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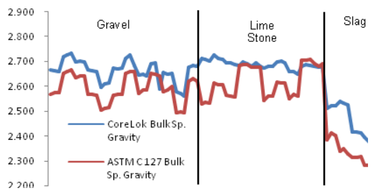
AUTOMATED LABORATORY TESTING METHODS FOR SPECIFIC GRAVITY AND ABSORPTION VERIFIED TO MATCH THE CURRENT METHOD RESULTS



FINAL REPORT

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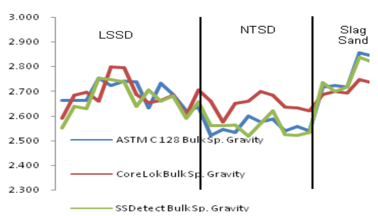
State Job No. 134302
June 2009

Prepared in cooperation with
The Ohio Department of Transportation and
The U.S. Department of Transportation
Federal Highway Administration



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1. Report No. **FHWA/OH-2009/3**	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and subtitle **Automated Laboratory Testing Methods for Specific Gravity and Absorption: Verified to Match the Current Test Methods**		5. Report Date **June 2009** 6. Performing Organization Code
7. Author(s) **Arudi Rajagopal, PhD**		8. Performing Organization Report No. 10. Work Unit No. (TRAIS)
9. Performing Organization Name and Address **Infrastructure Management & Engineering, Inc.** **2300 East Kemper Road, Suite A-17** **Cincinnati OH 45241-6501**		11. Contract or Grant No. **134302** 13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address **Ohio Department of Transportation, 1980, West Broad Street** **Columbus, OH 43223**		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract:

Twenty six coarse aggregate (12 gravel, 10 lime stone, 4 slag) and nine fine aggregate (4 lime stone, 3 natural sand, 2 slag sand) materials were collected from various sources in Ohio. Specific gravity and water absorption of the coarse aggregate samples were determined using CoreLok and ASTM C 127 procedures while testing of fine aggregate samples involved CoreLok, SSDetect and ASTM C 128 procedures. All the tests were performed in a single laboratory and by the same technician. The primary intent of the study was to investigate the ability of CoreLok and SSDetect to obtain faster results while, at the same time, improving the accuracy of results. The results led to the following conclusions:

- Coarse Aggregates: CoreLok bulk specific gravity (G_{sb}) values are up to 8% higher than the ASTM C127 G_{sb} values. The difference between the corresponding apparent specific gravity (G_{sa}) values vary from 0 to 12%. The CoreLok absorption values are 1 to 81% lower except for two slag samples. These differences are statistically significant at 95% confidence interval.
- Fine Aggregates: The SSDetect G_{sb} results closely follow the ASTM C 128 values. CoreLok G_{sb} values are moderately higher than ASTM and SSDetect for natural sand, but lower for slag. G_{sa} results of all the three test procedures follow each other closely. These differences are not statistically significant. The difference in absorption values between CoreLok and ASTM C 128 procedure ranges from 1.5% to 243.7%. In case of SSDetect vs. ASTM, this difference is 0.9% to 124.2%.
- An in-depth absorption study of coarse aggregates using CoreLok highlighted some inconsistencies in the procedure.

The principal recommendation of the study for the Ohio Department of Transportation is to continue specific gravity and absorption tests of coarse and fine aggregates using the traditional ASTM procedures.

17. Key Words CoreLok, SSDetect, Specific Gravity, Absorption, Coarse aggregates, Fine aggregates,		18. Distribution Statement **No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161**	
19. Security Classif. (of this report) **Unclassified**	20. Security Classif. (of this page) **Unclassified**	21. No. of Pages **84**	22. Price

Form DOT F 1700.7 (8-72) **Reproduction of completed pages authorized**

ACKNOWLEDGMENTS

The investigators wish to convey their appreciation to Mr. Lloyd Welker of the Ohio Department of Transportation for his contributions throughout the life of this project. Special thanks are due Mr. Jeff Wigdahl for his valuable suggestions. The cooperation extended by the Office of Research and Development is duly acknowledged. Mr. Matt Hyden conducted laboratory tests. Mr. Scott Snyder, Mr. Dan Crago and many others of Valley Asphalt Corporation provided valuable support. Dr. C. Keshava helped in data interpretation. Thanks are also due to Instrotek and Thermolyne for reviewing the data and responding to our queries.

