. Adjustments to the algorithm used by the CoreLok procedure could produce more acceptable results. The SSDetect procedure showed promise as a replacement to AASHTO T-84; however, refinement in the procedure would be necessary before it could be recommended for use. The CoreLok procedure for a blended aggregate did not produce bulk specific gravity results that were statistically significant to values calculated using AASHTO T-84 and T-85 results.

17. Key Words Aggregate specific gravity, CoreLok, SSDetect	18. Distribution Statement No restriction. This publication is available from the office of Planning & Research Division, Oklahoma DOT.		
19. Security Classification. (of this report) Unclassified	20. Security Classification. (of this page) Unclassified	21. No. of Pages 77	22. Price

SI (METRIC) CONVERSION FACTORS

Approximate Conversions to SI Units					***Approximate Conversions from SI Units***				
Symbol	**When you know**	**Multiply by**	**To Find**	**Symbol**	**Symbol**	**When you know**	**Multiply by**	**To Find**	**Symbol**
		LENGTH					**LENGTH**		
in	inches	25.40	millimeters	mm	mm	millimeters	0.0394	inches	in
ft	feet	0.3048	meters	m	m	meters	3.281	feet	ft
yd	yards	0.9144	meters	m	m	meters	1.094	yards	yds
mi	miles	1.609	kilometers	km	km	kilometers	0.6214	miles	mi
		AREA					**AREA**		
in^2	square inches	645.2	square millimeters	mm^2	mm^2	square millimeters	0.00155	square inches	in^2
ft^2	square feet	0.0929	square meters	m^2	m^2	square meters	10.764	square feet	ft^2
yd^2	square yards	0.8361	square meters	m^2	m^2	square meters	1.196	square yards	yd^2
ac	acres	0.4047	hectacres	ha	ha	hectacres	2.471	acres	ac
mi^2	square miles	2.590	square kilometers	km^2	km^2	square kilometers	0.3861	square miles	mi^2
		VOLUME					**VOLUME**		
fl oz	fluid ounces	29.57	milliliters	mL	mL	milliliters	0.0338	fluid ounces	fl oz
gal	gallon	3.785	liters	L	L	liters	0.2642	gallon	gal
ft^3	cubic feet	0.0283	cubic meters	m^3	m^3	cubic meters	35.315	cubic feet	ft^3
yd^3	cubic yards	0.7645	cubic meters	m^3	m^3	cubic meters	1.308	cubic yards	yd^3
		MASS					**MASS**		
oz	ounces	28.35	grams	g	g	grams	0.0353	ounces	oz
lb	pounds	0.4536	kilograms	kg	kg	kilograms	2.205	pounds	lb
T	short tons (2000 lb)	0.907	megagrams	Mg	Mg	megagrams	1.1023	short tons (2000 lb)	T
		TEMPERATURE (exact)					**TEMPERATURE (exact)**		
°F	degrees Fahrenheit	(°F-32)/1.8	degrees Celsius	°C	°C	degrees Fahrenheit	9/5(°C)+32	degrees Celsius	°F
		FORCE and PRESSURE or STRESS					**FORCE and PRESSURE or STRESS**		
lbf	poundforce	4.448	Newtons	N	N	Newtons	0.2248	poundforce	lbf
lbf/in^2	poundforce per square inch	6.895	kilopascals	kPa	kPa	kilopascals	0.1450	poundforce per square inch	lbf/in^2

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CHAPTER 1

INTRODUCTION

PROBLEM STATEMENT

The measured bulk specific gravity and percent absorption of coarse and fine aggregate is regularly used in design and construction of pavement materials. The ability to measure the water absorption and bulk specific gravity of aggregate materials with a high degree of accuracy and repeatability in a short time frame is important for pavement engineers and designers.

Specifically, in the Superpave mix design system the bulk specific gravity and percent absorption of the aggregates, both fine and coarse, are crucial for the design and control of quality asphalt mixtures. The bulk specific gravity of the coarse and fine aggregate fractions are used to determine the bulk specific gravity of the aggregate blend of hot mix asphalt (HMA). The bulk specific gravity of the blended aggregate is then used in the calculation of the voids in the mineral aggregate (VMA), a critical void parameter used in design and control of HMA mixtures.

The bulk specific gravity of the fine aggregate is used to determine the uncompacted void content, a measure of fine aggregate angularity in the Superpave mix design system. Absorption values are used to screen out aggregates that are highly porous and could cause performance problems in HMA mixtures. Aggregates with high absorptions can increase asphalt cement demand and result in uneconomical mixtures.

The current AASHTO procedures for determination of specific gravity and absorption of coarse and fine aggregates are time consuming and the repeatability is less than desired. According to AASHTO T- 84 and T-85, the acceptable range of two bulk specific gravity results for single operator precision is 0.032 and 0.025, respectively. For multilaboratory T-84 and T-85 precision, the acceptable range of two results is 0.066 and 0.038, respectively. When combined for VMA calculations, a single operator could expect a maximum variation in VMA of over 0.5% and in a multilaboratory situation, a maximum variation in VMA of approximately 1.5 % (1).

Recently there has been concern expressed with the repeatability of the current method for determination of fine aggregate specific gravity (AASHTO T-84). This is especially true for angular fine aggregates with high absorption and rough surface textures because they do not slump readily. Determining the saturated surface dry (SSD) mass for these samples is difficult with the cone method specified in the current standard. The fundamental problem with fine aggregate SSD condition is the inability to define SSD status of the aggregate grain. Two or more aggregate particles can stack up or attach to each other not allowing the surface of each individual aggregate to reach SSD condition (2).

The current standard for coarse aggregate (AASHTO T-85) requires the user to pat the aggregates with a towel to the surface dry condition and use this weight as the SSD weight of the sample. Again, this procedure is highly operator dependent. In this method if the material is not washed correctly, the towel can remove fines as well as water from the aggregates, indicating reduced SSD mass, resulting in a lower absorption rate than the true value. Furthermore, using a towel to dry the surface of the aggregate requires that the operator decide the degree of dryness of the aggregate making the procedure subjective.

A new test procedure that could reduce the variability of bulk specific gravity measurements, especially for fine aggregates, would result in improved precision of VMA calculations and better control of HMA mixtures. A procedure that reduces the minimum 48 hour test time for AASHTO T-84 and T-85 would result in cost savings.

There are two new methods available for determining bulk specific gravity and absorption of coarse and fine aggregates. The first procedure is the AggPlus^{tm} system using the CoreLok device. The procedure is applicable to both coarse and fine aggregates. An additional feature of the CoreLok procedure is the ability of determining specific gravity and absorption of a blended aggregate gradation, reducing testing time. The second procedure currently available is the SSDetect system. This procedure is applicable to fine aggregates and is an alternative method for determining the SSD condition of fine aggregate.

OBJECTIVES

The objectives of this study were to determine if either the AggPlus^{tm} system or the SSDetect system would produce statistically similar results to the current AASHTO T-84 and T-85 procedures and to investigate the ease of use of each method.

SCOPE

The four basic aggregate types which are used in Oklahoma for HMA and Portland cement concrete construction were selected for evaluation in this study. The aggregate types are limestone, sandstone, granite and rhyolite, natural sands and gravels.

Fine and coarse aggregate samples were selected from each of the four aggregate types. At least one sources from each aggregate type was classified as having high absorption (> 1.5 %), and at least one source was classified as having low absorption (≤ 1.5%). Each aggregate sample was tested for bulk specific gravity, apparent specific gravity and percent absorption using AASHTO T-84, AASHTO T-85, AggPlus^{tm} system and SSDetect method. The data were analyzed using analysis of variance (ANOVA) procedures. Duncan's multiple range test was used to determine which means were significantly different when the ANOVA indicated a statistical different in means.

CHAPTER 2

LITERATURE REVIEW

The AggPlus[tm] system using the CoreLok device and the SSDetect system are two procedures which are relatively new to pavement engineers. The AggPlus[tm] system has only been made available in the past few years and the SSDetect system was just recently commercially available. Therefore, there is a minimal amount of research results available in the literature for either of the two methods.

DEFINITIONS

Bulk specific gravity (Gsb) is the ratio of weight in air of a unit volume of aggregate at a stated temperature to the weight in air of an equal volume of gas-free distilled water at a stated temperature (3). This unit volume of aggregates is composed of the solid particle, permeable voids, and impermeable voids in aggregate. The Gsb is calculated using the following formula:

$$Gsb = A / (B - C) \qquad [1]$$

where: A = oven dry mass of aggregate
B = SSD mass of aggregate
C = mass of aggregate in water.

Apparent specific gravity (Gsa) is the ratio of the weight in air of a unit volume of impermeable portion of aggregate (does not include the permeable pores in aggregate) to the weight in air of an equal volume of gas-free distilled water at a stated temperature (3). The Gsb is calculated using the following formula:

$$Gsa = A / (A - C) \qquad [2]$$

where: A = oven dry mass of aggregate
C = mass of aggregate in water.

Absorption is the increase in weight of aggregate due to water in the pores of the material, but not including water adhering to the outside surface of the particles (3) and is determined using the following formula:

$$\%\ Abs. = [(B - A) / A] \times 100 \qquad [3]$$

where: A = oven dry mass of aggregate
B = SSD mass of aggregate.

Bulk specific gravity of fine and coarse aggregate is used in Superpave mix design calculations to determine the VMA, dust percentage (DP) and the effective (Pbe) and absorbed (Pba) binder percentages. The formulas for VMA, DP, Pbe and Pba are listed below (4). The three equations below show the importance of bulk specific gravity in determination of volumetrics during hot mix asphalt design and production.

$$VMA = 100 - \frac{Gmb \times Ps}{Gsb} \quad [4]$$

Where: Gmb = bulk specific gravity of a compacted HMA specimen
Ps = percent aggregate in the HMA mixture (equal to 100-binder content)
Gsb = bulk specific gravity of the aggregate.

$$Pba = 100 \times \frac{Gse - Gsb}{Gsb \times Gse} \times Gb \quad [5]$$

Where: Pba = absorbed asphalt, percent by mass of aggregate
Gse = effective specific gravity of aggregate
Gsb = bulk specific gravity of aggregate
Gb = specific gravity of asphalt binder.

$$Pbe = Pb - \frac{Pba}{100} \times Ps \quad [6]$$

Where: Pbe = effective asphalt content, percent by total mass of mixture
Pb = asphalt content, percent by total mass of mixture
Pba = absorbed asphalt, percent by mass of aggregate
Ps = aggregate content, percent by total mass of mixture.

$$DP = \frac{P200}{Pbe} \quad [7]$$

Where: DP = dust percentage
P200 = percent material passing No.200 sieve.

VMA is sensitive to slight changes in Gsb of the blended aggregate. To illustrate, a 12.5 mm maximum nominal aggregate size mix has a specified minimum VMA of 14.0%. If a sample of this mix had a Gmb 2.442, Ps of 94.7 % and Gsb of 2.703, the VMA would be 14.4%. A slight change in Gsb of 0.018 to 2.685 for the same mix, within the single operator precision, results to a VMA of 13.9 % which is below the specified minimum. This simple example shows the need for specific gravity values obtained by different testing methods to be statistically similar if they are to be used interchangeably.

BACKGROUND RESEARCH

Previous researchers have attempted to pinpoint the SSD condition of aggregates to improve the reproducibility of the bulk specific gravity test results. As mentioned by Kandhal et al. (2), they included Howard's glass jar method (5), Martin's wet and dry bulb temperature method (6), Saxer's absorption time curve procedure (7) and Hughes and Bahramian's saturated air- drying method (8). Kandhal et al. (2) reported that the various modifications either offered little improvement or were too complicated to be of practical value in the field or average laboratory.

Thermodynamic Procedure

A prototype device for determining SSD condition using basic principles of thermodynamics was developed by the Arizona Department of Transportation during the 1970's (9). A wet fine aggregate sample was placed in a small rotating drum and hot air was blown into one end of the drum to dry the falling aggregate uniformly. Temperatures of the incoming and outgoing hot air were monitored using thermocouples mounted in the inlet and outlet of the prototype rotating drying drum. The SSD region was determined using the plots of the inlet and outlet temperature and the basic principles of thermodynamics (9). Encouraging results were obtained from the preliminary prototype; however, the development of the equipment was not finalized and additional testing on a variety of fine aggregates was recommended.

Calorimetric Procedure

A calorimetric procedure was developed by Kandhal and Lee (10) to establish the SSD condition of both coarse and fine aggregates. The calorimetric procedure involved soaking the aggregate in water containing a chemical dye. The aggregate acquires the color of the wet dye on removal from water. The dye changes color when dry (for example cobalt chloride changes color from red to blue). The SSD condition is reached as soon as the fine aggregate particles change color (when subjected to drying with a fan). According to Kandhal and Lee (10), the following problems were associated with this method.

1) The dyes do not show well on dark colored aggregates
2) An efficient method of mixing the fine aggregate during the drying operation is needed so that larger particles do not dry out sooner than the finer particles, and
3) Detection of the color change needs to be automated so that the subjective judgment of the operator is eliminated.

Offset Method

Haddock and Prowell (11) developed a method to determine aggregate bulk specific gravity in HMA. The method was intended to avoid the problems associated with the determination of Gsb. Haddock and Prowell (11) developed a method where an offset between the Gsb and Gse is determined during the mixture design stage and applied during HMA production to the Gse determined from the maximum theoretical specific gravity (Gmm) test. A field Gsb can be calculated by using the offset value and the VMA determined. The following example was used by Haddock and Prowell to illustrate the proposed procedure.

> Suppose that during the design phase of an HMA mixture that the combined Gsb for the aggregate gradation being used is determined to be 2.663 and the Gse to be 2.678. The difference between these two, or 0.015(2.678 – 2.663), is the offset value. To continue the example, during HMA production, the G_{mm} is measured and the Gse calculated to be 2.671. Applying the offset value yields a field Gsb of 2.656 (2.671 – 0.015). This field Gsb value is then used in the calculation of VMA (11).

Haddock and Prowell (11) concluded that the offset method did a reasonable job of estimating Gsb and that the study should be expanded to include more aggregate types, mixture types, and gradations.

CoreLok Device

Initially, the CoreLok device was developed to measure the bulk specific gravity of compacted HMA samples (Gmb). Measurement of Gmb is critical, especially with the introduction of Superpave volumetrics. The Gmb is the basis for the volumetric calculations used during HMA mix design, field control, and construction acceptance. Inaccurate measurement of Gmb could result in incorrect calculations for air voids, VMA, voids filled with asphalt (VFA), and correlations with the nuclear density gauge.

AASHTO T-166 covers the determination of bulk specific gravity of specimens of compacted bituminous mixtures which do not contain interconnecting voids and absorb less than 2 percent of water by volume. However, incorrect Gmb measurements have occurred with the adoption of the Superpave mix design system and the use of stone matrix asphalt (SMA) mixtures. With the use of Superpave, more coarse–graded mixtures have been utilized, and SMA has the properties of a gap–graded mixture. With these types of mixtures, the internal air voids can become interconnected, which allows water to penetrate into the sample quickly during the saturation process. However, when measuring the SSD condition using AASHTO T-166, the water tends to drain quickly from the sample and can not be measured. The infiltration of water, according to AASHTO T-166, should not exceed 2.0 percent; hence, the errors can be introduced into the measurements of bulk specific gravity of compacted HMA (12). If the water absorption exceeds 2.0 percent, AASHTO T-275 (Paraffin wax) should be used to seal the sample prior to measuring the Gmb (12). The CoreLok device and AASHTO T-275 can be used to determine the Gmb of compacted HMA samples with high water absorption; however, AASHTO T-275 is not routinely used because of the difficulty associated with preparing and testing paraffin-coated specimens.

The CoreLok device has been reported as being able to determine maximum specific gravity (Gmm) of HMA, aggregate bulk specific gravity (Gsb), apparent specific gravity (Gsa), and absorption (12). The CoreLok system uses a controlled vacuum system to seal samples. Samples are placed inside a polymer bag, which is then inserted into the vacuum chamber. Under vacuum, the bag conforms tightly around the sample, which prevents water from infiltrating the sample. The volume of the sample is encapsulated within the bag and considered as the bulk volume (Figure 1). This is different than most other procedures that measure apparent volume.

Figure 1. CoreLok device (1).

Recent research has attempted to determine if the CoreLok device can determine the specific gravity of aggregates. The major concern of the on going research is to determine if the CoreLok method produces results which are statistically similar to the traditional methods AASHTO T-84 and T-85.

Hall (13) conducted a study using a single test (CoreLok) to determine the specific gravity and absorption of aggregate blends. The results were compared to the conventional method using AASHTO T-84 and T-85. In all cases evaluated, the CoreLok tests showed lower variability compared to AASHTO T-84 and T-85. The standard deviations from five replicate CoreLok tests were well below the values associated with both the AASHTO T-84 and T-85 tests. Also, the CoreLok method over estimated the bulk specific gravity of an aggregate blend (Figure 2). Hall (13) reported that the vacuum sealing method for determining specific gravity and absorption of aggregates showed promise as a substitute to traditional SSD-based test methods but that improvement is needed for the vacuum seal method before it could be substituted for traditional methods due to some actual differences in test values.

SSDetect System

The saturated surface dry condition tester is a two part, automated system which provides the necessary data to determine the bulk specific gravity (dry), bulk specific gravity (SSD), apparent specific gravity, and absorption of fine aggregate (Figure 3). The device is manufactured by Thermolyne. SSDetect measures the saturated surface dry condition of the fine aggregate by way of an infrared light source tuned to water. This infrared signal looks at the surface of the aggregate for traces of water. By measuring the amount of infrared reflectance, the SSD condition can be accurately measured (14).

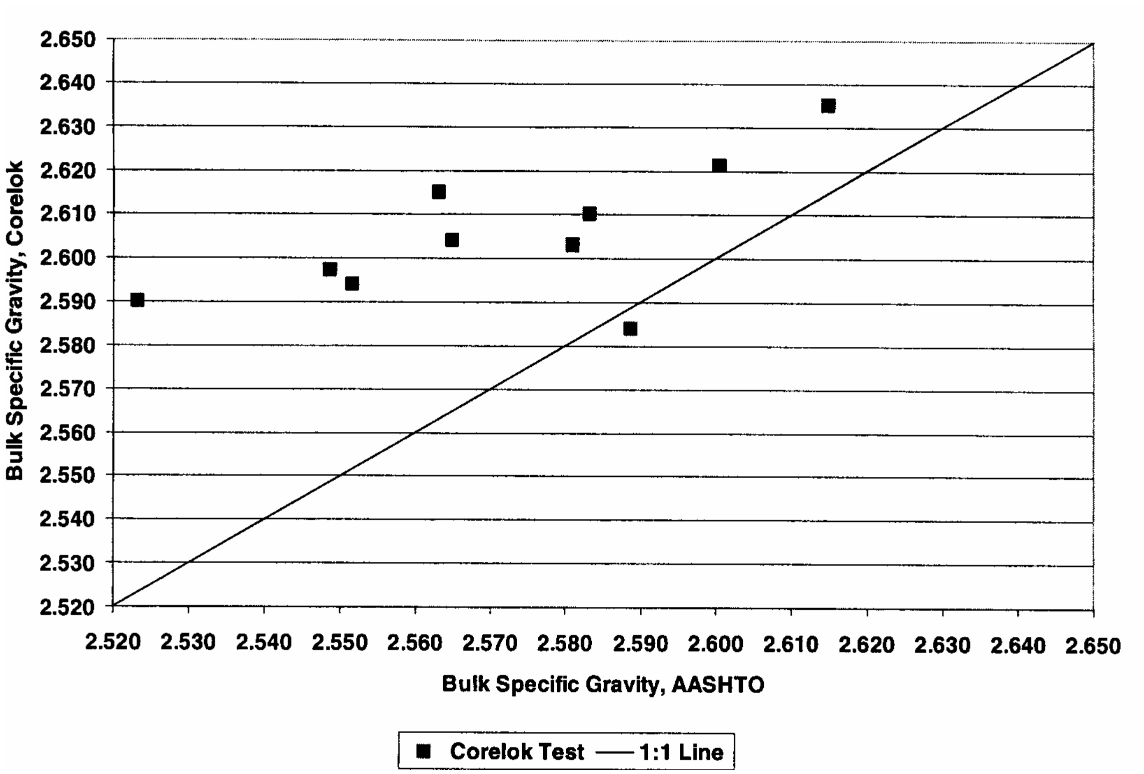

Figure 2. Gsb Corelok vs. Gsb AASHTO (blend) (13).