DISCLAIMER

The contents of this report reflect the views of the authors who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Ohio Department of Transportation or the federal Highway Administration. This report does not constitute a standard, specification or regulation.

The Ohio Department of Transportation
Office of Research & Development
Executive Summary Report

AUTOMATED LABORATORY TESTING METHODS FOR SPECIFIC GRAVITY AND ABSORPTION: VERIFIED TO MATCH THE CURRENT METHODS

Start Date: 7/1/2006

Duration:

Completion Date: 1/1/2009

Report Date: June 2009

State Job Number: 134302

Report Number: FHWA/OH-2009/3

Funding:

Principal Investigators:
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For copies of this final report go to *http://www.dot.state.oh.us/divplan/research* *or call 614-644-8173*

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Problem Statement

In recent years, a number of agencies are exploring automated laboratory testing methods for the measurement of specific gravity and absorption of aggregates. The primary intent of such efforts is to obtain faster results while, at the same time, improving the accuracy of results. Two automated devices that are commercially available are the InstroTek CoreLok and Thermolyne SSDetect. CoreLok is a vacuum sealing device. Unlike the traditional ASTM procedure, the CoreLok method bypasses the saturated surface dry (SSD) weight measurement on its way to determine the specific gravity and absorption of coarse and fine aggregates. The SSDetect system uses infrared light to trace surface water on fine aggregate particles. While the CoreLok device has been designed to bypass the SSD condition, the purpose of SSDetect device is to produce SSD sample using an objective procedure. This report outlines an experimental plan to review the CoreLok and SSDetect devices for their potential use in Ohio.

Objectives

Conduct a comparative evaluation of the CoreLok, SSDetect and ASTM test procedures in determining the specific gravity and absorption values of representative coarse and fine aggregates sources in Ohio.

Methodology

Twenty six coarse aggregate (12 gravel, 10 lime stone, 4 slag) and nine fine aggregate (4 lime stone, 3 natural sand, 2 slag sand) materials were collected from various sources in Ohio. Specific gravity and water absorption tests were conducted on three replicate samples from each source. The coarse aggregate samples were tested using the CoreLok and ASTM C 127 procedures.

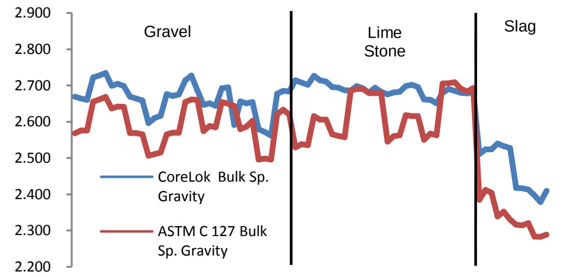
Fine aggregate samples were tested using the CoreLok, SSDetect and ASTM C 128 procedures.

Conclusions:

The results of statistical analysis led to the following conclusions:

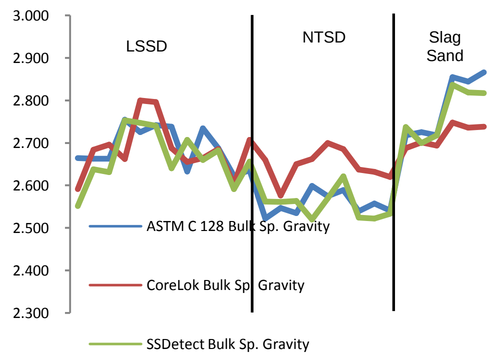
<u>Coarse aggregates:</u>

- The CoreLok G_{sb} values are 0 to 8% higher than the ASTM C 127 values. At 95% confidence interval, the difference between the test procedures is statistically significant.
- The difference between CoreLok and ASTM C 127 G_{sa} values vary from 0 to 12%; this difference is statistically significant at 95% confidence interval.
- The CoreLok absorption values are 1 to 81% lower except for two slag samples.



<u>Fine Aggregates:</u>

- The SSDetect G_{sb} results closely follow the ASTM C 128 values. CoreLok G_{sb} values are moderately higher than ASTM and SSDetect for natural sand, but lower for slag. These differences are not statistically significant.