Figure 3. SSDetect system (14).

Prowell and Baker (15) evaluated the SSDetect and CoreLok methods for determining the dry bulk specific gravity (Gsb) of fine aggregates. Each method was evaluated against the standard method described in AASHTO T-84. The evaluation was based on a round robin study with twelve labs and six materials, four crushed and two uncrushed (natural) fine aggregate sources. Prowell and Baker (15) found that a statistical differences exits between the automated methods (Corelok and SSDetect) and AASHTO T-84. The SSDetect method showed lower variability compared to AASHTO T-84, as shown in table 1. Prowell and Baker (15) concluded that the precision of the CoreLok method was not as good as AASHTO T-84 and that the precision of the CoreLok method could improve as technicians become more familiar with the procedure.

Table 1. Precision estimates (15).

	Within Laboratory (Single Operator)			Between Laboratory (Multilaboratory)		
Method	CoreLok	SSDetect	T-84	CoreLok	SSDetect	T-84
			Pooled Standard Deviation			
Gsb	0.0440	0.0138	0.0157	0.0519	0.0222	0.0230
Gsa	0.0230	0.0066	0.0093	0.0238	0.0085	0.0151
Abs.	0.3168	0.1979	0.2170	0.5709	0.3241	0.4380
			Acceptable Differences Between Two Results			
Gsb	0.1245	0.0389	0.0443	0.1468	0.0628	0.0651
Gsa	0.0651	0.0187	0.0264	0.0672	0.0241	0.0428
Abs.	1.0233	0.5598	0.6137	1.6148	0.9166	1.2389

CHAPTER 3

TEST PLAN

AGGREGATES

Eight coarse aggregates and 15 fine aggregates were chosen for this study. Table 2 lists the aggregates tested. The aggregates were selected to represent the four basic types of aggregates used in Oklahoma for HMA and Portland cement concrete construction. There were 13 different pits or quarries sampled. There were four limestone quarries sampled. Each limestone quarry supplied chips and screenings, and two of the quarries also produced manufactured sand. Chips were the only material tested from the APAC-OK quarry in Tulsa. There were two sandstone quarries tested that supplied chips and screenings. The granite producing quarry supplied chips, screenings and manufactured sand. The rhyolite quarry only produced chips and screenings. One crushed gravel source was sampled. The crushed gravel was split on the No. 4 sieve and the plus No. 4 material tested as coarse aggregate and the minus No. 4 material tested as fine aggregate. Four pits supplied natural sand fine aggregate. All samples were obtained from production facilities by owner's representative, usually quality control personnel. Samples were obtained in accordance with AASHTO T- 2 procedures.

SAMPLE PREPARATION

Shortly after aggregate samples arrived, they were logged in and then placed into a forced draft oven and dried to a constant mass at 105^{o}C. The samples were then reduced to testing size in accordance with AASHTO T-248.

Coarse Aggregate Samples

For each coarse aggregate source two samples were split out for sieve analysis testing (AASHTO T-11 and T-27) and two samples were split out for each of the two specific gravity procedures evaluated, AASHTO T-85 and the CoreLok procedure. The specific gravity samples were screened over the No. 8 sieve and washed to remove fines. The sieve analysis samples were tested as received.

Fine Aggregate Samples

For each fine aggregate source two samples were split out for sieve analysis testing (AASHTO T-11 and T-27) and two samples were split out for each of the three specific gravity procedures evaluated, AASHTO T-84, CoreLok and the SSDetect procedure. All samples were tested as received except for the crushed gravel source that had the plus No. 4 material removed.

Table 2. Aggregate sources tested.

Supplier	Pit #	County	Quarry	Aggregate	Material
Dolese	905	Canadian	Yukon	Natural Sand	Fill Sand
Dolese	1601	Comanche	Richard Spur	Limestone	Screenings
Tiger Ind.	3101	Haskell	Tiger Ind.	Sandstone	5/8" Chips
Tiger Ind.	3101	Haskell	Tiger Ind.	Sandstone	Screenings
Martin Marietta	3502	Johnston	Mill Creek	Granite	5/8" Chips
Martin Marietta	3502	Johnston	Mill Creek	Granite	Screenings
Martin Marietta	3502	Johnston	Mill Creek	Granite	ManSand
Dolese	3702	Kingfisher	Dover	Natural Sand	Fill Sand
Eagle Sand & Rock	4701	Major	Cleo Springs	Natural Sand	Fill Sand
Dolese	5002	Murray	Davis	Limestone	5/8" Chips
Dolese	5002	Murray	Davis	Limestone	Screenings
Dolese	5002	Murray	Davis	Limestone	ManSand
Hanson Aggregates	5008	Murray	Davis	Rhyolite	1/2" Chips
Hanson Aggregates	5008	Murray	Davis	Rhyolite	Screenings
Anchor Stone	7201	Tulsa	46th Street	Limestone	3/4" Chips
Anchor Stone	7201	Tulsa	46th Street	Limestone	Screenings
Anchor Stone	7201	Tulsa	46th Street	Limestone	ManSand
APAC-OK	7203	Tulsa	Tulsa D-Ledge	Limestone	1/2" Chips
E.D. Baker Corp.	7808	Hutchinson	Borger	Gravel	Crushed Gravel
Arkhola	7902	Sebastian	Jennylind	Sandstone	1/2" Chips
Arkhola	7902	Sebastian	Jennylind	Sandstone	Screenings
Arkhola	5103	Muskogee	Muskogee	Sand	Fill Sand

SPECIFIC GRAVITY TESTING

Replicate samples were tested for each specific gravity procedure evaluated. Two different operators were used for testing. Each operator tested each replicate. Samples were oven dried prior to retesting by the second operator. The following testing matrix was used to evaluate the specific gravity test methods.

	Coarse Aggregate	Fine Aggregate
Test Methods	2	3
Operators	2	2
Replicates	2	2

AASHTO T-84

The bulk specific gravity, apparent specific gravity and percent absorption of each fine aggregate sample were determined in accordance with AASHTO T-84. A Langley fine aggregate de-airing device was used to remove air bubbles from the sample in the flask, rather than the hand agitation method prescribed by AASHTO T-84. The Langley de-airing device rotates the flask automatically for the prescribed 20 minutes to assist in removing entrapped air bubbles. A Langley de-airing device is shown in figure 4.

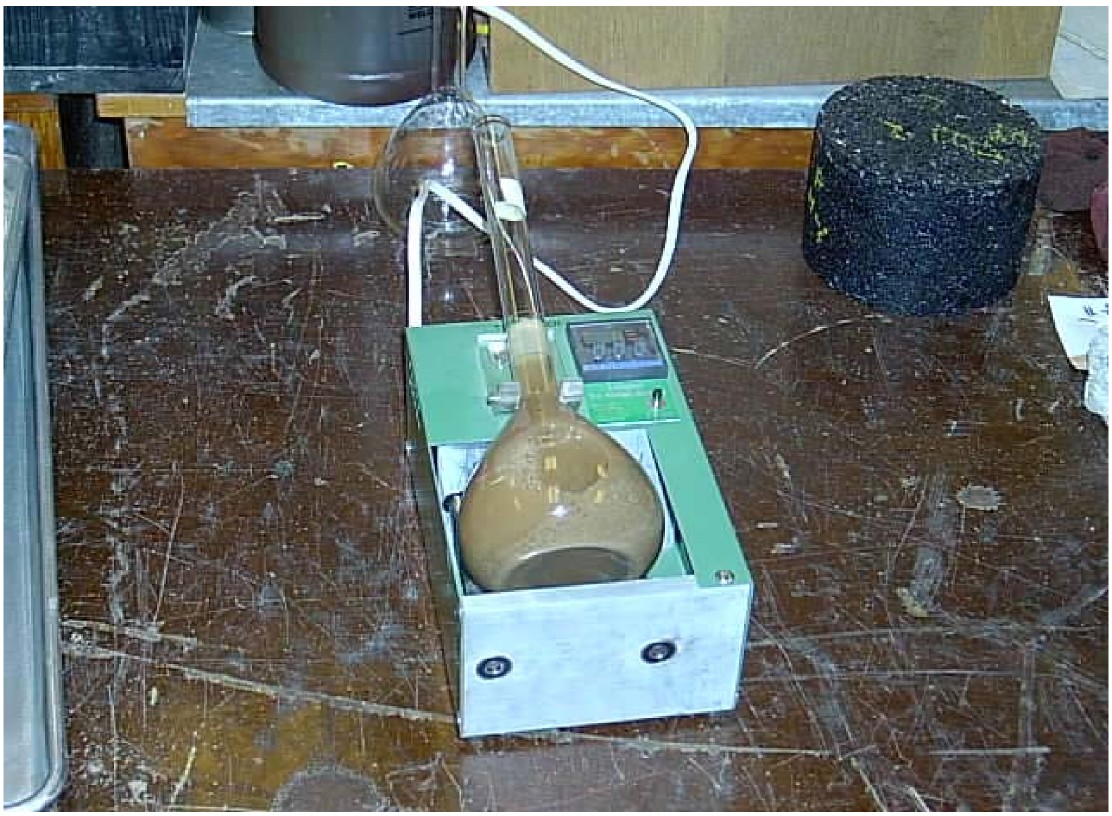

Figure 4. Langley fine aggregate de-airing device.

AASHTO T-85

The bulk specific gravity, apparent specific gravity and percent absorption of each coarse aggregate sample were determined in accordance with AASHTO T-85.

CoreLok Procedures

The CoreLok procedures for coarse and fine aggregate specific gravity and percent absorption are contained in the AggPlus^{tm} system software package provided by the manufacturer (16). The procedures have not been accepted by AASHTO or ASTM at this time. The tests were performed in accordance with the manufacturer's recommendations. The test procedures for the CoreLok device for fine and coarse aggregates are contained in Appendix A and B, respectively.

The CoreLok procedure is a four step procedure. The steps are 1) calibration of the volumeter, 2) determination of the mass of volumeter and sample, 3) sealing of samples using vacuum, and 4) water displacement analysis. Test samples for CoreLok testing were prepared in accordance with AASHTO T-84 and T-85, respectively.

SSDetect Procedures

The Barnstead Thermolyne SSDetect System is a two part automated system for developing the data necessary to determine the bulk specific gravity and absorption of fine aggregates. The system is based on a dry to wet method, unlike the traditional wet to dry methods (14). The test procedure uses an infrared light to detect the SSD condition and an automated de-airing device to remove entrapped air from the flask. Detailed procedures for this test are contained in Appendix C.

BLENDED AGGREGATES

Eight combinations of aggregates were blended together and the bulk specific gravity determined using the CoreLok procedure for a blended aggregate sample of coarse and fine aggregate. The procedure is the same as for coarse aggregate and is shown in Appendix B. The specific gravity of the blended aggregate was also calculated using both the AASHTO results and CoreLok results of the bulk specific gravity of the individual components using the formula shown below.

$$Gsb(blend) = \frac{(P_1 + P_2 + \ldots P_N)}{P_1/G_1 + P_2/G_2 + \ldots + P_N/G_N} \qquad [8]$$

Where: P_1, P_2, P_N = individual percentages by mass of aggregate
G_1, G_2, G_N = individual bulk specific gravities of aggregate

CHAPTER 4

TEST RESULTS

SIEVE ANALYSIS

The results of the sieve analysis performed in accordance with AASHTO T-11 and T-27 for the coarse and fine aggregate samples are summarized in tables 3 and 4, respectively. The results present an average of two tests. For the coarse aggregate samples, there were three sources with a maximum aggregate size of 1/2 inch (1/2" chips), three sources with a maximum aggregate size of 3/4 inch (5/8" chips), one source with a maximum aggregate size of 1 inch (3/4" chips) and one crushed gravel with a maximum aggregate size of 1/2 inch. For the fine aggregate samples, there were four natural sand sources. Three sources produced screenings and manufactured sand. The remaining four sources produced screenings only.

SPECIFIC GRAVITY AND ABSORPTION TESTING

The results of the specific gravity and percent absorption testing for the coarse aggregate samples, determined using AASHTO T-85 and CoreLok procedures, are shown in table 5. The results of the specific gravity and percent absorption testing for the fine aggregate samples, determined using AASHTO T-84, CoreLok and SSDetect procedures, are provided in table 6.

BLENDED SPECIFIC GRAVITY

The results from the measured specific gravity of various blends of coarse and fine aggregate, determined using the CoreLok procedure on the blended aggregate, are shown in table 7. The calculated specific gravity of the aggregate blends using the coarse and fine aggregate specific gravities using the CoreLok procedures and AASHTO T-84 and T-85, are presented as well.

Table 3. Coarse aggregate gradation analysis.

Supplier	**Tiger Ind.**	**Martin Marietta**	**Dolese**	**Hanson**	**Anchor Stone**	**APAC OK**	**ED Baker**	**Arkhola**
Pit	3101	3502	5002	5008	7201	7203	7808	7902
Material	Sandstone	Granite	Limestone	Rhyolite	Limestone	Limestone	Gravel Cr.	Sandstone
Gradation	5/8” Chips	5/8” Chips	5/8” Chips	1/2” Chips	3/4” Chips	1/2” Chips	Gravel*	1/2” Chips
Sieve Size	Percent Passing							
1”					100			
3/4"	100	100	100		99.3	100		
1/2"	81.8	86.5	98.9	100	64.8	99.8	100	100
3/8”	33.7	44.1	73.2	82.8	38.8	80.5	86.1	84.9
No.4	2.9	5.6	4.1	24.7	6.9	10.6	4.3	20.7
No.8	1.6	1.6	1.3	4.3	2.6	4.0	1.1	2.2
No.16	1.4	1.0	1.3	2.8	1.9	3.7	0.6	1.5
No.30	1.3	0.8	1.2	2.5	1.8	3.5	0.5	1.4
No.50	1.3	0.7	1.2	2.2	1.7	3.4	0.4	1.3
No.100	1.3	0.6	1.2	2.0	1.7	3.3	0.3	1.2
No.200	1.0	0.5	1.2	1.8	1.6	3.1	0.3	1.0

* As received gradation. Material split on No. 8 sieve for coarse and fine aggregate testing.

Table 4. Fine aggregate gradation analysis.

Supplier	**Dolese**	**Dolese**	**Tiger Ind.**	**Martin Marietta**	**Martin Marietta**	**Dolese**	**Eagle Sand**
Pit	905	1601	3101	3502	3502	3702	4701
Material	Natural Sand	Limestone	Sandstone	Granite	Granite	Natural Sand	Natural Sand
Gradation	Fill Sand	Screenings	Screenings	Screenings	ManSand	Fill Sand	Fill Sand
Sieve Size	Percent Passing						
3/8”		100	100	100	100		
No.4	100	90.8	81.5	71.2	99.0	100	100
No.8	99.9	58.4	38.8	48.2	91.3	99.9	99.8
No.16	99.3	36.4	24.6	34.2	65.9	99.2	99.7
No.30	92.2	24.6	19.0	23.3	41.6	87.0	97.3
No.50	65.3	18.1	16.5	14.8	22.1	48.3	70.9
No.100	13.3	14.0	14.5	8.6	8.3	10.3	15.6
No.200	1.2	11.6	9.2	5.2	3.1	1.0	1.7

Table 4 (Con’t). Fine aggregate gradation analysis.

Supplier	**Dolese**	**Dolese**	**Hanson**	**Arkhola**	**Anchor Stone**	**Anchor Stone**	**Arkhola**
Pit	5002	5002	5008	5103	7201	7201	7902
Material	Limestone	Limestone	Rhyolite	Natural Sand	Limestone	Limestone	Sandstone
Gradation	Screenings	ManSand	Screenings	Fill Sand	Screenings	ManSand	Screenings
Sieve Size	Percent Passing						
3/8”	100	100	100	100	100	100	100
No.4	85.9	99.8	81.6	98.7	92.9	82.1	87.4
No.8	56.6	88.2	50.3	93.3	68.5	57.6	59.4
No.16	34.6	49.5	30.5	78.7	49.7	35.7	44.2
No.30	22.5	23.6	19.3	46.5	37.7	21.4	36.5
No.50	15.8	9.1	13.0	11.6	29.9	11.5	32.0
No.100	11.9	2.6	8.9	1.3	24.5	5.9	23.0
No.200	9.9	1.5	6.3	0.4	20.8	4.4	12.9

Table 5. Coarse aggregate specific gravity and absorption test results.

Pit	Aggregate	Material	Test Method	Engr.	Sample	Gsb	Gsa	% Abs.
3101	Sandstone	5/8" Chips	T85	M	1	2.394	2.615	3.5
3101	Sandstone	5/8" Chips	T85	M	2	2.399	2.612	3.4
3101	Sandstone	5/8" Chips	T85	Y	1	2.395	2.622	3.6
3101	Sandstone	5/8" Chips	T85	Y	2	2.395	2.621	3.6
3101	Sandstone	5/8" Chips	CL	M	1	2.515	2.693	2.6
3101	Sandstone	5/8" Chips	CL	M	2	2.514	2.696	2.7
3101	Sandstone	5/8" Chips	CL	Y	1	2.514	2.697	2.7
3101	Sandstone	5/8" Chips	CL	Y	2	2.516	2.696	2.7
3502	Granite	5/8" Chips	T85	M	1	2.76	2.801	0.5
3502	Granite	5/8" Chips	T85	M	2	2.76	2.802	0.5
3502	Granite	5/8" Chips	T85	Y	1	2.768	2.81	0.6
3502	Granite	5/8" Chips	T85	Y	2	2.769	2.812	0.6
3502	Granite	5/8" Chips	CL	M	1	2.777	2.796	0.2
3502	Granite	5/8" Chips	CL	M	2	2.774	2.795	0.3
3502	Granite	5/8" Chips	CL	Y	1	2.78	2.798	0.2
3502	Granite	5/8" Chips	CL	Y	2	2.777	2.797	0.3
5002	Limestone	5/8" Chips	T85	M	1	2.677	2.729	0.7
5002	Limestone	5/8" Chips	T85	M	2	2.675	2.728	0.7
5002	Limestone	5/8" Chips	T85	Y	1	2.656	2.709	0.7
5002	Limestone	5/8" Chips	T85	Y	2	2.657	2.710	0.8
5002	Limestone	5/8" Chips	CL	M	1	2.688	2.714	0.4
5002	Limestone	5/8" Chips	CL	M	2	2.685	2.710	0.4
5002	Limestone	5/8" Chips	CL	Y	1	2.691	2.720	0.4
5002	Limestone	5/8" Chips	CL	Y	2	2.690	2.718	0.4

T85 = AASHTO T-85
CL = CoreLok procedure

Table 5 (Cont.). Coarse aggregate specific gravity and absorption test results.

Pit	Aggregate	Material	Test Method	Engr.	Sample	Gsb	Gsa	% Abs.
5008	Rhyolite	1/2" Chips	T85	M	1	2.682	2.784	1.4
5008	Rhyolite	1/2" Chips	T85	M	2	2.683	2.785	1.4
5008	Rhyolite	1/2" Chips	T85	Y	1	2.686	2.789	1.4
5008	Rhyolite	1/2" Chips	T85	Y	2	2.687	2.790	1.4
5008	Rhyolite	1/2" Chips	CL	M	1	2.720	2.751	0.4
5008	Rhyolite	1/2" Chips	CL	M	2	2.719	2.753	0.5
5008	Rhyolite	1/2" Chips	CL	Y	1	2.715	2.756	0.5
5008	Rhyolite	1/2" Chips	CL	Y	2	2.718	2.754	0.5
7201	Limestone	3/4" Chips	T85	M	1	2.540	2.679	2.0
7201	Limestone	3/4" Chips	T85	M	2	2.543	2.682	2.0
7201	Limestone	3/4" Chips	T85	Y	1	2.543	2.681	2.0
7201	Limestone	3/4" Chips	T85	Y	2	2.544	2.682	2.0
7201	Limestone	3/4" Chips	CL	M	1	2.625	2.716	1.3
7201	Limestone	3/4" Chips	CL	M	2	2.628	2.714	1.2
7201	Limestone	3/4" Chips	CL	Y	1	2.621	2.724	1.4
7201	Limestone	3/4" Chips	CL	Y	2	2.627	2.720	1.3
7203	Limestone	1/2" Chips	T85	M	1	2.566	2.694	1.9
7203	Limestone	1/2" Chips	T85	M	2	2.563	2.687	1.8
7203	Limestone	1/2" Chips	T85	Y	1	2.563	2.699	2.0
7203	Limestone	1/2" Chips	T85	Y	2	2.564	2.701	2.0
7203	Limestone	1/2" Chips	CL	M	1	2.65	2.722	1.0
7203	Limestone	1/2" Chips	CL	M	2	2.65	2.723	1.0
7203	Limestone	1/2" Chips	CL	Y	1	2.647	2.726	1.1
7203	Limestone	1/2" Chips	CL	Y	2	2.648	2.725	1.1

T85 = AASHTO T-85
CL = CoreLok procedure

Table 5 (cont.). Coarse aggregate specific gravity and absorption test results.

Pit	Aggregate	Material	Test Method	Engr.	Sample	Gsb	Gsa	% Abs.
7808	Gravel	1/2" Chips	T85	M	1	2.633	2.671	0.5
7808	Gravel	1/2" Chips	T85	M	2	2.631	2.669	0.6
7808	Gravel	1/2" Chips	T85	Y	1	2.630	2.669	0.6
7808	Gravel	1/2" Chips	T85	Y	2	2.631	2.670	0.6
7808	Gravel	1/2" Chips	CL	M	1	2.659	2.675	0.2
7808	Gravel	1/2" Chips	CL	M	2	2.655	2.673	0.3
7808	Gravel	1/2" Chips	CL	Y	1	2.659	2.675	0.2
7808	Gravel	1/2" Chips	CL	Y	2	2.657	2.675	0.3
7902	Sandstone	1/2" Chips	T85	M	1	2.529	2.633	1.6
7902	Sandstone	1/2" Chips	T85	M	2	2.527	2.633	1.6
7902	Sandstone	1/2" Chips	T85	Y	1	2.532	2.643	1.7
7902	Sandstone	1/2" Chips	T85	Y	2	2.533	2.643	1.6
7902	Sandstone	1/2" Chips	CL	M	1	2.61	2.676	0.9
7902	Sandstone	1/2" Chips	CL	M	2	2.613	2.675	0.9
7902	Sandstone	1/2" Chips	CL	Y	1	2.608	2.675	1.0
7902	Sandstone	1/2" Chips	CL	Y	2	2.611	2.676	0.9

T85 = AASHTO T-85
CL = Corelok procedure

Table 6. Fine aggregate specific gravity and absorption test results.

Pit	Aggregate	Material	Test Method	Engr.	Sample	Gsb	Gsa	% Abs.
905	N'Sand	Fill Sand	T84	M	1	2.622	2.642	0.3
905	N'Sand	Fill Sand	T84	M	2	2.609	2.645	0.5
905	N'Sand	Fill Sand	T84	Y	1	2.632	2.650	0.3
905	N'Sand	Fill Sand	T84	Y	2	2.633	2.648	0.2
905	N'Sand	Fill Sand	CL	M	1	2.623	2.648	0.4
905	N'Sand	Fill Sand	CL	M	2	2.621	2.646	0.4
905	N'Sand	Fill Sand	CL	Y	1	2.627	2.648	0.3
905	N'Sand	Fill Sand	CL	Y	2	2.632	2.646	0.2
905	N'Sand	Fill Sand	SSDetect	M	1	2.603	2.643	0.6
905	N'Sand	Fill Sand	SSDetect	M	2	2.609	2.651	0.6
905	N'Sand	Fill Sand	SSDetect	Y	1	2.604	2.646	0.6
905	N'Sand	Fill Sand	SSDetect	Y	2	2.604	2.647	0.6
1601	Limestone	Screenings	T84	M	1	2.558	2.717	2.3
1601	Limestone	Screenings	T84	M	2	2.568	2.717	2.1
1601	Limestone	Screenings	T84	Y	1	2.591	2.725	2.0
1601	Limestone	Screenings	T84	Y	2	2.596	2.731	2.0
1601	Limestone	Screenings	CL	M	1	2.654	2.710	0.8
1601	Limestone	Screenings	CL	M	2	2.657	2.710	0.7
1601	Limestone	Screenings	CL	Y	1	2.649	2.709	0.8
1601	Limestone	Screenings	CL	Y	2	2.653	2.711	0.8
1601	Limestone	Screenings	SSDetect	M	1	2.648	2.716	0.9
1601	Limestone	Screenings	SSDetect	M	2	2.650	2.714	0.9
1601	Limestone	Screenings	SSDetect	Y	1	2.665	2.726	0.8
1601	Limestone	Screenings	SSDetect	Y	2	2.660	2.725	0.9
3101	Sandstone	Screenings	T84	M	1	2.409	2.625	3.4
3101	Sandstone	Screenings	T84	M	2	2.393	2.672	4.4
3101	Sandstone	Screenings	T84	Y	1	2.443	2.670	3.5
3101	Sandstone	Screenings	T84	Y	2	2.447	2.670	3.4
3101	Sandstone	Screenings	CL	M	1	2.474	2.696	3.3
3101	Sandstone	Screenings	CL	M	2	2.474	2.692	3.3
3101	Sandstone	Screenings	CL	Y	1	2.461	2.703	3.6
3101	Sandstone	Screenings	CL	Y	2	2.472	2.699	3.4
3101	Sandstone	Screenings	SSDetect	M	1	2.513	2.644	2.0
3101	Sandstone	Screenings	SSDetect	M	2	2.508	2.641	2.0
3101	Sandstone	Screenings	SSDetect	Y	1	2.488	2.625	2.1
3101	Sandstone	Screenings	SSDetect	Y	2	2.500	2.640	2.1

T84 = AASHTO T-84
CL = Corelok procedure

Table 6 (con't.). Fine aggregate specific gravity and absorption test results.

Pit	Aggregate	Material	Test Method	Engr.	Sample	Gsb	Gsa	% Abs.
3502	Granite	Screenings	T84	M	1	2.594	2.663	1.0
3502	Granite	Screenings	T84	M	2	2.591	2.661	1.0
3502	Granite	Screenings	T84	Y	1	2.608	2.674	1.0
3502	Granite	Screenings	T84	Y	2	2.618	2.677	0.9
3502	Granite	Screenings	CL	M	1	2.639	2.653	0.2
3502	Granite	Screenings	CL	M	2	2.641	2.664	0.3
3502	Granite	Screenings	CL	Y	1	2.634	2.665	0.4
3502	Granite	Screenings	CL	Y	2	2.627	2.666	0.6
3502	Granite	Screenings	SSDetect	M	1	2.622	2.658	0.5
3502	Granite	Screenings	SSDetect	M	2	2.637	2.667	0.4
3502	Granite	Screenings	SSDetect	Y	1	2.634	2.662	0.4
3502	Granite	Screenings	SSDetect	Y	2	2.629	2.662	0.5
3502	Granite	ManSand	T84	M	1	2.594	2.664	1.0
3502	Granite	ManSand	T84	M	2	2.601	2.668	1.0
3502	Granite	ManSand	T84	Y	1	2.613	2.665	0.8
3502	Granite	ManSand	T84	Y	2	2.612	2.660	0.7
3502	Granite	ManSand	CL	M	1	2.607	2.648	0.6
3502	Granite	ManSand	CL	M	2	2.619	2.646	0.4
3502	Granite	ManSand	CL	Y	1	2.645	2.662	0.2
3502	Granite	ManSand	CL	Y	2	2.642	2.660	0.3
3502	Granite	ManSand	SSDetect	M	1	2.604	2.654	0.7
3502	Granite	ManSand	SSDetect	M	2	2.609	2.655	0.7
3502	Granite	ManSand	SSDetect	Y	1	2.608	2.661	0.8
3502	Granite	ManSand	SSDetect	Y	2	2.596	2.662	1.0
3702	N'Sand	Fill Sand	T84	M	1	2.615	2.640	0.3
3702	N'Sand	Fill Sand	T84	M	2	2.622	2.647	0.4
3702	N'Sand	Fill Sand	T84	Y	1	2.631	2.650	0.3
3702	N'Sand	Fill Sand	T84	Y	2	2.642	2.662	0.3
3702	N'Sand	Fill Sand	CL	M	1	2.623	2.649	0.4
3702	N'Sand	Fill Sand	CL	M	2	2.629	2.651	0.3
3702	N'Sand	Fill Sand	CL	Y	1	2.621	2.652	0.4
3702	N'Sand	Fill Sand	CL	Y	2	2.627	2.652	0.4
3702	N'Sand	Fill Sand	SSDetect	M	1	2.603	2.651	0.7
3702	N'Sand	Fill Sand	SSDetect	M	2	2.606	2.651	0.7
3702	N'Sand	Fill Sand	SSDetect	Y	1	2.607	2.653	0.7
3702	N'Sand	Fill Sand	SSDetect	Y	2	2.607	2.651	0.6

T84= AASHTO T-84
CL = CoreLok procedure

Table 6 (con't.). Fine aggregate specific gravity and absorption test results.

Pit	Aggregate	Material	Test Method	Engr.	Sample	Gsb	Gsa	% Abs.
4701	N'Sand	Fill Sand	T84	M	1	2.619	2.644	0.4
4701	N'Sand	Fill Sand	T84	M	2	2.622	2.648	0.4
4701	N'Sand	Fill Sand	T84	Y	1	2.627	2.646	0.3
4701	N'Sand	Fill Sand	T84	Y	2	2.628	2.648	0.3
4701	N'Sand	Fill Sand	CL	M	1	2.620	2.648	0.4
4701	N'Sand	Fill Sand	CL	M	2	2.621	2.646	0.4
4701	N'Sand	Fill Sand	CL	Y	1	2.626	2.648	0.3
4701	N'Sand	Fill Sand	CL	Y	2	2.635	2.649	0.2
4701	N'Sand	Fill Sand	SSDetect	M	1	2.606	2.647	0.6
4701	N'Sand	Fill Sand	SSDetect	M	2	2.606	2.646	0.6
4701	N'Sand	Fill Sand	SSDetect	Y	1	2.607	2.658	0.7
4701	N'Sand	Fill Sand	SSDetect	Y	2	2.612	2.661	0.7
5002	Limestone	Screenings	T84	M	1	2.591	2.733	2.0
5002	Limestone	Screenings	T84	M	2	2.580	2.727	2.1
5002	Limestone	Screenings	T84	Y	1	2.634	2.727	1.3
5002	Limestone	Screenings	T84	Y	2	2.620	2.720	1.4
5002	Limestone	Screenings	CL	M	1	2.672	2.690	0.2
5002	Limestone	Screenings	CL	M	2	2.655	2.714	0.8
5002	Limestone	Screenings	CL	Y	1	2.676	2.720	0.6
5002	Limestone	Screenings	CL	Y	2	2.673	2.719	0.6
5002	Limestone	Screenings	SSDetect	M	1	2.648	2.729	1.1
5002	Limestone	Screenings	SSDetect	M	2	2.651	2.734	1.1
5002	Limestone	Screenings	SSDetect	Y	1	2.640	2.725	1.2
5002	Limestone	Screenings	SSDetect	Y	2	2.633	2.723	1.3
5002	Limestone	ManSand	T84	M	1	2.625	2.730	1.5
5002	Limestone	ManSand	T84	M	2	2.635	2.722	1.2
5002	Limestone	ManSand	T84	Y	1	2.647	2.736	1.2
5002	Limestone	ManSand	T84	Y	2	2.657	2.750	1.3
5002	Limestone	ManSand	CL	M	1	2.679	2.718	0.5
5002	Limestone	ManSand	CL	M	2	2.682	2.715	0.5
5002	Limestone	ManSand	CL	Y	1	2.677	2.720	0.6
5002	Limestone	ManSand	CL	Y	2	2.681	2.718	0.5
5002	Limestone	ManSand	SSDetect	M	1	2.667	2.714	0.7
5002	Limestone	ManSand	SSDetect	M	2	2.661	2.713	0.7
5002	Limestone	ManSand	SSDetect	Y	1	2.655	2.710	0.7
5002	Limestone	ManSand	SSDetect	Y	2	2.651	2.707	0.8

T84 = AASHTO T-84
CL = CoreLok procedure

Table 6 (con't.). Fine aggregate specific gravity and absorption test results.

Pit	Aggregate	Material	Test Method	Engr.	Sample	Gsb	Gsa	% Abs.
5008	Rhyolite	Screenings	T84	M	1	2.610	2.819	2.8
5008	Rhyolite	Screenings	T84	M	2	2.614	2.818	2.8
5008	Rhyolite	Screenings	T84	Y	1	2.634	2.817	2.5
5008	Rhyolite	Screenings	T84	Y	2	2.650	2.823	2.3
5008	Rhyolite	Screenings	CL	M	1	2.660	2.787	1.7
5008	Rhyolite	Screenings	CL	M	2	2.673	2.789	1.6
5008	Rhyolite	Screenings	CL	Y	1	2.656	2.792	1.8
5008	Rhyolite	Screenings	CL	Y	2	2.659	2.793	1.8
5008	Rhyolite	Screenings	SSDetect	M	1	2.717	2.789	0.9
5008	Rhyolite	Screenings	SSDetect	M	2	2.713	2.781	0.9
5008	Rhyolite	Screenings	SSDetect	Y	1	2.722	2.790	0.9
5008	Rhyolite	Screenings	SSDetect	Y	2	2.725	2.780	1.0
5103	N'Sand	Fill Sand	T84	M	1	2.618	2.645	0.4
5103	N'Sand	Fill Sand	T84	M	2	2.628	2.645	0.2
5103	N'Sand	Fill Sand	T84	Y	1	2.623	2.646	0.3
5103	N'Sand	Fill Sand	T84	Y	2	2.631	2.651	0.3
5103	N'Sand	Fill Sand	CL	M	1	2.619	2.643	0.4
5103	N'Sand	Fill Sand	CL	M	2	2.620	2.643	0.3
5103	N'Sand	Fill Sand	CL	Y	1	2.634	2.648	0.2
5103	N'Sand	Fill Sand	CL	Y	2	2.632	2.646	0.2
5103	N'Sand	Fill Sand	SSDetect	M	1	2.613	2.641	0.4
5103	N'Sand	Fill Sand	SSDetect	M	2	2.610	2.640	0.5
5103	N'Sand	Fill Sand	SSDetect	Y	1	2.604	2.641	0.5
5103	N'Sand	Fill Sand	SSDetect	Y	2	2.610	2.644	0.5
7201	Limestone	Screenings	T84	M	1	2.606	2.721	2.0
7201	Limestone	Screenings	T84	M	2	2.552	2.732	3.0
7201	Limestone	Screenings	T84	Y	1	2.448	2.736	4.3
7201	Limestone	Screenings	T84	Y	2	2.427	2.730	4.6
7201	Limestone	Screenings	CL	M	1	2.432	2.721	4.4
7201	Limestone	Screenings	CL	M	2	2.442	2.719	4.2
7201	Limestone	Screenings	CL	Y	1	2.466	2.725	3.9
7201	Limestone	Screenings	CL	Y	2	2.466	2.721	3.8
7201	Limestone	Screenings	SSDetect	M	1	2.524	2.684	2.4
7201	Limestone	Screenings	SSDetect	M	2	2.529	2.682	2.3
7201	Limestone	Screenings	SSDetect	Y	1	2.532	2.681	2.2
7201	Limestone	Screenings	SSDetect	Y	2	2.525	2.677	2.2

T84 = AASHTO T-84
CL = CoreLok procedure

Table 6 (con't.). Fine aggregate specific gravity and absorption test results.

Pit	Aggregate	Material	Test Method	Engr.	Sample	Gsb	Gsa	% Abs.
7201	Limestone	ManSand	T84	M	1	2.449	2.760	4.6
7201	Limestone	ManSand	T84	M	2	2.472	2.720	3.6
7201	Limestone	ManSand	T84	Y	1	2.503	2.731	3.3
7201	Limestone	ManSand	T84	Y	2	2.495	2.727	3.4
7201	Limestone	ManSand	CL	M	1	2.537	2.723	2.7
7201	Limestone	ManSand	CL	M	2	2.537	2.721	2.7
7201	Limestone	ManSand	CL	Y	1	2.540	2.720	2.6
7201	Limestone	ManSand	CL	Y	2	2.551	2.723	2.5
7201	Limestone	ManSand	SSDetect	M	1	2.615	2.688	1.0
7201	Limestone	ManSand	SSDetect	M	2	2.611	2.688	1.1
7201	Limestone	ManSand	SSDetect	Y	1	2.614	2.690	1.1
7201	Limestone	ManSand	SSDetect	Y	2	2.623	2.693	1.0
7808	Gravel	Screenings	T84	M	1	2.587	2.669	1.2
7808	Gravel	Screenings	T84	M	2	2.597	2.695	1.4
7808	Gravel	Screenings	T84	Y	1	2.579	2.680	1.5
7808	Gravel	Screenings	T84	Y	2	2.556	2.671	1.7
7808	Gravel	Screenings	CL	M	1	2.642	2.670	0.4
7808	Gravel	Screenings	CL	M	2	2.639	2.673	0.5
7808	Gravel	Screenings	CL	Y	1	2.624	2.672	0.7
7808	Gravel	Screenings	CL	Y	2	2.621	2.671	0.7
7808	Gravel	Screenings	SSDetect	M	1	2.654	2.665	0.2
7808	Gravel	Screenings	SSDetect	M	2	2.651	2.665	0.2
7808	Gravel	Screenings	SSDetect	Y	1	2.650	2.667	0.3
7808	Gravel	Screenings	SSDetect	Y	2	2.650	2.668	0.3
7902	Sandstone	Screenings	T84	M	1	2.531	2.671	2.1
7902	Sandstone	Screenings	T84	M	2	2.528	2.649	1.8
7902	Sandstone	Screenings	T84	Y	1	2.564	2.674	1.6
7902	Sandstone	Screenings	T84	Y	2	2.583	2.683	1.4
7902	Sandstone	Screenings	CL	M	1	2.470	2.650	2.8
7902	Sandstone	Screenings	CL	M	2	2.511	2.660	2.2
7902	Sandstone	Screenings	CL	Y	1	2.530	2.663	2.0
7902	Sandstone	Screenings	CL	Y	2	2.537	2.666	2.0
7902	Sandstone	Screenings	SSDetect	M	1	2.549	2.648	1.5
7902	Sandstone	Screenings	SSDetect	M	2	2.538	2.646	1.6
7902	Sandstone	Screenings	SSDetect	Y	1	2.542	2.657	1.7
7902	Sandstone	Screenings	SSDetect	Y	2	2.552	2.661	1.6

T84 = AASHTO T-84
CL = CoreLok procedure

Table 7. Blended bulk specific gravity test results.

Blend	Pit	Pct. In Blend	Material	Sample	CoreLok Blended	Calculated CoreLok	Calculated AASHTO
1	3502	30	5/8" Chips	1	2.674	2.669	2.642
	3502	40	Screenings	2	2.670	2.673	2.643
	3502	30	ManSand				
2	5002	40	5/8" Chips	1	2.687	2.680	2.632
	5002	40	Screenings	2	2.687	2.672	2.628
	5002	20	ManSand				
3	7201	35	3/4" Chips	1	2.636	2.545	2.511
	7201	20	Screenings	2	2.632	2.548	2.512
	7201	45	ManSand				
4	7203	50	1/2" Chips	1	2.633	2.636	2.590
	3702	50	Fill Sand	2	2.650	2.639	2.592
5	3502	50	5/8" Chips	2	2.740	2.717	2.683
	5008	50	Screenings	1	2.772	2.723	2.685
6	5008	40	1/2" Chips	1	2.723	2.678	2.640
	5008	45	Screenings	2	2.727	2.683	2.640
	905	15	Fill Sand				
7	7902	40	1/2" Chips	1	2.615	2.592	2.569
	7902	45	Screenings	2	2.614	2.600	2.572
	5103	15	Fill Sand				
8	3101	40	5/8" Chips	1	2.561	2.512	2.432
	3101	45	Screenings	2	2.560	2.512	2.427
	3702	15	Fill Sand				

CHAPTER 5

ANALYSIS OF TEST RESULTS

COARSE AGGREGATE

ANOVA Results

Bulk Specific Gravity

An analysis of variance (ANOVA) was performed to determine if there was a statistical difference in bulk specific gravity between test methods, operators, and the respective interaction for coarse aggregates. The results, shown in table 8, indicate that there was a statistically significant difference in bulk specific gravity between AASHTO T-85 and the CoreLok procedure. The difference was statistically significant at a confidence limit exceeding 98 %. No statistical difference in bulk specific gravity was found between operators or the interaction between test methods and operators. The analysis indicates that operators were not a significant factor for either test, and that AASHTO T-85 and CoreLok gave statistically different bulk specific gravity values.