- G_{sa} results of all the three test procedures follow each other closely.
- The difference in absorption values between CoreLok and ASTM C 128 procedure ranges from 1.5% to 243.7%. In case of SSDetect vs. ASTM, this difference is 0.9% to 124.2%.
- An in-depth absorption study of coarse aggregates using CoreLok highlighted some deficiencies in the procedure.

Implementation Potential:

The CoreLok and SSDetect devices are promising and user-friendly. In terms of the amount of time reduced in performing specific gravity and absorption tests, they are unequivocally satisfying. However, there are still inconsistencies that have to be addressed before these devices can be routinely used in Ohio.

AUTOMATED LABORATORY TESTING METHODS FOR SPECIFIC GRAVITY AND ABSORPTION: VERIFIED TO MATCH THE CURRENT METHODS

1. INTRODUCTION

1.1 Definition and Significance of Specific Gravity and Absorption

The specific gravity of an aggregate is defined as the ratio of the mass of a given volume of aggregate to the mass of an equal volume of water and is expressed as:

$$Specific\ Gravity = \frac{Weight}{(Volume\ x\ Unit\ Weight\ of\ Water)}$$

Absorption is defined as the increase in weight of aggregate particles due to water contained in the pores and is expressed as:

$$Absorption, \% = \frac{(Saturated\ Surface\ Dry\ Weight - Oven\ Dry\ Weight)x100}{Oven\ Dry\ Weight}$$

Saturated Surface Dry (SSD) relates to a condition of aggregate wherein its pores are completely filled (saturated) with water and the surface is free of moisture. Several definitions of specific gravity exist with the most commonly used being:

- *Apparent Specific Gravity*: The ratio of weight of dry aggregate to the weight of water having a volume equal to the solid volume of the aggregate excluding its permeable pores.

- *Bulk Specific Gravity*: The ratio of the weight of dry aggregate to the weight of water having a volume equal to the volume of the aggregate including both its permeable and impermeable pores.
- *Bulk Specific Gravity-Saturated Surface Dry (SSD)*: The ratio of the weight of the aggregate, including the weight of water it contains when its permeable voids are saturated, to the weight of an equal volume of water.

Specific gravity and absorption values are important for several reasons as follows:

1. *Presence of Deleterious Materials*: Foreign or deleterious materials present in aggregate particles are often lighter than the good aggregate and make them unsuitable for paving mixtures. Specific gravity values can be used to separate the bad aggregate particles from the good ones.
2. *Hot Mix Asphalt (HMA) Mix Design*: The specific gravity values of aggregates are required for the computation of volumetric properties such as air voids, voids in mineral aggregates, voids filled with asphalt, and percent maximum density at a certain number of gyrations, which are used to evaluate the acceptability of mixes. The mix design calculations are highly sensitive to the specific gravity values of aggregates. If the specific gravity of aggregate used in HMA mix design calculations is higher than the actual value, the design procedure yields an asphalt mix having an excessive amount of asphalt, resulting in an uneconomical and unstable mix. On the other hand, if the specific gravity value used is lower than the actual value, then an amount of asphalt, lower than optimal asphalt content is obtained that can lead to the raveling of aggregate and early

failure. Absorption of aggregates indicates its ability to absorb asphalt. A highly absorptive aggregate is undesirable since it can affect the durability of asphalt mix.

3. *Portland Cement Concrete Applications*: The specific gravity of the aggregate is employed in calculating the percentage of voids and the solid volume of aggregates in computations of yield. The absorption is important in determining the net water-cement ratio in the concrete mix. Knowing the specific gravity of aggregates is also critical to the construction of water filtration systems, slope stabilization projects, railway bedding and many other applications [1]. In concrete mix design methods, aggregate at SSD condition will neither contribute to or remove mix water from fresh concrete. Thus, bulk specific gravity at SSD is very important in correcting the amount of water in concrete mixes to account for aggregate moisture conditions.

Equipment and procedures for determining the specific gravity and absorption of coarse aggregates are described in AASHTO T85 and ASTM C127, while the equipment and procedures for fine aggregates are described in AASHTO T84 and ASTM C128. Here, the coarse aggregate is a graded aggregate made up of particles that are retained on No.4 sieve; fine aggregate is a graded aggregate and consists of particles that almost entirely pass a No.4 sieve [2].