Figure 5 is a plot of CoreLok bulk specific gravity versus AASHTO T-85 bulk specific gravity. It can be seen that the Corelok procedure tends to over estimate the bulk specific gravity values compared to AASHTO T-85 method. The relationship has a coefficient of determination (R^2) of 0.97. The high goodness of fit indicates that the algorithm used in the CoreLok procedure could be adjusted to better match AASHTO T-85 bulk specific gravity values for Oklahoma aggregates.

Table 8. ANOVA for bulk specific gravity, coarse aggregates.

Source	Degrees of Freedom	Sum Squares	Mean Square	F Ratio	Prob. > F
Test Method	1	0.053245	0.053246	5.99	0.0173
Operator	1	0.000002	0.000002	0.00	0.9874
Test M. * Operator	1	0.000001	0.000001	0.00	0.9937
Error	60	0.533000	0.009000		
Total	63	0.586565			

Apparent Specific Gravity

The results for the ANOVA on apparent specific gravity are provided in table 9. The analysis indicates that there was no significant different in apparent specific gravity values between test methods, operators, or the interaction.

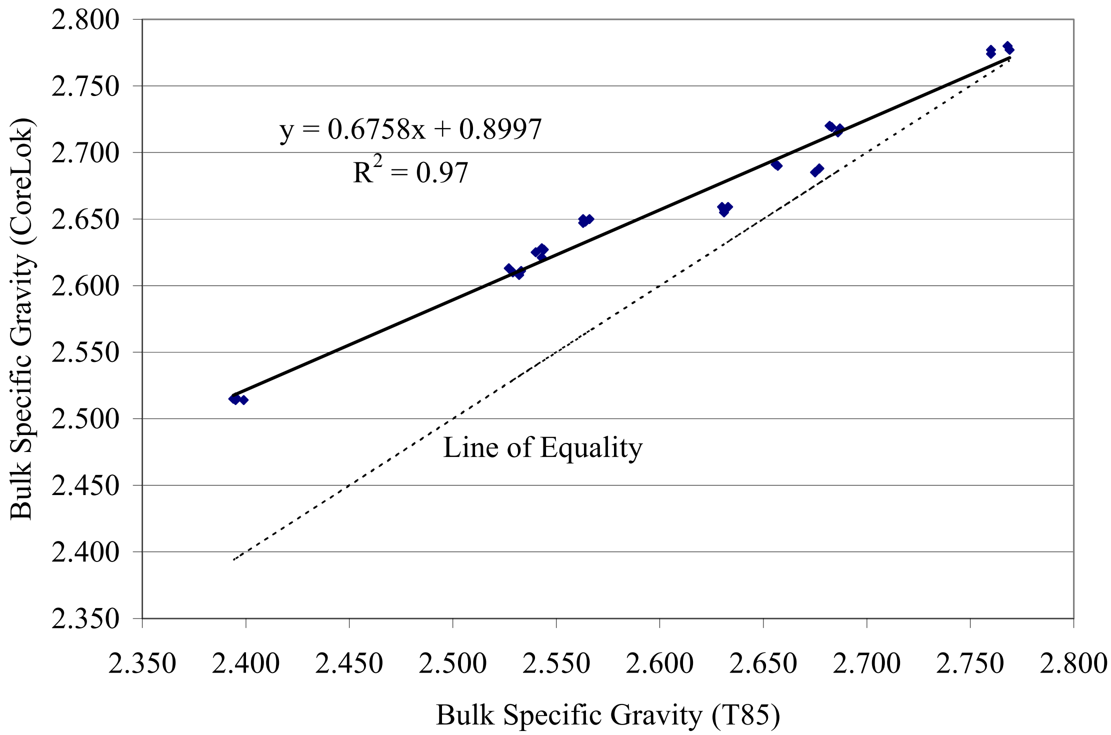

Figure 5. CoreLok Gsb vs. AASHTO T-85 Gsb, coarse aggregates.

Table 9. ANOVA for apparent specific gravity, coarse aggregates.

Source	Degrees Freedom	Sum Squares	Mean Square	F Ratio	Prob. > Fcr
Test Method	1	0.00658	0.00658	2.30	0.1345
Operator	1	0.00055	0.00055	0.19	0.6636
Test M * Operator	1	0.00014	0.00013	0.05	0.8286
Error	60	0.17153	0.00286		
Total	63	0.17879			

The relationship between CoreLok apparent specific gravity versus AASHTO T-85 apparent specific gravity is shown in figure 6. The relationship has a coefficient of determination (R^2) of 0.68, indicating a poor correlation. The data had enough scatter that the differences in apparent specific gravity were not significantly different unless the user is willing to accept the possibility of a type 1 error of greater than 10%.

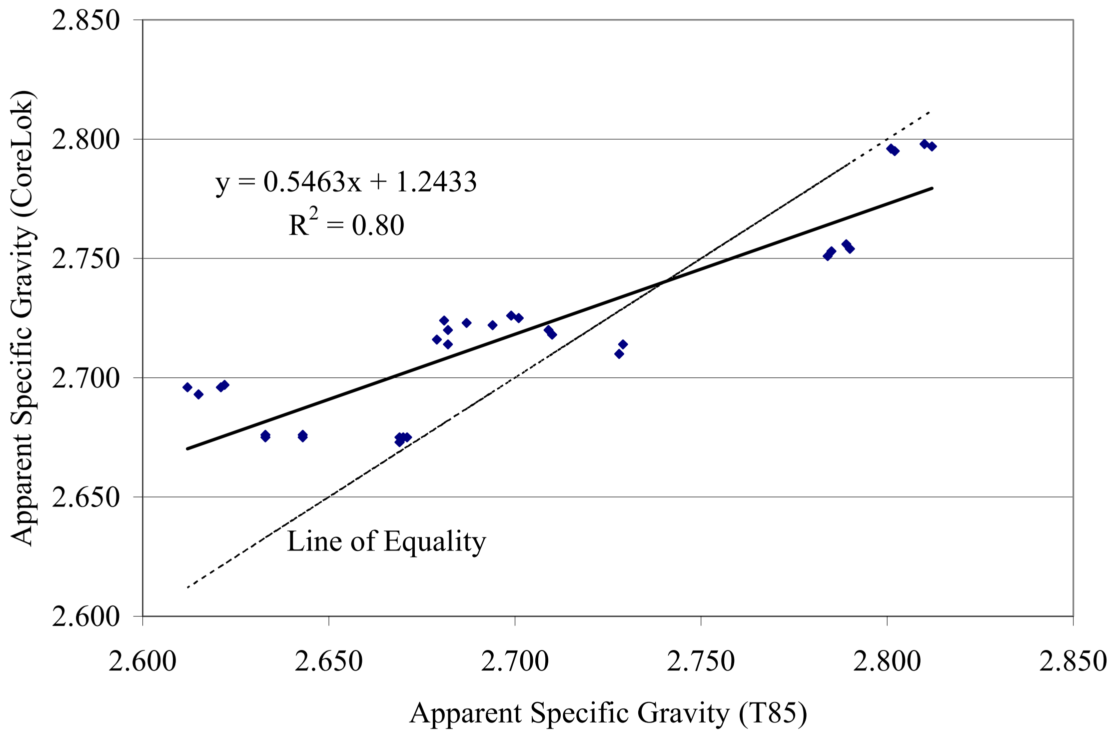

Figure 6. CoreLok Gsa vs. AASHTO T-85 Gsa, coarse aggregates.

Absorption

The results of the ANOVA on absorption values are shown in table 10. The analysis indicates a significant difference in absorption values between AASHTO T-85 and the CoreLok procedure at a confidence limit exceeding 99%. No statistical difference in percent absorption was found between operators or the interaction.

Table 10. ANOVA for percent absorption, coarse aggregates.

Source	Degrees Freedom	Sum Squares	Mean Square	F Ratio	Prob. > Fcr
Test Method	1	6.250	6.250	8.13	0.0060
Operator	1	0.051	0.051	0.07	0.7984
Test M * Operator	1	0.003	0.003	0.00	0.9547
Error	60	46.146	0.769		
Total	63	52.449			

Figure 7 shows a plot of AASHTO T-85 percent absorption versus CoreLok percent absorption. The results indicate that the CoreLok procedure tends to under estimate absorption values compared to the AASHTO procedure. The relationship has a coefficient of determination (R^2) of 0.95.

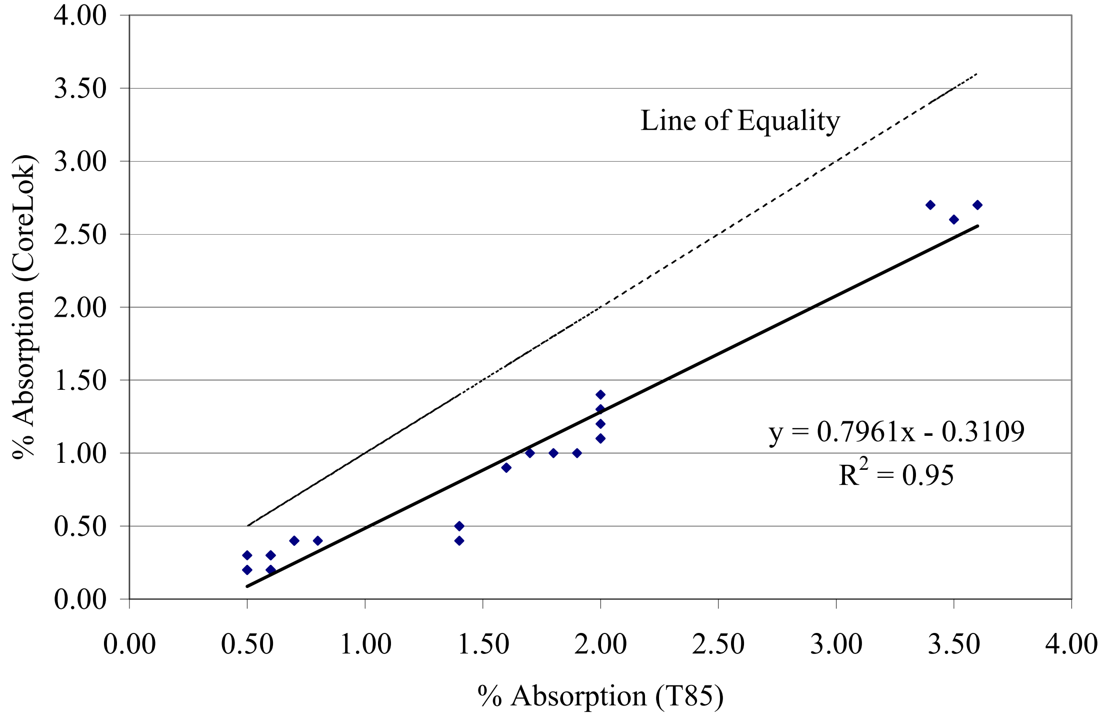

Figure 7. CoreLok absorption vs. AASHTO T-85 absorption, coarse aggregates.

Simple Statistics

The above ANOVAs indicated that there was no significant difference between operators; therefore, the test results can be pooled by operator. The results of the average bulk specific gravity, apparent specific gravity, percent absorption and the associated average standard deviations, by test procedure, are provided in table 11. The precision limits for AASHTO T-85 are shown in table 12.

Bulk Specific Gravity

From the statistics shown in table 11 and the precision limits shown in table 12, it can be seen that the standard deviations for both AASHTO T-85 and CoreLok are less than the multilaboratory precision limit of 0.013. In fact, the standard deviations were less than the single operator precision limit of 0.009 for all sources with the CoreLok procedure and all but one source for AASHTO T-85. The averages of the standard deviations were 0.0021 and 0.0034, for the CoreLok and T-85 procedures, respectively.

Table 11. Simple statistics, coarse aggregate specific gravity testing.

Pit	Aggregate	Test Method	Gsb Avg.	Gsb Std.	Gsa Avg.	Gsa Std.	% Abs. Avg.	% Abs. Std.
7902	Sandstone	T85	2.530	0.003	2.638	0.006	1.6	0.05
7902	Sandstone	CL	2.611	0.002	2.698	0.045	0.9	0.05
7203	Limestone	T85	2.564	0.001	2.695	0.006	1.9	0.10
7203	Limestone	CL	2.649	0.002	2.724	0.002	1.1	0.06
3502	Granite	T85	2.764	0.005	2.806	0.006	0.6	0.06
3502	Granite	CL	2.777	0.002	2.797	0.001	0.3	0.06
5002	Limestone	T85	2.666	0.011	2.719	0.011	0.7	0.05
5002	Limestone	CL	2.689	0.003	2.716	0.004	0.4	0.00
5008	Rhyolite	T85	2.685	0.002	2.787	0.003	1.4	0.00
5008	Rhyolite	CL	2.718	0.002	2.754	0.002	0.5	0.05
7808	Gravel	T85	2.631	0.001	2.670	0.001	0.6	0.05
7808	Gravel	CL	2.658	0.002	2.675	0.001	0.3	0.06
3101	Sandstone	T85	2.396	0.002	2.618	0.005	3.5	0.10
3101	Sandstone	CL	2.515	0.001	2.696	0.002	2.7	0.05
7201	Limestone	T85	2.543	0.002	2.681	0.001	2.0	0.00
7201	Limestone	CL	2.625	0.003	2.719	0.004	1.3	0.08

Table 12. AASHTO T-85 precision indices.

	Single-Operator		Multilaboratory	
	Standard Deviation	Acceptable Range of Two Results	Standard Deviation	Acceptable Range of Two Results
Gsb	0.009	0.025	0.013	0.038
Gsa	0.007	0.020	0.011	0.032
% Abs.	0.088	0.25	0.145	0.41

The ANOVA indicated a significant difference between CoreLok and AASHTO T-85 bulk specific gravity. When comparing CoreLok bulk specific gravity to AASHTO T-85 bulk specific gravity, only two sources had bulk specific gravities within the acceptable range of two results for single-operator precision and four sources were within the multilaboratory acceptable range.

Figure 8 shows the difference between CoreLok bulk specific gravity and AASHTO T-85 bulk specific gravity versus AASHTO T-85 percent absorption. The plot shows that the difference between bulk specific gravity increases as the absorption of the aggregate increases.

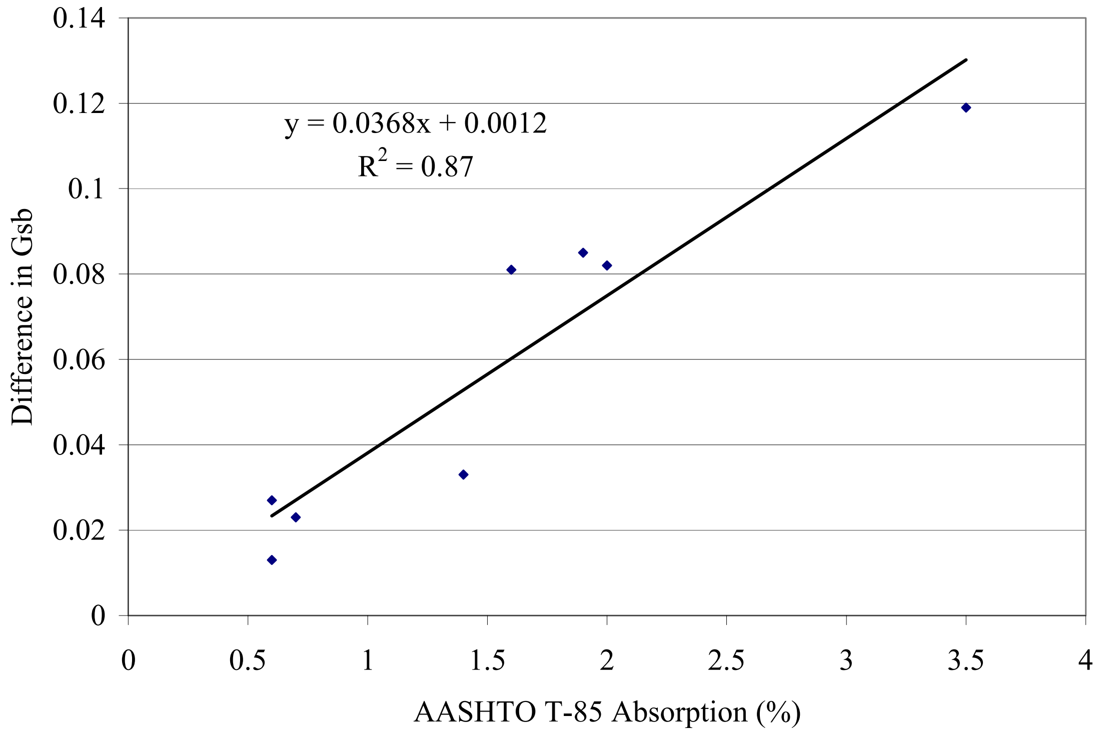

Figure 8. Difference in Gsb between CoreLok and AASHTO T-85 vs. AASHTO T-85 percent absorption.

Apparent Specific Gravity

The standard deviations for both AASHTO T-85 and CoreLok are less than or equal to the multilaboratory precision limit of 0.011 and the single operator precision limit of 0.007 for all but one source each. The averages of the standard deviations were 0.0076 and 0.0049, for the CoreLok and T-85 procedures, respectively. The ANOVA indicated no significant difference between CoreLok and AASHTO T-85 apparent specific gravity. When comparing CoreLok to AASHTO T-85 apparent specific gravity, only three sources had apparent specific gravities within the acceptable range of two results for single-operator precision and four sources were within the multilaboratory acceptable range.

Absorption

The standard deviations for both AASHTO T-85 and CoreLok percent absorption are less than the multilaboratory precision limit of 0.145. The standard deviations were less than the single operator precision limit of 0.088 for all sources for the CoreLok procedure and all but two sources for AASHTO T-85. The averages of the standard deviations were 0.0508 and 0.0500, for the CoreLok and T-85 procedures, respectively. The ANOVA indicated a significant difference between CoreLok and AASHTO T-85 percent absorption. When comparing CoreLok to AASHTO T-85 percent absorption, no sources had absorptions within the acceptable range of two results for single-operator precision and only three sources were within the multilaboratory acceptable range.

FINE AGGREGATE

ANOVA Results

An ANOVA was performed to determine if there was a statistical difference in test results between test methods, operators, and the interaction between test method and operators for fine aggregates. Duncan's Multiple Range Test was performed to determine which means were significantly different from each other when the ANOVA showed a significant different in means.

Bulk Specific Gravity

The results of the ANOVA on bulk specific gravity are shown in table 13. The results indicate a statistically significant different at a confidence limit exceeding 97%. No statistical difference existed between operators or the interaction between test methods and operators. Table 14 shows results from Duncan's Multiple Range Test on test methods. Means with the same letter not significantly different at a confidence limit of 95% (alpha = 0.05). No statistical difference in bulk specific gravity exists between SSDetect and CoreLok, or CoreLok and AASHTO T-84. A statistical difference does exist between SSDetect and AASHTO T-84. These results are similar to those found by Hall (13) and Prowell (15).

Table 13. ANOVA for bulk specific gravity, fine aggregates.

Source	Degrees Freedom	Sum Squares	Mean Square	F Ratio	Prob. > F
Test Method	2	0.0321	0.0160	3.82	0.024
Operator	1	0.0014	0.0014	0.34	0.559
Test M * Operator	2	0.0011	0.0005	0.13	0.878
Error	174	0.7291	0.0042		
Total	179	0.7637			

Table 14. Results of Duncan's Multiple Range Test for bulk specific gravity, fine aggregates.

Grouping*	Mean Bulk Specific Gravity	N	Test Method
A	2.612	60	SSDetect
A & B	2.602	60	CoreLok
B	2.580	60	T84

*Means with the same letter are not statistically different

Shown in figure 9 is a plot of CoreLok versus AASHTO T-84 bulk specific gravity. It can be seen that the CoreLok method tends to over estimate the bulk specific gravity values compared to AASHTO T-84 method. The relationship has a coefficient of determination (R^2) of 0.61.

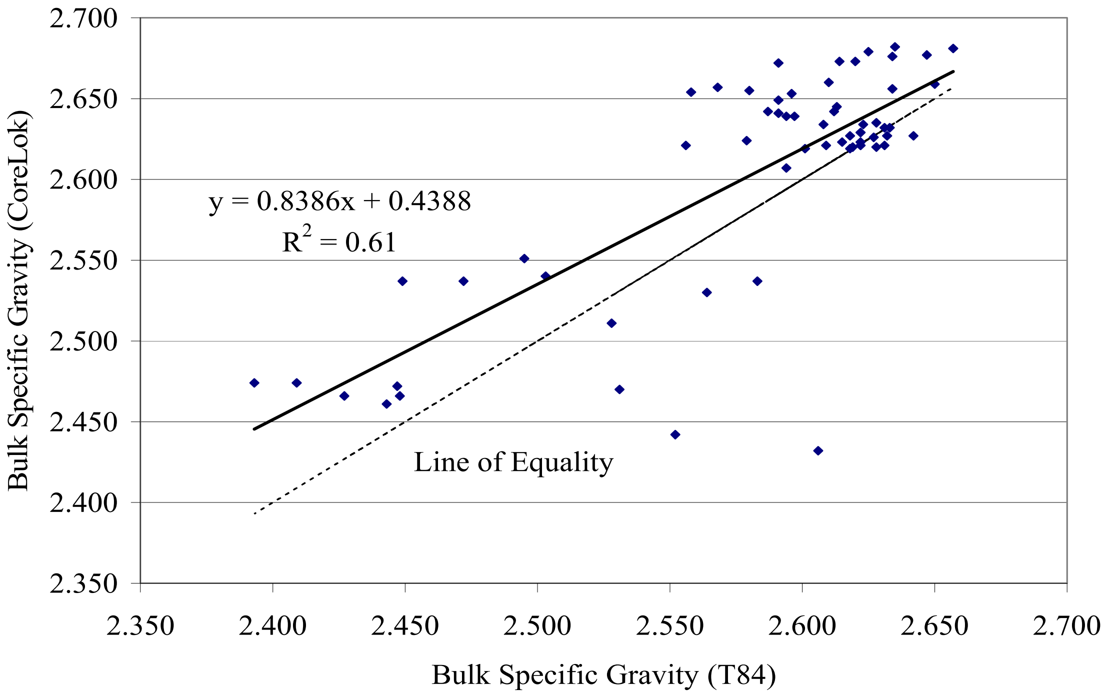

Figure 9. CoreLok Gsb vs. AASHTO T-84 Gsb, fine aggregates.

Figure 10 is a plot of SSDetect versus AASHTO T-84 bulk specific gravity. The results indicate that the SSDetect method tends to over estimate bulk specific gravity at lower values of Gsb compared to AASHTO T-84. The relationship has a low coefficient of determination (R^2) of 0.38.

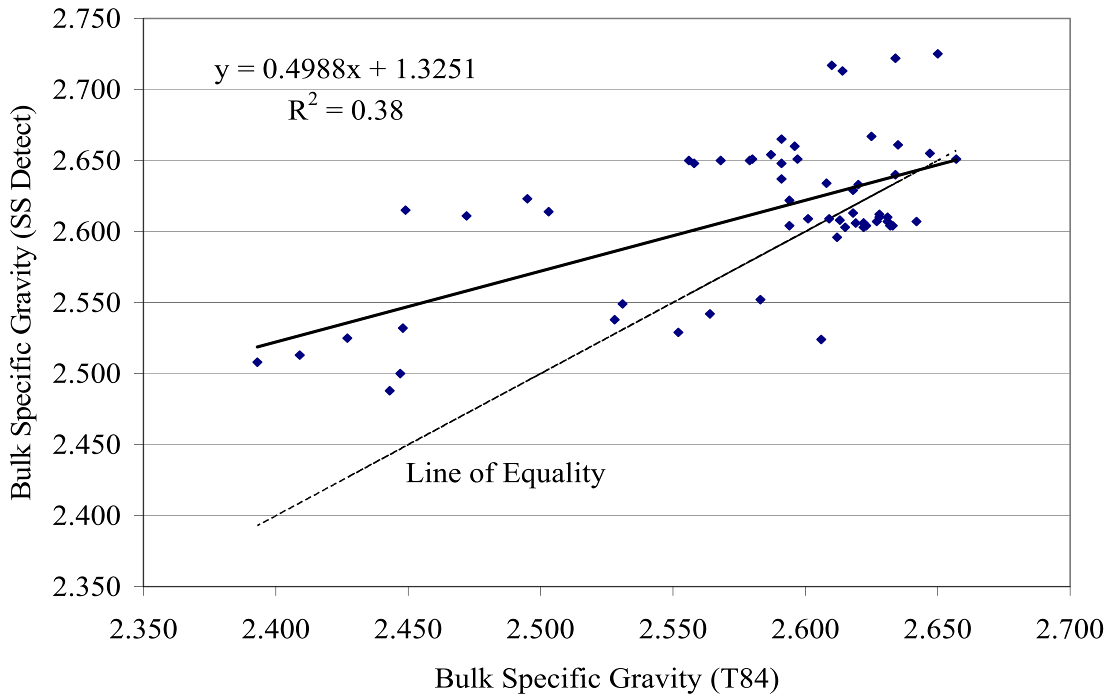

Figure 10. SSDetect Gsb vs. AASHTO T-84 Gsb, fine aggregates.

Figure 11 is a plot of CoreLok versus SSDetect bulk specific gravity. It can be seen that the CoreLok method tends to under estimate the bulk specific gravity at lower values of Gsb compared to SSDetect method. The relationship has a coefficient of determination (R^2) of 0.73.

Apparent Specific Gravity

The results of the ANOVA on apparent specific gravity are shown in table 15. The analysis indicates that there was no significant difference in apparent specific gravity values for test methods, operators or the interaction. Figures 12, 13 and 14 show the relationships between the three procedures. The relationships are strong, supporting the ANOVA results that no statistically significant difference exists between the three procedures for apparent specific gravity.

Percent Absorption

The results of the ANOVA on percent absorption are shown in table 16. There is a statistically significant difference between test methods at a confidence limit exceeding 99%. No statistical difference exists between operators or the interaction between test methods and operators. Table 17 shows the results of Duncan's Multiple Range Test on test methods. No statistically significant difference exists between SSDetect and the

CoreLok method. A significant statistical difference exists between AASHTO T-84 and CoreLok, and AASHTO T-84 and SSDetect.

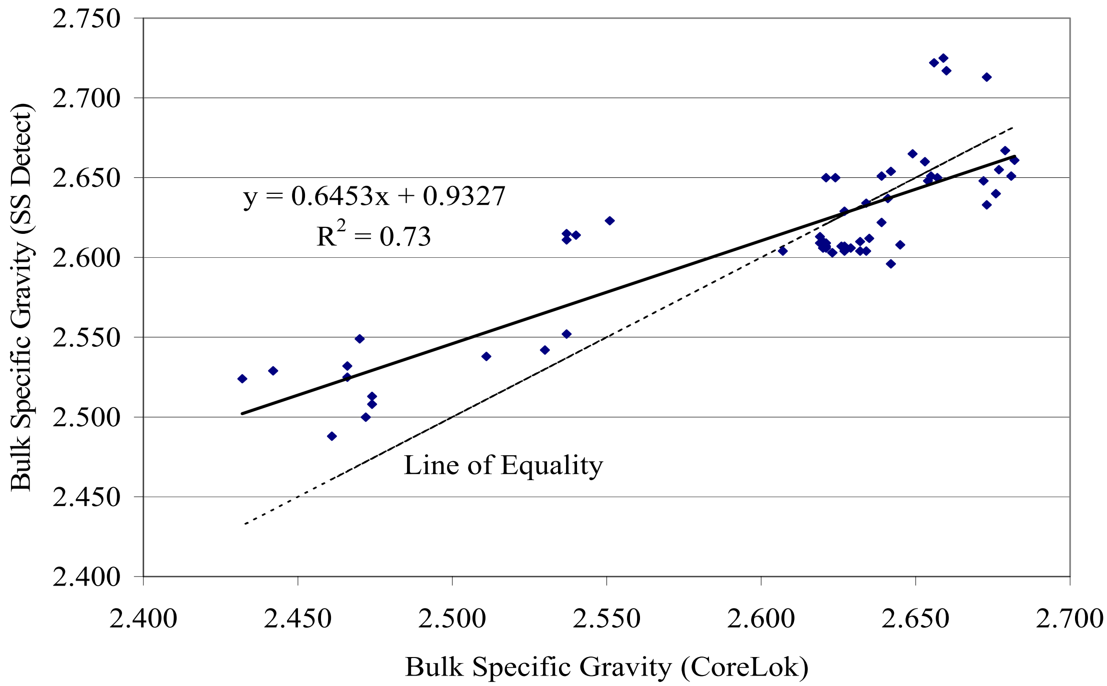

Figure 11. SSDetect Gsb vs. CoreLok Gsb, fine aggregates.

Table 15. ANOVA for apparent specific gravity, fine aggregates.

Source	Degrees Freedom	Sum Squares	Mean Square	F Ratio	Prob. > F
Test Method	2	0.0061	0.0030	1.57	0.210
Operator	1	0.0007	0.0007	0.38	0.540
Test M * Operator	2	0.0001	0.0001	0.04	0.965
Error	174	0.3348	0.0019		
Total	179	0.3417			

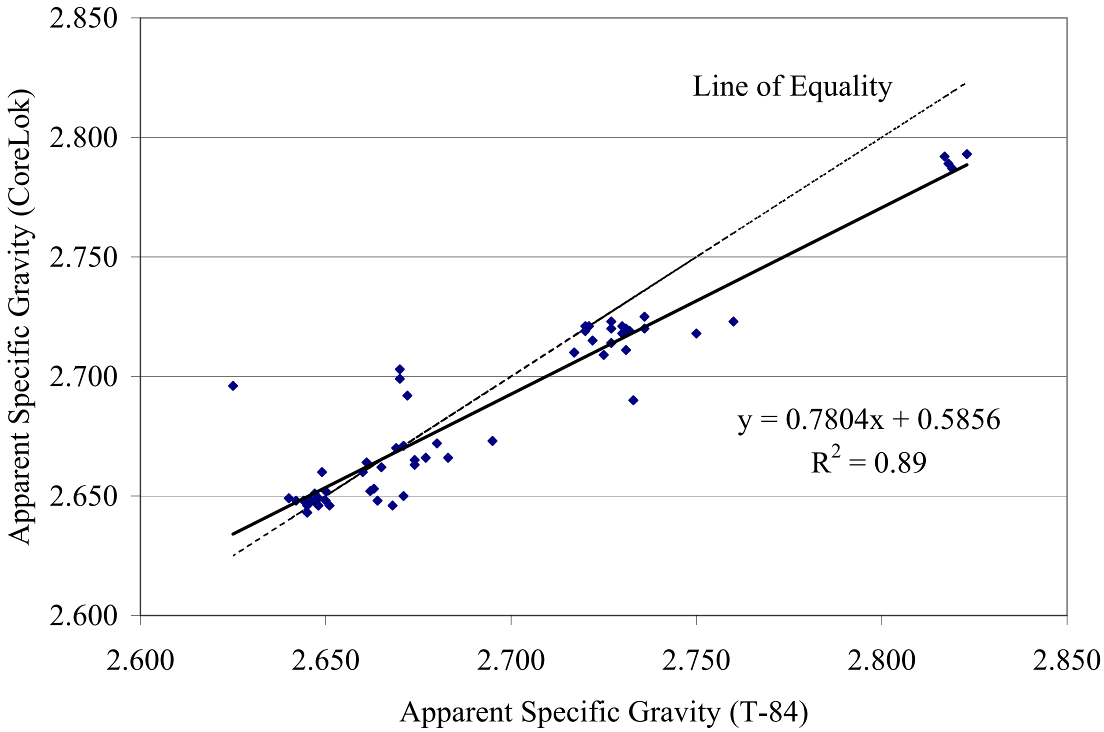

Figure 12. CoreLok Gsa vs. AASHTO T-84 Gsa, fine aggregates.

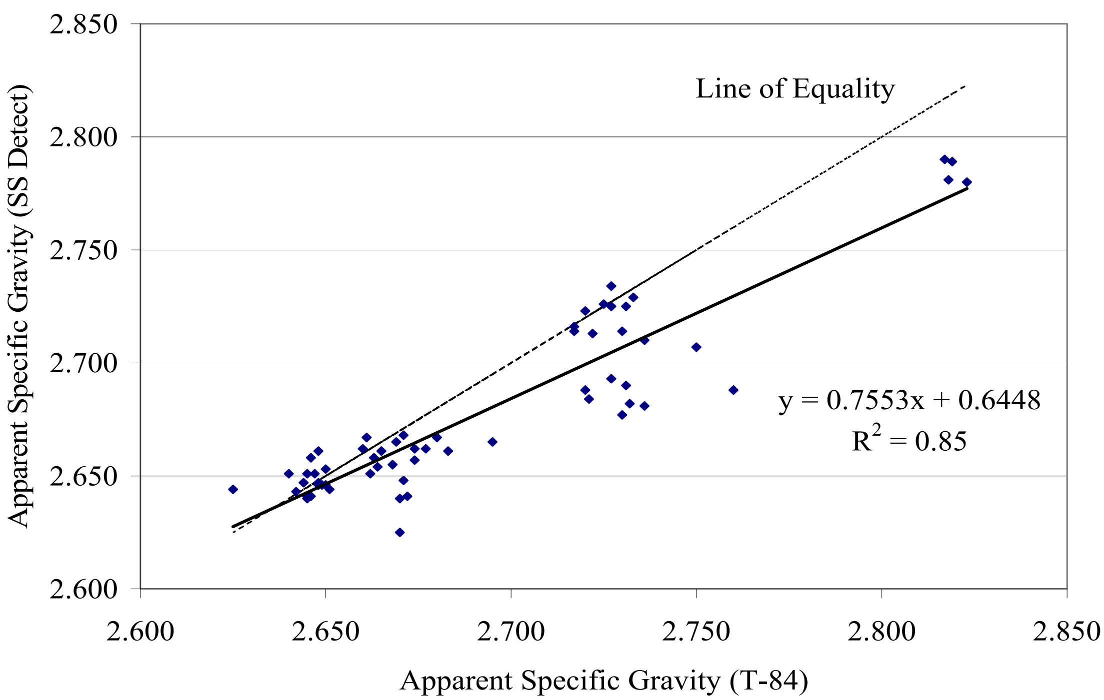

Figure 13. SSDetect Gsa vs. AASHTO T-84 Gsa, fine aggregates.

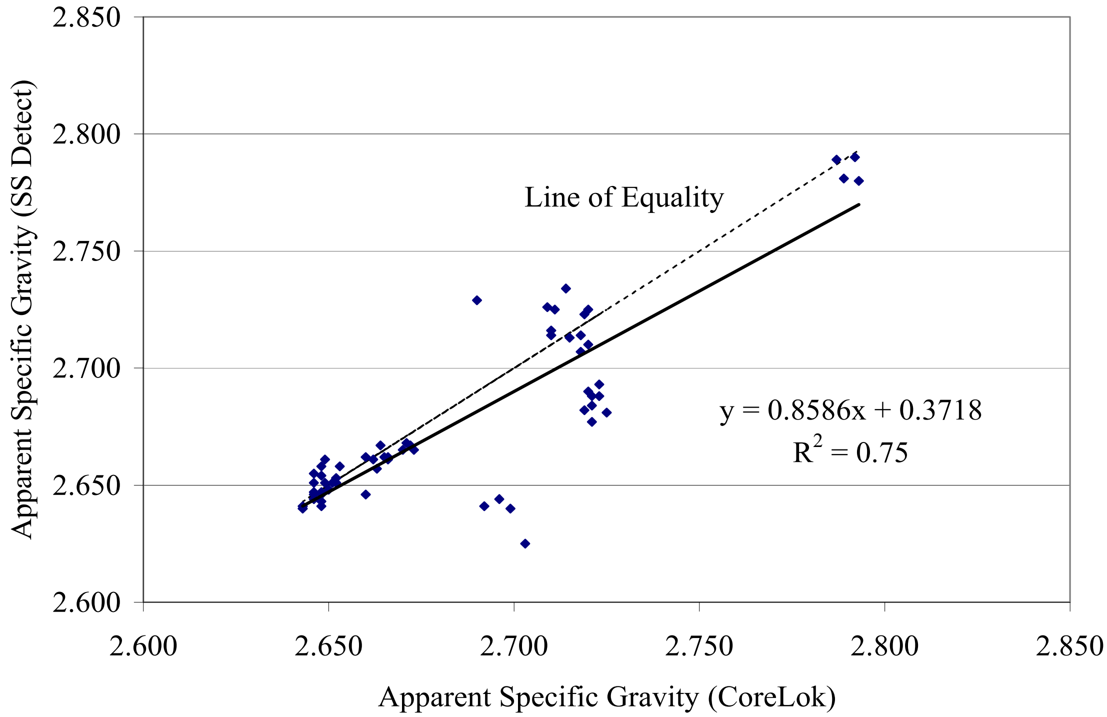

Figure 14. SSDetect Gsa vs. CoreLok Gsa, fine aggregates.

Table 16. ANOVA for percent absorption, fine aggregates.

Source	Degrees of Freedom	Sum Squares	Mean Square	F Ratio	Prob. > F
Test Method	2	14.465	7.232	6.24	0.002
Operator	1	0.047	0.047	0.04	0.841
Test M. * Operator	2	0.145	0.072	0.06	0.940
Error	174	201.774	1.160		
Total	179	216.430			

Table 17. Results of Duncan's Multiple Range Test for percent absorption, fine aggregate.

Grouping*	Mean percent Absorption	N	Test Method
A	0.972	60	SSDetect
A	1.237	60	CoreLok
B	1.660	60	T-84

* Means with the same letter not significantly different

Figures 15 and 16 are plots of AASHTO T-84 versus CoreLok percent absorption and AASHTO T-84 versus SSDetect percent absorption. The results indicate that, at higher percent absorption, the CoreLok procedure tends to slightly under estimate absorption values compared to AASHTO T-84. The relationship has a coefficient of determination (R^2) of 0.70. Figure 16 shows that, at higher absorption values, the SSDetect method tends to under estimate the percent absorption values compared to AASHTO T-84. The relationship has a low coefficient of determination (R^2) of 0.47.

Figure 17 is a plot of CoreLok versus SSDetect percent absorption. It can be seen that the CoreLok method over estimates the absorption values compared to SSDetect at high absorption values. The relationship has a coefficient of determination (R^2) of 0.78.

Simple Statistics

The above ANOVAs indicated that there was no significant difference between operators; therefore, the test results can be pooled by operator. The results of the average bulk specific gravity, apparent specific gravity, percent absorption and the associated average standard deviations, by test procedures, are provided in table 18. The precision limits for AASHTO T-84 are shown in table 19.