1.2 Extent of Specific Gravity and Absorption Testing in Ohio

In Ohio, the Aggregate Section [3] of the Office of Materials Management (OMM) at the Ohio Department of Transportation (ODOT) is responsible to provide technical support to the district and county officials as well as the paving contractors in developing tests required for the design of Portland cement concrete, Hot Mix Asphalt (HMA), and special aggregate bases. Each year, the Aggregate Section conducts specific gravity test on aggregate samples from various approved locations in Ohio and prepares a comprehensive 'Specific Gravity List' which will be accessible to the paving contractors. The list contains Bulk Specific Gravity, Saturated Surface Dry Gravity and Absorption values to be used by the paving contractors in their mix design. Table 1 illustrates an example of the information provided in ODOT's Specific Gravity List for each location.

Table 1. An Illustration of ODOT's Specific Gravity List

2004 ODOT - Specific Gravity List							
Producer/Supplier# 4385, Alleghany Minerals							
Location	Revised Date	District	Material Type	Size	Bulk Dry Specific Gravity	SSD Specific Gravity	Absorption
Harrisville	1/1/04	4	Lime Stone	57	2.697	2.704	0.26
Harrisville	1/1/04	4	Lime Stone	67	2.700	2.708	0.27
Harrisville	1/1/04	4	Lime Stone	8	2.684	2.684	0.31

Prior to conducting mix designs, the Ohio contractors always conduct specific gravity and absorption tests on representative aggregate samples obtained from one of the approved locations and compare the results with the values listed in ODOT's Specific Gravity List. The goal of this process is to ensure the difference in specific gravity test results are within ±0.5%.

Owing to these practices, it is estimated that ODOT technicians conduct at least 1,500 specific gravity and absorption tests each year. An equal or even greater number of tests are conducted by the paving contractors during each construction season. Given the fact that it takes approximately 30 to 60minutes to complete one test, excluding the 24-hour soaking period, it is seen that an enormous amount of time is expended by the technicians at ODOT test lab and at the contractor's lab to conduct specific gravity and absorption tests. Development of an alternate testing procedure which can reduce testing time can not only result in considerable amount of savings in technician time but it can optimize production and construction of facilities.

1.3 The Present Study

In the recent years, a number of agencies are exploring automated laboratory testing methods for the measurement of specific gravity and absorption of aggregates. The primary intent of such efforts is to obtain faster results while, at the same time, improving the accuracy of results. In its continuing efforts to improve material testing practices in Ohio, the OMM sought a comparative evaluation of the new automated methods and conventional test procedures to determine specific gravity and absorption of aggregate samples. The basic focus of this evaluation was on two issues:

- What type of automated methods and processes are in use or under investigation by other agencies?
- Do these new methods have potential applicability to Ohio's conditions?

This report outlines (i) a program of study to critically review the automated testing methods under investigation by other agencies, and (ii) an experimental plan to conduct laboratory studies on a range of aggregate samples that would result in evaluation of results from selected methods and conventional test procedures. The study includes varying materials for multiple tests to arrive at sound conclusions as to the device reliability, repeatability, precision and durability compared to conventional methods.

2. OBJECTIVES OF THE STUDY

The objectives of this study are as follows:

1. Conduct a review and evaluation of available automated laboratory testing methods that are in use and/or being investigated by other agencies,
2. Prepare physical samples and conduct specific gravity and absorption tests on a range of materials using current ASTM procedures,
3. Conduct specific gravity and absorption tests on physical samples using new automated methods,
4. Analyze the data, and
5. Prepare recommendations to ODOT on specification changes and equipment to purchase based on the capability, precision, and durability of the equipment evaluated.

3. BACKGROUND AND SIGNIFICANCE OF WORK

3.1 Current Test Procedures and Inherent Problems

Specific gravity indicates relative weight of aggregate particles in comparison to an equal amount of water. Specific gravity values can be used as a measure of strength and quality of aggregate. Accurate specific gravity measurements are important in the mix design and quality control for HMA, PCC and many other aggregate applications.

Determination of specific gravity and absorption of coarse aggregate is a relatively simple procedure and fairly consistent. The specific gravity is determined by the following three aggregate weights [1]:

A = Weight of oven dry sample of aggregate in air

B = Weight of saturated, surface dry sample in air. Usually the weight is measured after 24 hours of soaking in water followed by rolling the aggregate on a large, absorbent cloth until all visible films of surface water are removed

C = Weight of saturated sample in water

The specific gravity values are then calculated as follows:

$$Apparent\ Specific\ Gravity = \frac{A}{A-C}$$

$$Bulk\ Specific\ Gravity = \frac{A}{B-C}$$

$$Bulk\ Specific\ Gravity, SSD = \frac{B}{B-C}$$

Water absorption is calculated as:

$$Water\ Absorption, \% = \frac{(B-A)\ x\ 100}{A}$$

Determination of specific gravity of fine aggregate is relatively complex and inconsistent. A sample of fine aggregate is oven dried and then soaked in water overnight. Drying the saturated sample to SSD condition is critical. To determine SSD condition, the aggregate sample is filled in a conical mold and tamped 25 times. Upon removal of mold, if the sand cone retains its shape, it means some surface moisture is still present. Then the sample is dried, often using currents of warm air, and the mini-slump test is repeated until the aggregate slumps when the cone is removed. This relates to SSD condition. The volume of the sample is determined using a pycnometer. Specific gravity calculations however, follow a set of slightly different equations. It should be realized here that individual judgment is necessary to identify SSD condition of fine aggregates and this can cause variation in test results.

3.2 Consequences of Inaccuracies in Measurement of Specific Gravity

Experience suggests that the current procedure for the determination of specific gravity of fine aggregate often results in inconsistent results. This is particularly true in case of angular or rough fine aggregates and those with higher amounts of minus No. 200 sieve. During HMA mix design, inaccuracies in specific gravity values of fine aggregates can cause inaccuracies in the calculated Voids in Mineral Aggregate, and thus affect mix design calculations. In PCC applications, such inaccuracies can affect design mixture volume and concrete batch yield. Also, gravimetric air contents calculated from concrete unit weight tests could be inaccurate. On the other hand, coarse aggregate specific gravity measurements are considered relatively consistent. However, if a significant portion of the fractions lie between 3/8” and No. 4 sieves, inconsistencies in SSD measurements are likely to occur.

In view of these inconsistencies, user agencies are looking for test procedures that will result in consistent test results and reduce testing time as well.

3.3 Automated Test Methods

In the recent times, several studies have been initiated to develop automated test methods for the measurement of specific gravity and absorption of aggregates. These studies may fall into two groups namely,

- Studies directed toward development of new,
- Studies to evaluate feasibility of commercial equipment.

3.3.1 <u>Development of New Equipment</u>

The first study reported on the development of an automated method was conducted by Dana and Peters [4] of Arizona Department of Transportation. Their equipment consisted of a small drum and an air blower. Wet fine aggregate sample was placed in the drum which was rotated at a constant speed, while air was blown into one end of the drum. Thermocouples were installed to measure temperature of incoming and outgoing air. By continuously monitoring the temperatures and relative humidity, and by using principles of thermodynamics, they were able to detect when the aggregate sample reached SSD condition. The samples were then removed from the drum for further testing and determination of specific gravity. However, continued tests revealed greater variability in the specific gravity results.

In the 1990's, NCAT began investigating Arizona method with the intent to modify the equipment so as to produce more consistent results [5]. By changing the direction of air flow (from vertical to horizontal) and a few other modifications, the researchers partially succeeded in improving the results. However, the NCAT researchers concluded that more work is necessary to enhance repeatability and reproducibility of the test results.

3.3.2 Evaluation of Commercial Equipment

Two automated methods that are commercially available for determining the bulk specific gravity of aggregates are the Thermolyne SSDetect and InstroTek CoreLok.

The Thermolyne SSDetect [6] has been designed to directly measure SSD condition of fine aggregate and determine specific gravity and absorption values more consistently. The system uses infrared light to trace surface water on aggregate particles. CoreLok system [7] is capable of measuring specific gravity and absorption of both fine and coarse aggregates in about 30 minutes. This equipment uses vacuum to seal the aggregate in a plastic bag. By doing this, the CoreLok system essentially bypasses the SSD condition on its way to determine absorption and apparent specific gravity. Standard formulas are then used to calculate bulk specific gravity (dry and SSD).

A study in Arkansas reported evaluation of CoreLok device and comparing the results with the conventional procedure [8]. The study included six coarse aggregates and four fine aggregate samples. Ten blends, whose gradations generally met Superpave HMA specifications were created and tested. Five replicate tests were performed on each blend. The results displayed a strong correlation between the results of conventional procedure and the CoreLok system. The researchers concluded that while the vacuum seal procedure has shown great potential, some refinement is needed before it could replace the traditional methods.