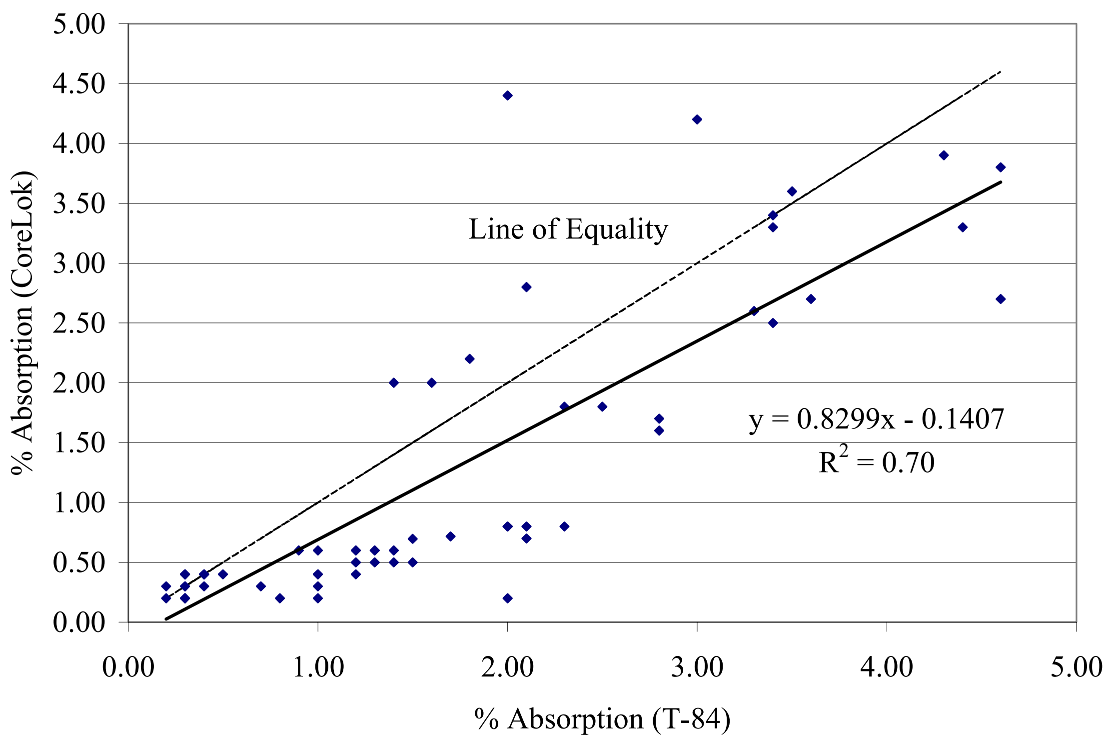

Figure 15. CoreLok absorption vs. AASHTO T-84 absorption, fine aggregates.

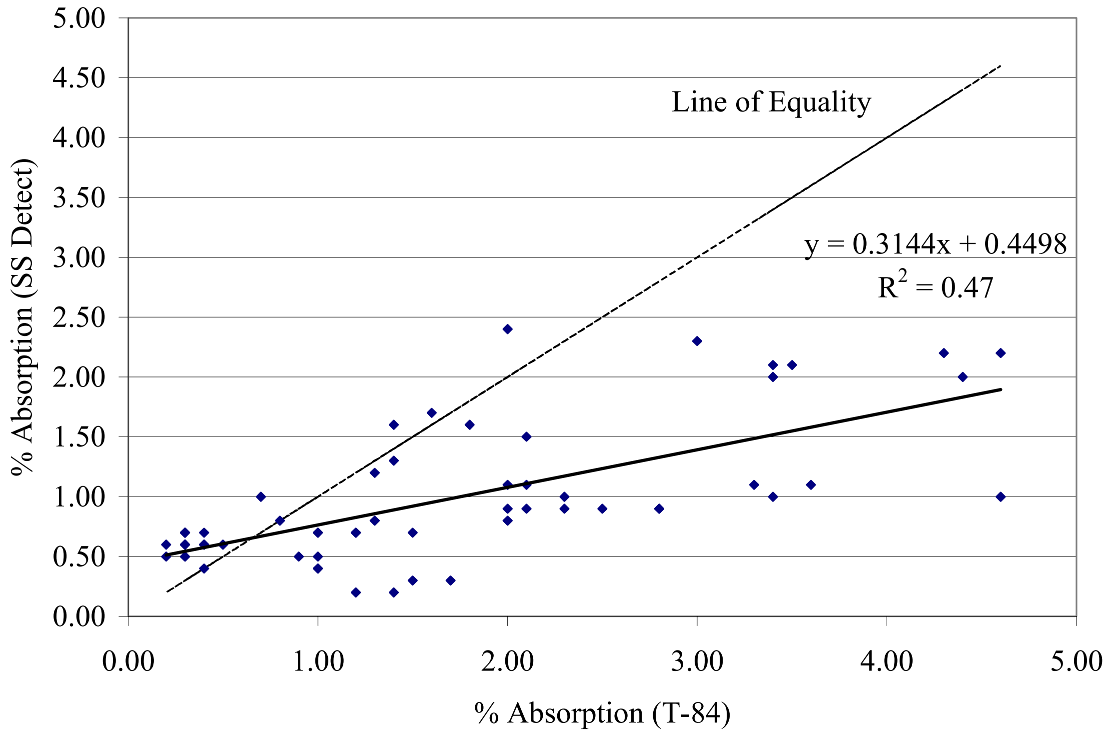

Figure 16. SSDetect absorption vs. AASHTO T-84 absorption, fine aggregates.

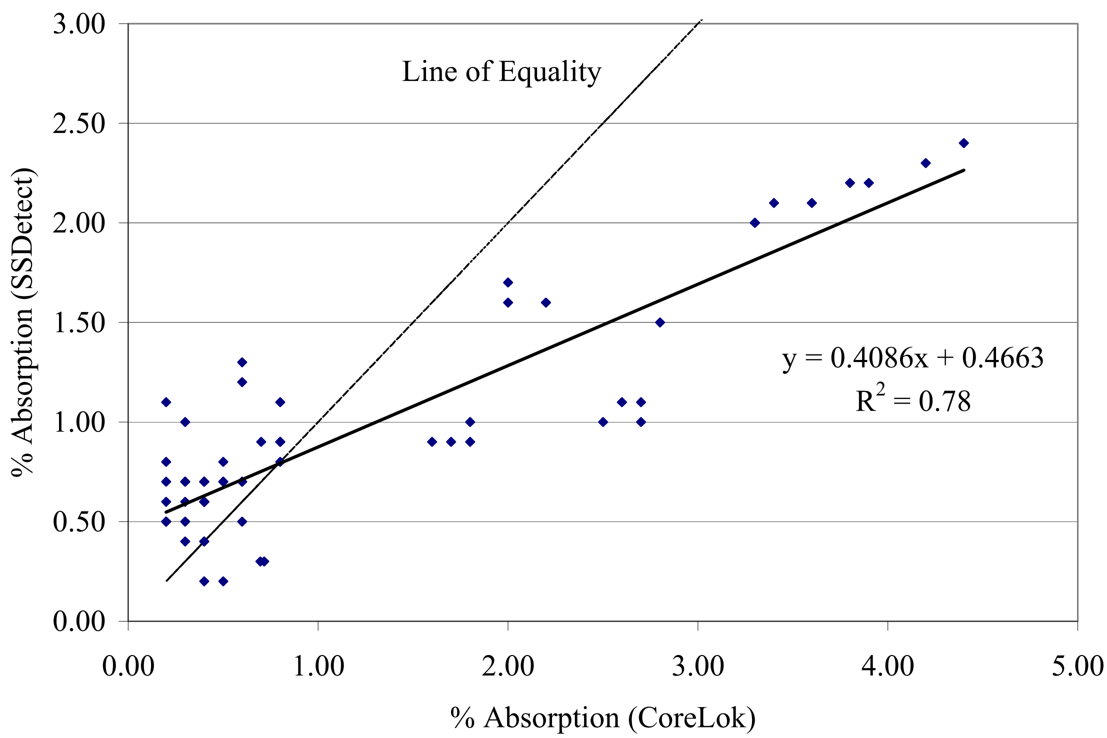

Figure 17. CoreLok absorption vs. SSDetect absorption, fine aggregates.

Table 18. Simple statistics for fine aggregate.

		Test	Gsb		Gsa		% Abs.	
Pit	Aggregate	Method	Avg.	Std.	Avg.	Std.	Avg.	Std.
905	N'Sand	T84	2.624	0.011	2.646	0.004	0.3	0.126
905	N'Sand	CL	2.626	0.005	2.647	0.001	0.3	0.096
905	N'Sand	SSDetect	2.605	0.003	2.647	0.003	0.6	0.000
1601	Limestone	T84	2.578	0.018	2.723	0.007	2.1	0.141
1601	Limestone	CL	2.653	0.003	2.710	0.001	0.8	0.050
1601	Limestone	SSDetect	2.656	0.008	2.720	0.006	0.9	0.050
3101	Sandstone	T84	2.423	0.026	2.659	0.023	3.7	0.486
3101	Sandstone	CL	2.470	0.006	2.698	0.005	3.4	0.141
3101	Sandstone	SSDetect	2.502	0.011	2.638	0.009	2.1	0.058
3502	Granite	T84	2.603	0.013	2.669	0.008	1.0	0.050
3502	Granite	CL	2.635	0.006	2.662	0.006	0.4	0.171
3502	Granite	SSDetect	2.631	0.007	2.662	0.004	0.5	0.058
3502	Granite	T84	2.605	0.009	2.664	0.003	0.9	0.150
3502	Granite	CL	2.628	0.018	2.654	0.008	0.4	0.171
3502	Granite	SSDetect	2.604	0.006	2.658	0.004	0.8	0.141
3702	N'Sand	T84	2.628	0.012	2.650	0.009	0.3	0.050
3702	N'Sand	CL	2.625	0.004	2.651	0.001	0.4	0.050
3702	N'Sand	SSDetect	2.606	0.002	2.652	0.001	0.7	0.050
4701	N'Sand	T84	2.624	0.004	2.647	0.002	0.4	0.058
4701	N'Sand	CL	2.626	0.007	2.648	0.001	0.3	0.096
4701	N'Sand	SSDetect	2.608	0.003	2.653	0.008	0.7	0.058
5002	Limestone	T84	2.641	0.014	2.735	0.012	1.3	0.141
5002	Limestone	CL	2.680	0.002	2.718	0.002	0.5	0.050
5002	Limestone	SSDetect	2.659	0.007	2.711	0.003	0.7	0.050
5002	Limestone	T84	2.606	0.025	2.727	0.005	1.7	0.408
5002	Limestone	CL	2.669	0.009	2.711	0.014	0.6	0.252
5002	Limestone	SSDetect	2.643	0.008	2.728	0.005	1.2	0.096
5008	Rhyolite	T84	2.627	0.019	2.819	0.003	2.6	0.245
5008	Rhyolite	CL	2.662	0.008	2.790	0.003	1.7	0.096
5008	Rhyolite	SSDetect	2.719	0.005	2.785	0.005	0.9	0.050

Table 18 (Con't.). Simple statistics for fine aggregate.

		Test	Gsb		Gsa		% Abs.	
Pit	Aggregate	Method	Avg.	Std.	Avg.	Std.	Avg.	Std.
5103	N'Sand	T84	2.625	0.006	2.647	0.003	0.3	0.082
5103	N'Sand	CL	2.626	0.008	2.645	0.002	0.3	0.096
5103	N'Sand	SSDetect	2.609	0.004	2.642	0.002	0.5	0.050
7201	Limestone	T84	2.480	0.024	2.735	0.018	3.7	0.597
7201	Limestone	CL	2.541	0.007	2.722	0.002	2.6	0.096
7201	Limestone	SSDetect	2.616	0.005	2.690	0.002	1.1	0.058
7201	Limestone	T84	2.508	0.085	2.730	0.006	3.5	1.204
7201	Limestone	SSDetect	2.528	0.004	2.681	0.003	2.3	0.096
7201	Limestone	CL	2.452	0.017	2.722	0.003	4.1	0.275
7808	Gravel	T84	2.580	0.017	2.679	0.012	1.5	0.208
7808	Gravel	CL	2.632	0.011	2.672	0.001	0.6	0.150
7808	Gravel	SSDetect	2.651	0.002	2.666	0.002	0.3	0.058
7902	Sandstone	T84	2.552	0.027	2.669	0.014	1.7	0.299
7902	Sandstone	CL	2.512	0.030	2.660	0.007	2.3	0.379
7902	Sandstone	SSDetect	2.545	0.006	2.653	0.007	1.6	0.082

Table 19. AASHTO T-84 precision indices.

	Single-Operator		Multilaboratory	
	Standard Deviation	Acceptable Range of Two Results	Standard Deviation	Acceptable Range of Two Results
Gsb	0.011	0.032	0.023	0.066
Gsa	0.0095	0.027	0.020	0.056
% Abs.	0.11	0.31	0.23	0.66

Bulk Specific Gravity

From the statistics shown in table 18, it can be seen that the standard deviations were variable. Five of the 15 sources were outside the multilaboratory precision range for AASHTO T-84. The CoreLok and SSDetect methods were more repeatable, with only one and no sources outside the multilaboratory precision range, respectively. Eleven sources were outside the single operator standard deviation for AASHTO T-84, three for CoreLok and none for SSDetect, indicating better repeatability for the CoreLok and SSDetect procedures. The averages of the standard deviations for AASHTO T-84, CoreLok and SSDetect were 0.021, 0.009 and 0.005, respectively.

The ANOVA indicated that there was a statistically significant difference between AASHTO T-84 and SSDetect but not between the CoreLok procedure and AASHTO T-84. When comparing CoreLok bulk specific gravity to AASHTO T-84 bulk specific gravity, only six of 15 sources were within the acceptable range of two results for single operator precision and 14 of 15 sources for multilaboratory situations. When comparing SSDetect bulk specific gravity to AASHTO T-84 bulk specific gravity, nine of 15 sources were within the acceptable range of two results for single operator precision and ten of 15 were within the multilaboratory range.

Figures 18 and 19 show the relationship between the difference in bulk specific gravity between CoreLok and AASHTO T-84 and SSDetect and AASHTO T-84, versus AASHTO T-84 percent absorption, respectively. There is no trend ($R^2 = 0.03$) between the difference in bulk specific gravity between CoreLok and AASHTO T-84 and T-84 percent absorption. However, the difference in bulk specific gravity between SSDetect and AASHTO T-84 increase as the AASHTO T-84 percent absorption increases.

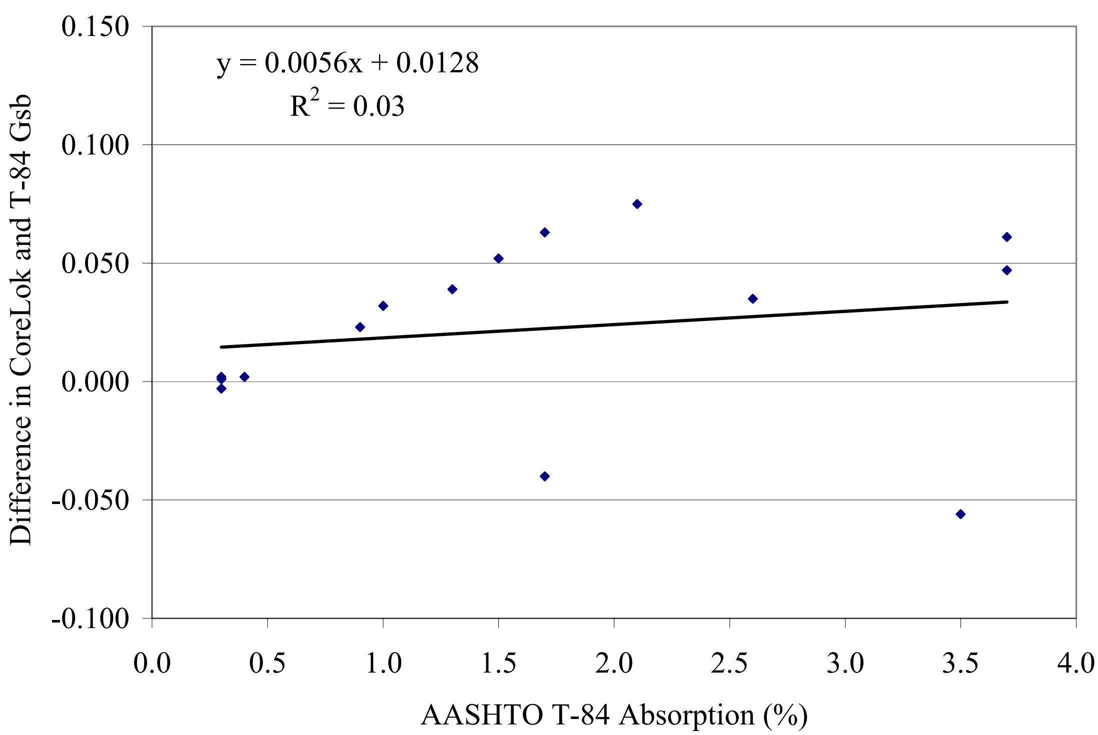

Figure 18. Difference in Gsb between CoreLok and AASHTO T-84 vs. AASHTO T-84 percent absorption.

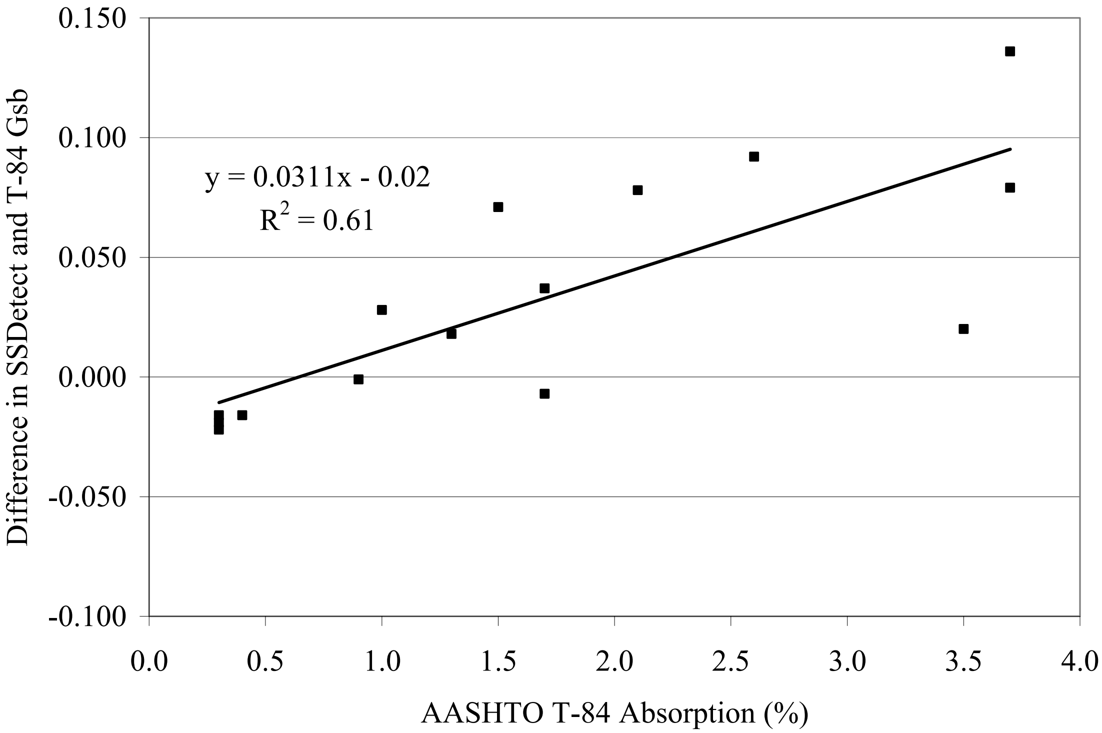

Figure 19. Difference in Gsb between SSDetect and AASHTO T-84 vs. AASHTO T-84 percent absorption.

Apparent Specific Gravity

The standard deviations for the all three procedures were less than or equal to the multilaboratory precision limit of 0.020 for all sources except one source for AASHTO T-84. Five of the 15 sources had standard deviations greater than the single operator standard deviation for AASHTO T-84, one for the CoreLok procedure and none for the SSDetect method. The averages of the standard deviations for AASHTO T-84, CoreLok and SSDetect were 0.009, 0.004 and 0.004, respectively.

When comparing CoreLok apparent specific gravity to AASHTO T-84 apparent specific gravity, 13 of 15 sources had apparent specific gravities within the acceptable range of two results for single operator precision and all sources were within the acceptable range of results for multilaboratory testing. When comparing SSDetect apparent specific gravity to AASHTO T-84 apparent specific gravity, 12 of 15 sources had apparent specific gravities within the acceptable range of two results for single operator precision and all sources were within the acceptable range of results for multilaboratory testing. It should be noted that there is very little difference in the procedure for determining apparent specific gravity between SSDetect and AASHTO T-84. The ANOVA indicated that there was no statistically significant difference in apparent specific gravity between the three procedures.

Percent Absorption

For the AASHTO T-84 procedure, six of the 15 sources had standard deviations outside the multilaboratory precision range for AASHTO T-84 percent absorption. The CoreLok and SSDetect methods were more repeatable with only three and no sources outside the multilaboratory precision range, respectively. The AASHTO T-84 procedure had 11 of 15 sources outside the single operator standard deviation of AASHTO T-84; there were seven of 15 sources outside the single operator limit for CoreLok and one source outside the limit for SSDetect, indicating better repeatability for the SSDetect procedure. AASHTO T-84 precision limits are based on samples with absorptions below 2.0 percent. Five of the 15 sources had absorptions greater than 2.0%. The averages of the standard deviations for AASHTO T-84, CoreLok and SSDetect were 0.283, 0.145 and 0.064, respectively. Based on the averages of the percent absorptions, the CoreLok and SSDetect procedures produced lower percent absorptions than AASHTO T-84.

The ANOVA indicated that there was a statistically significant difference between AASHTO T-84 and both the SSDetect procedure and the CoreLok procedure. There was no statistically significant difference between CoreLok and SSDetect. When comparing CoreLok percent absorption to AASHTO T-84 percent absorption, five of 15 sources had absorptions within the acceptable range of two results for single operator precision and nine of 15 sources were within the acceptable range of results for multilaboratory testing. When comparing SSDetect percent absorption to AASHTO T-84 percent absorption, five of 15 sources had absorptions within the acceptable range of two results for single operator precision and nine of 15 sources were within the acceptable range for multilaboratory testing.

BLENDED AGGREGATES

Eight combinations of aggregates were blended together and the bulk specific gravity determined using the CoreLok procedure for a blended aggregate sample of coarse and fine aggregate. The specific gravity of the blended aggregate was also calculated using both the AASHTO results and CoreLok results of the bulk specific gravity of the individual components. Only one operator's individual AASHTO and CoreLok test results were used in the analysis, operator M. The results of the one-way ANOVA on the bulk specific gravity of the aggregate blends are shown in table 20.

Table 20. ANOVA results for blended bulk specific gravity.

Source	Degrees Freedom	Sum of Squares	Mean Square	F Ratio	Prob. > F
Method	2	0.04407	0.022035	4.42	0.0177
Error	45	0.22439	0.0049864		
Total	47	0.26846			

The results of the ANOVA indicate a significant difference in the bulk specific gravity of the blended aggregates, by test method. The difference is statistically significant at a 95% confidence limit. Duncan's Multiple Range Test was performed on the means of the test methods to determine which means were significantly different from each other. The results are shown in table 22. Means with the same letter not significantly different at a confidence limit of 95% (alpha = 0.05). No statistical difference in bulk specific gravity exists between the calculated CoreLok Gsb and the CoreLok blended Gsb. There was no statistical difference in bulk specific gravity between the calculated CoreLok Gsb and the calculated AASHTO Gsb. However, there was a statistically significant difference between the CoreLok blended Gsb and the AASHTO calculated Gsb.

Table 21. Results of Duncan's Multiple Range Test for blended bulk specific gravity.

Grouping*	Mean Gsb	N	Test Method
A	2.661	16	CoreLok Blended
A B	2.630	16	Calculated CoreLok
B	2.587	16	Calculated AASHTO

*Means with the same letter not significantly different

The relationship between blended CoreLok bulk specific gravity versus AASHTO calculated bulk specific gravity is shown in figure 20. It can be seen that the blended Corelok procedure over estimates the bulk specific gravity values compared to calculated values using AASHTO T-84 and T-85 bulk specific gravities. The relationship has a coefficient of determination (R^2) of 0.82. The goodness of fit indicates that the algorithm used in the CoreLok procedure could be adjusted to better match AASHTO calculated bulk specific gravity values for Oklahoma aggregates.

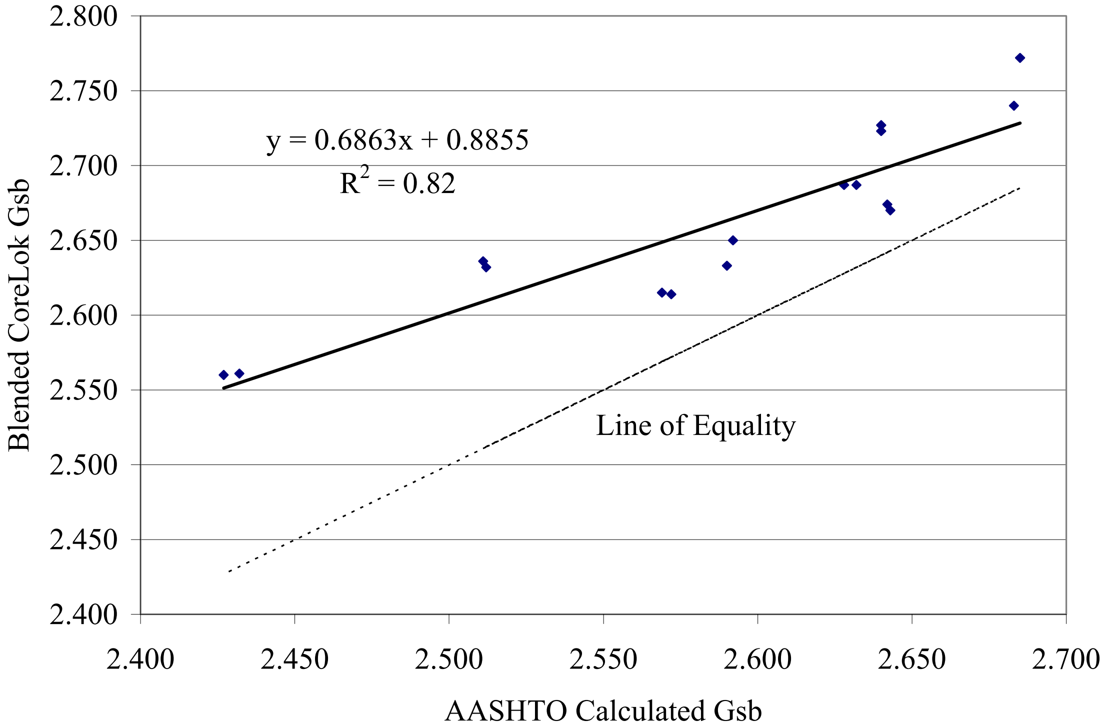

Figure 20. Blended CoreLok Gsb vs. calculated AASHTO blended Gsb.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Based on the results of this study and for the materials, test methods and equipment evaluated, the following conclusions are warranted.

Coarse Aggregate

1. The ANOVA indicated a statistically significant difference in bulk specific gravity and percent absorption between AASHTO T-85 and the CoreLok procedure. There was no statistically significant difference in apparent specific gravity.
2. The CoreLok procedure produced bulk specific gravities that were higher than AASHTO T-85.
3. The CoreLok procedure produced percent absorptions that were lower than AASHTO T-85.
4. As the percent absorption of an aggregate increased, the difference between CoreLok and AASHTO T-85 bulk specific gravity increased.
5. When comparing CoreLok bulk specific gravity to AASHTO T-85 bulk specific gravity, only two of eight coarse aggregate sources had bulk specific gravities within the AASHTO T-85 acceptable range of two results for single-operator precision and only four of eight coarse aggregate sources had bulk specific gravities within the AASHTO T-85 acceptable range of two results for multilaboratory precision.
6. When comparing CoreLok apparent specific gravity to AASHTO T-85 apparent specific gravity, only three of eight coarse aggregate sources had apparent specific gravities within the AASHTO T-85 acceptable range of two results for single-operator precision and only four of eight coarse aggregate sources had apparent specific gravities within the AASHTO T-85 acceptable range of two results for multilaboratory precision.
7. When comparing CoreLok percent absorption to AASHTO T-85 percent absorption, no sources had percent absorptions within either the AASHTO T-85 acceptable range of two results for single-operator precision or the acceptable range of two results for multilaboratory precision.
8. The averages of the standard deviations for bulk specific gravity, apparent specific gravity and percent absorption, by aggregate source, were lower for the CoreLok procedure than AASHTO T-85.
9. Both procedures were easy to perform with the operators reporting no difficulty with either method. The CoreLok procedure can be completed in less time than AASHTO T-85.

Fine Aggregate

1. The ANOVA indicated a statistically significant difference in bulk specific gravity between the SSDetect procedure and AASHTO T-84. There was no statistically significant difference in bulk specific gravity between SSDetect and CoreLok or between CoreLok and AASHTO T-84.
2. The SSDetect procedure produced the largest bulk specific gravities followed by the CoreLok procedure and AASHTO T-84.
3. The ANOVA indicated no statistically significant difference in apparent specific gravity between SSDetect, CoreLok or AASHTO T-84.
4. The ANOVA indicated a statistically significant difference in percent absorption between the SSDetect procedure and AASHTO T-84, and between the CoreLok procedure and AASHTO T-84. There was no statistically significant difference in percent absorption between the SSDetect and CoreLok procedures.
5. The SSDetect procedure produced the lowest percent absorptions followed by the CoreLok procedure and AASHTO T-84.
6. As the percent absorption of an aggregate increased, the difference between SSDetect and AASHTO T-85 bulk specific gravity increased. This trend was not true for the CoreLok procedure.
7. When comparing CoreLok bulk specific gravity to AASHTO T-84 bulk specific gravity, only six of 15 fine aggregate sources had bulk specific gravities within the AASHTO T-84 acceptable range of two results for single-operator precision and 14 of 15 fine aggregate sources had bulk specific gravities within the AASHTO T-84 acceptable range of two results for multilaboratory precision.
8. When comparing SSDetect bulk specific gravity to AASHTO T-84 bulk specific gravity, nine of 15 fine aggregate sources had bulk specific gravities within the AASHTO T-84 acceptable range of two results for single-operator precision and 10 of 15 fine aggregate sources had bulk specific gravities within the AASHTO T-84 acceptable range of two results for multilaboratory precision.
9. When comparing CoreLok apparent specific gravity to AASHTO T-84 apparent specific gravity, 13 of 15 fine aggregate sources had apparent specific gravities within the AASHTO T-84 acceptable range of two results for single-operator precision and all fine aggregate sources had apparent specific gravities within the AASHTO T-84 acceptable range of two results for multilaboratory precision.
10. When comparing SSDetect apparent specific gravity to AASHTO T-84 apparent specific gravity, 12 of 15 fine aggregate sources had apparent specific gravities within the AASHTO T-84 acceptable range of two results for single-operator precision and all fine aggregate sources had apparent specific gravities within the AASHTO T-84 acceptable range of two results for multilaboratory precision.
11. When comparing CoreLok percent absorption to AASHTO T-84 percent absorption, only five of 15 fine aggregate sources had percent absorptions within the AASHTO T-84 acceptable range of two results for single-operator precision and nine of 15 fine aggregate sources had percent absorptions within the AASHTO T-84 acceptable range of two results for multilaboratory precision.
12. When comparing SSDetect percent absorption to AASHTO T-84 percent absorption, five of 15 fine aggregate sources had percent absorptions within the

AASHTO T-84 acceptable range of two results for single-operator precision and nine of 15 fine aggregate sources had percent absorptions within the AASHTO T-84 acceptable range of two results for multilaboratory precision.

13. The averages of the standard deviations for bulk specific gravity, apparent specific gravity and percent absorption, by aggregate source, were lower for the SSDetect and CoreLok procedures, compared to AASHTO T-84.
14. All three procedures were easy to perform with the operators reporting no difficulty with any of the methods. The CoreLok procedure can be completed in less time than either the AASHTO T-85 or the SSDetect procedure.

Blended Aggregate

1. The ANOVA indicated a statistically significant difference in bulk specific gravity between the CoreLok procedure for blended aggregate samples and calculated blended specific gravity of the blend using AASHTO T-84 and T-85. There was no statistically significant difference between the blended CoreLok procedure and the calculated bulk specific gravity from the CoreLok procedure or between the calculated bulk specific gravity using CoreLok and AASHTO T-84 and T-85 results.
2. The CoreLok procedure for blended aggregate samples produced the largest bulk specific gravity followed by the calculated CoreLok results and AASHTO T-84 and T-85 results.

RECOMMENDATIONS

Coarse Aggregate

At the current time it is recommended that ODOT continue to use AASHTO T-85 to determine the bulk specific gravity and absorption of coarse aggregates. There was a high correlation between CoreLok bulk specific gravity and AASHTO T-85 bulk specific gravity. If there is a desire to adopt the CoreLok procedure for coarse aggregates, additional research to adjust the algorithm used by the CoreLok procedure to produce acceptable differences in results would be necessary.

Fine Aggregate

The ANOVA indicated no statistically significant difference between the CoreLok procedure and AASHTO T-84 for bulk specific gravity. Only six of 15 sources were within the AASHTO T-84 acceptable range of two results for single-operator precision. However, the experiment was performed with two operators. Fourteen of 15 sources were within the AASHTO T-84 acceptable range of two results for multilaboratory precision. If ODOT wants to implement the CoreLok procedure for fine aggregate specific gravity, with its reduced testing time and lower standard deviation, round robin testing within the state is recommended to verify these results.

The SSDetect procedure showed some promise as a replacement to AASHTO T-84. Of the two new procedures evaluated, it is the only procedure that is not empirically based. However, refinement in the SSDetect procedure would be necessary before it could be recommended for use.

Blended Aggregate

The CoreLok procedure for a blended aggregate did not produce results that were statistically significant to values calculated using AASHTO T-84 and T-85 results. Therefore, it is not recommended that the CoreLok procedure be adopted for use at this time. There was a good correlation between the blended CoreLok bulk specific gravity and the bulk specific gravity of a blend calculated using AASHTO procedures. Adjustments to the CoreLok algorithm could produce acceptable results.

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APPENDIX A – CoreLok FINE AGGREGATE PROCEDURES (16)

A. STEP 1 – Calibrate the Volumeter (small container) for Fine Aggregate

Important: Make certain the water temperature is 77±2 degrees Fahrenheit.

Important: Be sure your fixture and volumeter are on a level surface. Use a level indicator to set up the fixture position.

Note: Make certain you have all the necessary accessories.

Important: To achieve the best repeatability, it is extremely important that the empty volumeter temperature remains at 77±2 degrees Fahrenheit. A simple way to keep the volumeter at the correct temperature is to fill a 5-gallon bucket with 77±2 degrees Fahrenheit water. Before each test, rinse the empty volumeter in this water and dry it with a towel. This will quickly stabilize the volumeter temperature and will allow you to start your testing. This step is particularly important on very cold or very hot days, when the volumeter temperature can change drastically by the use of tap water or by normal changes in ambient temperature in the lab.

1. Place the volumeter in the fixture and push it back until it makes contact with the stops. Fill the small spray bottle with isopropyl (rubbing) alcohol.

Make sure the volumeter is pushed all the way back to the stops!

2. Fill the volumeter with water to the level of the line indicated inside the volumeter. Approximately 0.375" (3/8") from the top. It is important that you keep the water level at or below the line to avoid spills during lid placement.
3. Using the alcohol spray bottle, spray the surface of the water to remove bubbles.
4. Gently place the lid on the volumeter with the 1/8" hole facing the front. Close the clamps.

When placing the lid on the bowl, make sure the 1/8-inch hole beside the lid post faces the front (see illustrations pg 23). Always locate lid this way.

5. Using the syringe, slowly fill the volumeter through he large hole through the lid post. Make sure the syringe tip is far enough in the volumeter to be below the water level. Gentle application in this step prevents formation of air bubbles inside the volumeter.
6. Fill the volumeter until you just see the water coming out the 18" hole on the surface of the lid.
7. Wipe the excess water form the top of the lid with a towel.
8. Immediately place the entire fixture with the volumeter on the scale and obtain the weight.

9. Record the weight in the top portion of the Aggregate Worksheet on "Fine Aggregate Only" row.
10. Repeat the above steps 2 more times and average the weights.
11. If the range between the 3 calibration weights is larger than 0.5 grams, then you are not performing the test correctly. Check to see if the fixture is level. Make certain the water injection with the syringe is done below the volumeter water surface and is applied gently. Check the water temperature. Check the volumeter temperature. Repeat the test until you have three weights that are within 0.5-gram range.
12. Record the average of the three weights.
13. The volumeter and the fixture are now calibrated and ready for testing. Re-calibrate the volumeter prior to changes in each aggregate source or a minimum of once per week.

B. Step 2 – Test Fine Aggregate sample

Again, be sure your fixture and volumeter are level.

1. Oven dry a sufficient quantity of aggregate to perform this test. A single test may require 2500 grams of sample. Split the sample into four portions. You will need two or three 500-gram samples for the test in the volumeter and one 1000-gram sample for vacuum test in the CoreLok.

Note: Oven dry the sample for a minimum of 24 hours at 105ºC. You can make certain you have completely dried the sample to a constant weight by periodically weighing the sample.

2. Cool the sample to 77±2º F. Use appropriate state or national standard procedure to split the sample.

It is important that proper splitting technique be used for dividing the test samples.

3. Submerge the volumeter (bowl and lid) into a 77±2º F rinse water to stabilize the temperature. Completely dry the AggPlus volumeter inside and out.

Important: Steps 6 through 16 shall be completed within 2 minutes. Increased test time will affect the accurate determination of absorption during this process.

4. Weigh a 500±1 gram of oven dry material and record in column A of the worksheet. Make certain the aggregates are at 77±2 degrees Fahrenheit. Do not test the aggregates if they are still hot.
5. Place the empty dry volumeter in the fixture and push the volumeter until it makes contact with the stops.

Make sure the volumeter is pushed all the way back to the stops.

6. Place approximately 500 ml (halfway full) of 77±2 º F water in the volumeter.
7. Slowly and evenly pour the sample into the volumeter.

Caution: Make certain you don't lose any aggregate in the process of filing the volumeter. Use the provided pouring container to help in transferring the aggregate into the AggPlus volumeter. Use the provided brush to sweep the remaining fines into the volumeter. If you loose any aggregates in the process of filling the volumeter you will have to start the test over.

8. Use the provided aluminum spatula and push it to the bottom of the volumeter against the inside circumference.
9. Slowly and gently drag the spatula to the center of the volumeter, removing the spatula after reaching the center.
10. Repeat this same procedure 7 more times so that the entire circumference is covered in 8 equal angles, i.e. every 45 degrees until the starting point is reached. If necessary use a squeeze bottle to rinse any sample residue off the spatula into the volumeter.
11. Fill the volumeter with water to the level of the line indicated inside the volumeter. Approximately 0.375" from the top. It is important that you keep the water level at or below the line to avoid spills during lid placement.
12. Use the spray bottle filled with isopropyl alcohol and spray the top of the water to remove air bubbles.
13. Gently place the lid on the volumeter and lock the clamps.

When placing the lid on the volumeter, make sure the 1/8-inch hole beside the lid post faces the front. Do this each time you perform this test.

14. Using the syringe, slowly fill the volumeter through the large center hole on top of the lid. Make sure the syringe tip is far enough in the volumeter to be below the water level. Gentle application in this step will prevent formation of air bubbles inside the volumeter.
15. Fill the volumeter until you just see water coming out the 1/8" hole on the surface of the lid.
16. Wipe the excess water from around the 1/8" hole with a towel.

Note: <u>Do not</u> wipe water from the rim of the volumeter if it seeps between the lid and volumeter. Allow this water to remain on fixture.

17. Immediately weight the volumeter and the fixture. Record this weight in column B of the worksheet.
18. Repeat steps 4 to 17.
19. If the difference in weight of column B for the two samples tested is less than or equal to 1 gram, go to step 21.
20. Repeat steps 4 to 17, if the column B weights for the first two tests, is larger than 1 gram.