The study at NCAT [9] compared specific gravity of fine aggregate obtained using CoreLok and SSDetect with conventional AASHTO T84 procedure. The evaluation was based on a round robin study with twelve labs and included six materials – four crushed fine and two uncrushed (natural) fine aggregate sources. The results were statistically analyzed and the authors concluded that the results of CoreLok and SSDetect systems are comparable to the conventional system. Cross et. al. [10] reported similar efforts on select fine aggregate samples in Oklahoma. They noted significant difference in bulk specific gravity values with the SSDetect device producing the highest bulk specific gravity values followed by CoreLok and ASTM T 84 procedures. However, the differences in apparent specific gravities were statistically insignificant.

A round robin study in Missouri [11] included tests on 11 aggregates by nine laboratories. Initial results showed considerable deviation from the tradition methods. However, based on certain correlations, the researchers concluded that the CoreLok is a viable method and recommended that the CoreLok method will be allowed in Missouri as an acceptable substitute for determining aggregate specific gravities.

Accurate specific gravity values for both fine and coarse aggregates are critical to mix design and quality control for HMA, PCC and many other aggregate applications. Although, the recently completed studies reveal that while commercially available devices have potential application in specific gravity and absorption tests, more research is needed to validate the repeatability, reliability, precision and durability of these devices. The present study is an attempt to further evaluate the ability of available equipment to accurately measure specific gravity and absorption of aggregates.

4. THE EXPERIMENT

An experiment was designed to systematically compare the specific gravities of a variety of coarse and fine aggregate samples through a series of well-controlled experiments. The coarse aggregate samples were tested using CoreLok and ASTM C 127 procedures while testing of fine aggregate samples involved CoreLok, SSDetect and ASTM C 128 procedures. All the tests were performed in a single laboratory and by the same technician.

CoreLok is a vacuum sealing device that can expedite the process of specific gravity and water absorption determination. Unlike the ASTM procedure which requires the measurement of SSD weight of materials, the CoreLok device bypasses the SSD weight measurement on its way to determine the specific gravity and water absorption. The procedure is automated and designed to produce consistent test results with no room for subjectivity or individual differences in technician experience or competence. The CoreLok device can be used for the determination of specific gravity and water absorption of both coarse and fine aggregates. The test procedure is user-friendly and can generate result in about 30 minutes.

The SSDetect device, on the other hand, can only work with fine aggregates. Briefly, the test procedure starts with a known amount of dry sample. The sample is placed in a plastic bowl inside the unit and keeps spinning throughout the duration of the test. A small amount of water is injected into the sample while it is spinning. The system emits near infrared rays devised to detect moisture. Initially when the aggregate sample is dry, the water injected is absorbed by the pores and the surface still remains dry. When this process continues, the sample reaches a state where the pores will be saturated with water and the sample cannot absorb any more water. At that time, the surface begins collecting moisture. Noting traces of moisture, the SSDetect system assumes that the sample has attained SSD condition and stops. The saturated sample thus obtained is removed from the system and further used for specific gravity determination. While the CoreLok device has been designed to bypass the SSD condition, the purpose of SSDetect device is to consistently produce SSD sample using an objective procedure.

5. TESTS ON COARSE AGGREGATES

5.1 Materials

A list of the coarse aggregate materials tested is given in Appendix 1 (Table 1-1). The coarse aggregate samples were collected from 26 sources in Ohio and included three aggregate types namely gravel (12 sources), lime stone (10 sources) and slag (4 sources). The size of aggregates confirmed to ODOT's No. 57 (25 mm and below) and No. 8 specifications (9.5 mm and below). All of the lime stone and slag aggregates were 100% crushed. Out of the 12 gravel aggregates, four samples were 100% crushed with four samples 40% crushed and the remaining four samples uncrushed. Water absorption of these aggregates varied from 0.45% to 3.6%. The gradation of the materials used in this study is given in Table 1-2 of Appendix 1.