21. Average the weights in column A and then average the weights in column B of the worksheet. Use the average values when using the AggSpec program.
22. Set the CoreLok unit to run on Program 1 (all settings of Program 1 are preset at the factory). Note: The CoreLok unit is setup at the factory to run this and other tests. Simply run program 1. For varying the settings use the Menu key and the Up or Down arrows.

Important: For the following test you need a large water tank with the InstroTek cushioned weighing basket connected to a scale capable of reading to ±0.1 gram. The temperature of the water should be maintained at 77±2 º F. The bath should be setup with an overflow system to correct for variations in weight resulting from changes in the water level.

23. Place the three white filler plates into the CoreLok chamber. The plates fit in the chamber without touching the sealing bar assembly. Rotate them 90º if they touch or are above the sealing bar assembly.
24. Tear a small bag from the roll. Inspect the bag to make sure there are no holes, stress points or discontinuity in the side seals. Never use damaged bags.
25. Weigh the bag. Record the weight in column C.
26. Column D asks for rubber sheet weight. These are normally only used with coarse aggregates to prevent punctures. Enter ‘0’ unless rubber sheets were used.

Caution: Always handle the bag with extreme care to avoid creating weak points and punctures.

27. Weigh 1000±1 grams of aggregate and record the weight in column E.
28. Place the sample in the small bag. Support the bottom of the bag on a smooth tabletop when pouring to protect against puncture and impact points.
29. Place the bag inside the CoreLok.
30. Grab the two sides of the bag and spread the sample flat by gentle shaking.

Important: Do not use your hand to press down or spread the sample from outside the bag. Pressing down on the sample from outside the bag will cause the bag to puncture and will negatively impact your results.

31. Place the open end of the bag over the seal bar and close the chamber door.
32. After the chamber door opens, gently remove the sample from the chamber.
33. Immediately submerge the sample in the water tank for water displacement analysis.

Note: It is extremely important that you remove the sample form the CoreLok and immediately place it in the water bath. Leaving the bag in the CoreLok or on a bench top after sealing can cause air to slowly enter the bag and can result in low apparent gravity measurements.

34. Cut one corner of the bag, approximately 1 to 2 inch from the side while the top of the bag is at least 2” down in the water. Make sure the bag is completely

submerged before cutting. Introducing air into the bag will produce inaccurate results.

35. Open the cut portion of the bag with your fingers and hold open for 45 seconds. Allow the water to freely flow into the bag. Allow any small residual air bubbles to escape. Do not shake or push on the bag. This ation can make the fines escape from the bag.
36. After water has filled in, cut the other corner of the bag approximately 1-2 inches. Squeeze any residual air bubbles out of the cut corners by running your fingers across the top of the bag.
37. Place the bag containing the aggregate on the weighing basket in the water to obtain the under water weight. You may fold the bag to place it on the basket. However, once on the basket under water, unfold the bag and allow water to freely flow into the bag. Keep the sample and bag under water at all times.

Caution: Make certain the bags or the sample are not touching the bottom, the sides, or floating out of the water tank. If the bag contacts the sides it can negatively impact the results of this test.

38. Allow the sample to stay in the water bath for ten (15) minutes.
39. Record the submerged weight and wait one minute. If after this time the weight increases by more than one-gram wait an additional five minutes. Record the weight and continue this process until the weight stops increasing.

Note: In our experience fine aggregate samples should stabilize in less than 15 minutes. However, there might be some aggregates that require a longer soak time.

40. Record the submerged weight in column F.
41. Open the AggSpec program.
42. Be sure that Fine Aggregate is selected.
43. Enter the weights from the Worksheet for sample A and B (average of two or three tests) into the program. The program will calculate the apparent density, percent absorption, Bulk Specific Gravity (SSD) and Bulk Specific Gravity (Bsg). If you have used the rubber sheets for your test, make sure that the rubber Vc is entered correctly. You may export the data into an Excel spreadsheet template and print the data as well as other functions provided under the excel program. Simply click on "Export to Excel" and the AggSpec program will automatically pull the data into Excel.
44. If your absorption is zero, there might be two problems. First, the results (apparent gravity) of your vacuum test in the bag is low. There might have been a puncture in the bag. Repeat the test in the bag under vacuum with another 1000-gram sample. Second, you are possibly spending more than 2 minutes performing the tests in the volumeter or the temperatures during the test. Increased test time during the volumeter test will cause the weights in column B to be higher than the actual values. Repeat this test with another 500-gram sample paying special attention to time and temperature (sample, water and volumeter).

APPENDIX B – CoreLok Coarse and Blended Aggregate Procedures

A. STEP 1 – Calibration of the Large Volumeter for Coarse Aggregate

Important: Make certain the water temperature is 77±2 degrees Fahrenheit.

Caution: Be sure your volumeter is on a level surface. Use a level indicator to setup the volumeter position!

Note: Make certain you have all the necessary accessories.

Important: To achieve the best repeatability, it is extremely important that the empty volumeter temperature remains at 77±2 degrees Fahrenheit. A simple way to keep the volumeter at the correct temperature is to fill a 5-gallon bucket with 77±2 degrees Fahrenheit water. Before each test, rinse the empty volumeter in this water and dry it with a towel. This will quickly stabilize the volumeter temperature and will allow you to start your testing. This step is particularly important on very cold or very hot days, when the volumeter temperature can change drastically by the use of tap water or by normal changes in ambient temperature in the lab.

1. Fill the large volumeter with water to the top of the volumeter.
2. Place the lid on the volumeter gently pressing it down so that water flows through the hole in the lid post. Be sure the lid is well seated by gently rotating the lid on top of the volumeter.
3. Make sure the small 1/8” hole on the lid is facing forward. Use the provided syringe and fill the container through the large hole in the post until water starts to flow through the small 1/8” hole.
4. Wipe the excess water from the volumeter with a towel. Place on a towel to wipe water from the bottom of the unit.
5. Place the volumeter filled with water on the scale and obtain the weight.
6. Record the weight in the top portion of the Aggregate Worksheet, on “Coarse Aggregate Only” row.
7. Repeat the above steps 2 more times and average the weights.
8. If the range in these weights is larger than 1.0 gram, then you are not performing the test correctly. Check to see if the volumeter is level. Check the water temperature. Check the volumeter temperature. Repeat the test until you have three weights that are within a 1-gram range.
9. Record the average weight on the worksheet.
10. The volumeter is now calibrated and ready for testing. Re-calibrate the volumeter prior to changes in each aggregate source or a minimum of once per week.

B. STEP 2 – Testing Coarse Aggregate samples

Be sure your volumeter is on a level surface by checking with a level.

1. Oven dry a sufficient quantity of aggregate to perform this test. A single test may require 5000 grams of sample. You will need two or three 1000 grams samples for tests in the volumeter and one 2000-gram sample for vacuum test in the CoreLok.

Note: Oven dry the sample for a minimum of 24 hours at 105º C. Make certain you have achieved constant weight.

Note: This test is designed for washed coarse aggregates. For coarse aggregates with high fine content or blended aggregates, small adjustments have to be made to the procedure. Contact InstroTek for more information on these procedures.

2. Cool the sample to 77±2º F. Use appropriate state or national standards to split the sample into three individual 1000 gram and one 2000 gram samples.

Important: Steps 4 through 10 should be completed within 2 minutes. Increased test time without the lid on the volumeter will affect the accurate determination of absorption during this process.

3. Weigh 1000±2 grams of the oven dry material and record weight in column A of the worksheet.
4. Fill the volumeter halfway with 77±2º F water.
5. Slowly and evenly distribute the sample into the volumeter. Make sure the water completely covers the aggregate.
6. Using the aluminum spatula gently move the aggregate sample around to ensure that there is no trapped air between the particles.
7. Fill the volumeter with water to the top and spray with rubbing alcohol to remove air bubbles.
8. Place the lid on the volumeter and press gently so that water flows smoothly from the post and the sides. Continue to press until the lid is properly seated. Rotate the lid on top of the volumeter making sure good contact is achieved and the 1/8" hole is facing forward.
9. Using the syringe, slowly fill the volumeter through the large center hole on top of the lid. Make sure the syringe tip is far enough in the volumeter to be below the water level. Gentle application in this step will prevent formation of air bubbles inside the volumeter.
10. Wipe the excess water from the volumeter with a towel. Place the volumeter on a towel to dry the bottom. Do not tilt or spill any of the water in the volumeter.
11. Obtain the total weight of the volumeter, aggregate, and water and record in column B of the worksheet.
12. Repeats Steps 3 to 10.
13. If the difference in weight in column B for the two samples tested is less than or equal to 2 grams, go to step 13.
14. Repeat steps 3 to 10, if the first two tests with the volumeter indicate weights that are more than 2 grams from each other.

15. Average the weights in column A and then average the weights in column B of the worksheet and use this average when entering numbers in AggSpec software.
16. Set unit to run on Program 1 (all settings of Program 1 are preset at the factory). Note: The CoreLok unit is setup at the factory to run this and other tests. Simply run program 1. For varying the settings use the Menu key and the Up or Down arrows.
17. Place the three white filler blocks into the CoreLok chamber. The plates fit in the chamber without touching the sealing bar assembly. If they appear too close to the seal bar or are above the seal bar, rotate them 90º.
18. Tear one large bag and one small off bag rolls. Inspect each bag for holes and tears.
19. Weigh the bags (one large and one small). Record the total weight in column C.
20. Weigh the two rubber sheets and record the weight in column D.
21. Weigh approximately 2000±2 grams of aggregate and record in column E.
22. Place the sample in the small bag. When filling, support the bottom of the bag on a tabletop to protect against puncture and impact points.
23. Place the large bag into the CoreLok chamber, then place one of the rubber sheets in the large bag. The rubber sheet should be flat, centered, and pushed all the way to the back of the large external bag.
24. Place the bag containing the sample into the large external bag centered on top of the rubber sheet.
25. Use your hand and spread and flatten the sample in the internal small bag. Be sure area taken up by the sample inside the small bag remains completely contained within the area of the rubber sheet.
26. Place the other rubber sheet on top of the small internal bag inside the large external bag.

Note: The internal bag should be completely sandwiched between the two rubber sheets. The rubber sheets are cut to a size so as to not cover the opening of the small bag. If the rubber sheets cover the small bag opening this will restrict the airflow from the bag causing error in the readings.

27. Place the open end of the large external bag over the seal bar and close the chamber door.
28. After the chamber door opens, gently remove the sample from the chamber.
29. Immediately place the sample in the water, for water displacement analysis.
30. Cut one corner of the bag, approximately 3 to 4 inch from the side. Make sure the bag is completely submerged before cutting. Introducing air into the bag will produce inaccurate results.
31. Open the cut portion of the large bag and the uncut small bag with your fingers and hold open for 25 seconds. Allow the water to freely flow into the bag. Allow any small residual air bubbles to escape from the bag.
32. After water has filled in, cut the other corner of the bag approximately 3-4 inches. Squeeze any residual air bubbles out of the cut corners by running your fingers across the top of the bag.

33. Place the bags containing the rubber sheets and the aggregate on the provided weighing basket under water. You may fold the bag to place it on the basket. However, once on the basket under water, unfold the bag and allow water to freely flow into the bag.

Caution: Make certain the bag or the sample are not touching the bottom, the sides, or floating out of the water tank. If the bag contacts the sides it can negatively impact the results of this test.

34. Allow the sample to stay in the water bath for twenty (20) minutes.
35. Record the submerged weight and wait one minute. If after this time the weight increases by more than one-gram wait an additional five minutes. Record the weight and continue this process until the weight stabilizes.

Note: In our experience most aggregates are fully saturated after 20 minutes. However, we have seen some aggregates with more than 8% absorption that requires longer soak times.

36. If your aggregate size is such that more than 2000 grams need to be tested, repeat steps 3-28. Average the results of the tests for the total aggregate amount required by ASTM C127 and AASHTO T-85.

Note: AggPlus tests should only be done with 2000 g or less samples.

37. Open the Gravity Suite program and select AggSpec.
38. Enter the average weight on the container with water only above the chart.
39. Enter sample identification. Tab over and select “coarse” aggregate.
40. Fill in columns 3 and 4 with the average weight (2 or 3 test) from column A and B of the worksheet.
41. In column 5 the combined weight of the rubber sheets is entered. The **first time** you try to enter this weight, a window will appear saying you must enter a value for “rubber sheet VC”. This value is the density of the rubber sheets and is written on the sheets (gm/cm^3). Select OK. Click on ‘EDIT’ and then select ‘SETTINGS’. You now must enter a password – the password is **density**. In the next window, enter the numerical value from the rubber sheets and click OK. **Tab back to the rubber sheet weight column and enter the combined weight of the sheets.** The ‘Rubber Sheet VC’ will display above the chart and will not need to be re-entered for future tests unless the rubber sheets are replaced or damaged. As a precaution, record the rubber sheet density value in this manual in case it wears off the rubber sheets.
42. Continue by entering the weights from the worksheet and the sealed sample weight. The program will calculate the apparent density, percent absorption, Bulk Specific Gravity (SSD) and Bulk Specific Gravity (Bsg).
43. You may export the data into an Excel spreadsheet template and print the data as well as other functions provided under the excel program. Simply click on

"Export to Excel" and the AggSpec program will automatically pull the data into Excel.

44. If your absorption is zero, there might be two problems. First, the results (apparent gravity) of your vacuum test in the bag is low. There might have been a puncture in the bag. Repeat the test in the bag under vacuum with another 1000-gram sample. Second, you are possibly spending more than 2 minutes performing the tests in the volumeter or the temperatures during the test (of water, sample or volumeter) is changing drastically during the test. Increased test time during the volumeter test will cause the weights in column B to be higher than the actual values. Repeat this test with another 500-gram sample paying special attention to time and temperature (sample, water and volumeter).

APPENDIX C – SSDetect PROCEDURES (14)

Pump Priming Procedure

Your SSDetect utilizes a methodology that requires the use of distilled water. This water can be purchased locally.

This procedure must be followed after the reservoir has been filled and prior to operating the unit. Before priming the pump, the reservoir should be filled with distilled water.

1. Place a small beaker or container under the injection tubing.
2. Close lid and turn power on. When the screen is activated and displays "Barnstead/Thermolyne SSDetect", immediately touch screen anywhere to enter into advanced functions.
3. "Manual Controls" will be displayed.
4. Press LEFT ARROW until "Prime Pump" is displayed.
5. Press ENTER.
6. Press START to begin priming pump.
7. Prime pump until water starts exiting through the injection tubing and bubbles are no longer preset in the injection tubing. (This will insure that all air has been removed from the injection tubing). Allow approximately two minutes for this process.
8. Press STOP to end pump priming or the unit will self time out in approximately 10 minutes.
9. If the pump will not prime, it is sometimes necessary to bleed the water supply feed line into the pump. Return to step 6 to begin the pump priming again.
10. Turn unit off and wait 5 seconds before restoring power. The unit will be in a normal operation mode when the power is turned back on.

Pump Calibration Procedure

1. The calibration process needs to be performed upon initial startup. Pump calibration should be verified on a monthly basis after the initial calibration.
2. Fill the water reservoir to the bottom of the rubber gasket and attach the cover.
3. Turn on the power switch on the rear of the unit.
4. When Barnstead/Thermolyne is displayed, immediately press the center of the screen to go to the Manual Controls screen.
5. Press right arrow key to advance to the Pump Calibration screen and press the enter key.
6. Place a clean, pre-weighed container capable of holding 50 ml of liquid under the nozzle in the lid to collect the water. Position the container so as to minimize splashing.
7. Press the start key to begin the water collection cycle. Pump will inject 3000 times.
8. At the end of the collection cycle, remove the container and place it on a scale to obtain the total weight. Subtract the empty container weight obtained in step 5 from this value and enter the resulting amount in grams, as directed on the touch screen,

using the up and down arrow keys. Press the exit key to end the routine. Pump calibration is now complete.

Unit Calibration Procedure

1. Unit should be powered on and allowed to warm up for the displayed 30 minute warm up period.
2. Remove the injection muzzle from the water tubing. Screw the nozzle into the lid containing the sapphire lenses. Take care NOT to cross thread the nozzle in the lid.
3. Screw the water tubing back onto the injection nozzle.
4. Turn unit off and wait for several seconds. Turn unit back on and press on the center of the screen when Barnstead Termolyne SSDetect is shown. Unit will enter into manual controls mode.
5. Press the left arrow on the display screen until "Unit Calibration" is displayed. Press enter.
6. The screen will display "Unit Calibration, press skip to enter value manually". Press skip to OBSERVE the value currently entered into the system. Make certain there is a value entered. The value should be approximately .140-.200. If no value is entered, manually enter a value of .177.
7. Press "exit" to leave this screen.
8. Press OK to revert back to the Unit Calibration screen. Press Enter to being unit calibration.
9. The screen will now display "Press skip or start". Press the Start button.
10. The screen will now display "Insert aggregate for unit calibration". Mount the test bowl onto the mixing platform of the SSDetect by centering the bowl on the platform with the square protrusion on the side of the bowl. Push down slightly 9on the "D" ring in the center of the bowl and turn ¼ clockwise to latch bowl to platform.
11. Using the calibration sand that was included with the SSDetect, measure 500 grams of this material and place in test bowl. Place lid on bowl securely.
12. Close SSDetect chamber door and latch. Press Start to begin calibration test. This test should take approximately 40 minutes to complete.
13. Unit will beep when calibration test is complete. Press OK to end.
14. Refill water reservoir after unit calibration test.

This procedure is automatic and the unit will store the calibration data upon completion. The unit calibration procedure should be performed monthly.

Theory of Operation

The Barnstead Thermolyne SSDetect System is a two-part automated system for developing the data necessary to determine the Bulk Specific Gravity and absorption of fine aggregates. This system is based on a dry to wet method unlike the traditional wet to dry method.

1. Begin by acquiring two samples of the material to be tested. Each sample should be 500 grams +/- .1 gram and should be completely dried.

2. The first sample is placed in the volumetric flask included with the system. The material is poured in and weighed after 250 mL of water have already been placed in the flask.
3. Wait 5 minutes, fill to calibration line and weigh. Record this weight.
4. Place the flask on the mixing platform of the Automated Vacuum Mixer and insert stopper with vacuum hose. Press start. The unit will begin to mix and vacuum, at different levels of vacuum, for 11 minutes and stop.
5. Refill the flask to calibration line and weigh. This is the Apparent Specific Gravity weight. Subtract the initial weight of the flask from the final weight.
6. Apply the difference to the following mathematical formula: $52+(4*X)-(0.11*X*X)$ using the difference in flask weights as "X". The number developed from this formula will be used as a "Film Coefficient" that will be input into the SSDetect device.
7. While the AVM is running, place the other 500 gram sample into the test bowl for the SSDetect.
8. Weigh the bowl and material as a total and record the weight.
9. Mount the bowl onto the mixing platform inside the SSDetect. Place the lid on the bowl, close the door of the SSDetect and enter the "Film Coefficient" into the display screen when ready. Press Start.
10. The SSDetect will begin to mix the material inside the bowl by using an orbital motion. While material is flowing in a counter clockwise direction in the bowl, the SSDetect will begin to inject water into the flow of material 8 ul per injection. This is a very small stream of water. While the water injection is occurring, an infrared source of a specific wavelength that is absorbed by water or "tuned to water", is looking at the surface of the aggregate for signs of water.

The water being injected into the river of material flowing in the bowl is being absorbed into the pores of the aggregate through capillary action and hysteresis. These forces act very strongly to pull water into the aggregate pores quickly. Once the pores have filled and water begins to gather on the surface of the aggregate, the infrared signal detects the water and is absorbed. This means that the infrared detection device on the system will no longer see the reflection of the infrared signal as it is being absorbed by the water.

Once the SSD condition has been recognized by the system, the unit will automatically stop and signal the user that the test has ended. The bowl can then be removed from the system and weighed. This value is the weight of the material at SSD.

You have now determined all of the values necessary to determine Apparent Specific Gravity, Bulk, Specific Gravity Dry and Bulk Specific Gravity at SSD. These can all be determined in 90 minutes or less.

The use of infrared energy or a light source to detect very small traces of particular elements is a science that has been available for many, many years. Barnstead International manufactures a full line of Fluorometers and Spectrophotometers, so we are quite experienced with this type of equipment and its applications. This type of technology is used today in many applications to repeatedly detect certain elements down to parts per million.