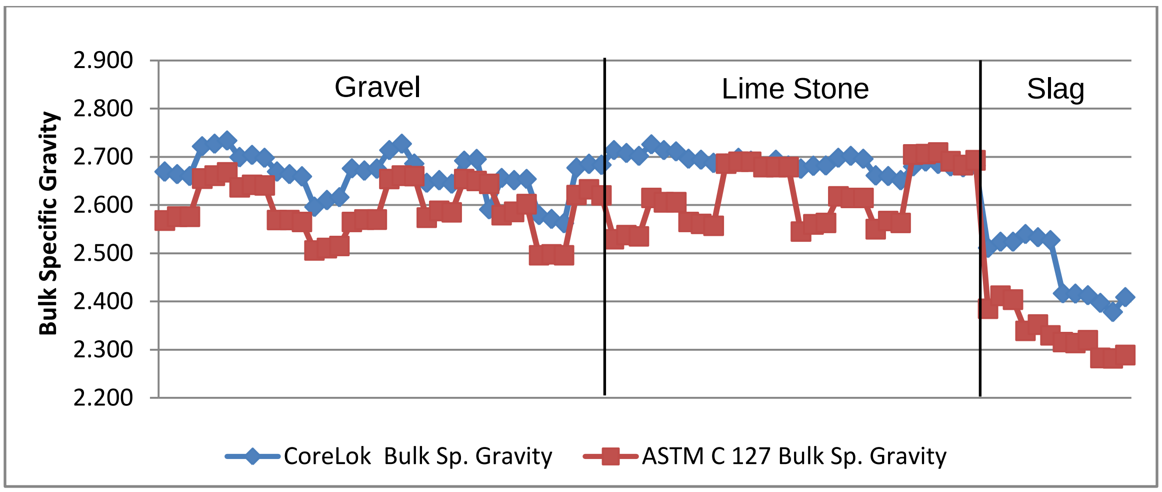
5.2 Comparative Evaluation of ASTM C 127 and CoreLok Test Procedures

Three tests were conducted on each of the 26 sources, amounting to 78 tests in all. These samples were tested for determining the specific gravity values and absorption using the ASTM C 127 and CoreLok test procedures. The following sections present the details of bulk specific gravity, apparent specific gravity and absorption test results.

5.2.1 Coarse Aggregate Bulk Specific Gravity (G_{sb}) Test Results

Results of G_{sb} are presented in Appendix 1, Table 1-3. A graphical illustration of the variation in G_{sb} values can be seen in Figure 1.

Figure 1. CoreLok vs. ASTM C 127 - Variation in G_{sb}



The ASTM G_{sb} values are in general lower than those obtained by the CoreLok device. The trend remains the same for all material types although the order of difference may have varied. Table 2 provides descriptive statistics. Such tables are presented in this report to illustrate the amount, range and dispersion of the data used in the analysis. The Coefficient of Variation (CV) presented in this table, also known as "relative variability", is calculated as the ratio of standard deviation and the mean and is expressed as a percentage. The CV is a useful statistic for comparing the degree of variation from one data series to another, even if the means are drastically different from each other. A high CV implies inconsistency among the samples within the group. Simply put, the lower the CV, better the data.

Table 2. Descriptive Statistics for Coarse Aggregate G_{sb} Values

	CoreLok G_{sb}	**ASTM C 127 G_{sb}**
Number of samples	78	78
Minimum value	2.378	2.282
Maximum value	2.734	2.709
Mean	2.643	2.564
Standard deviation	0.087	0.113
Coefficient of Variation, %	3.3	4.4

The difference between the two mean values is 0.079. The Missouri Department of Transportation [11] reported that variations as large as 0.100 represents approximately a 3% difference in the calculation of voids in the mineral aggregate. In order to determine if the differences in the test results are statistically significant, a statistical paired *t*-test was conducted. This test computes the difference between the average values of the two variables for each case and tests whether the values differ from zero. The hypothesis follows,

Null Hypothesis H_o: The difference between the average ASTM G_{sb} and the average CoreLok G_{sb} values = 0

Alternative Hypothesis H_a: The difference between the average ASTM G_{sb} and the average CoreLok G_{sb} values ≠ 0

To Test: Whether the difference in the results between the two test procedures is statistically significant or not at 95% Confidence Interval (CI)

The results of the t-test are shown in Table 3. The t-test returned a p-value of 0.000 at 95% confidence interval. Since the p-value is less than 0.05, the null hypothesis is rejected; meaning the difference in results between the two test procedures is statistically significant.

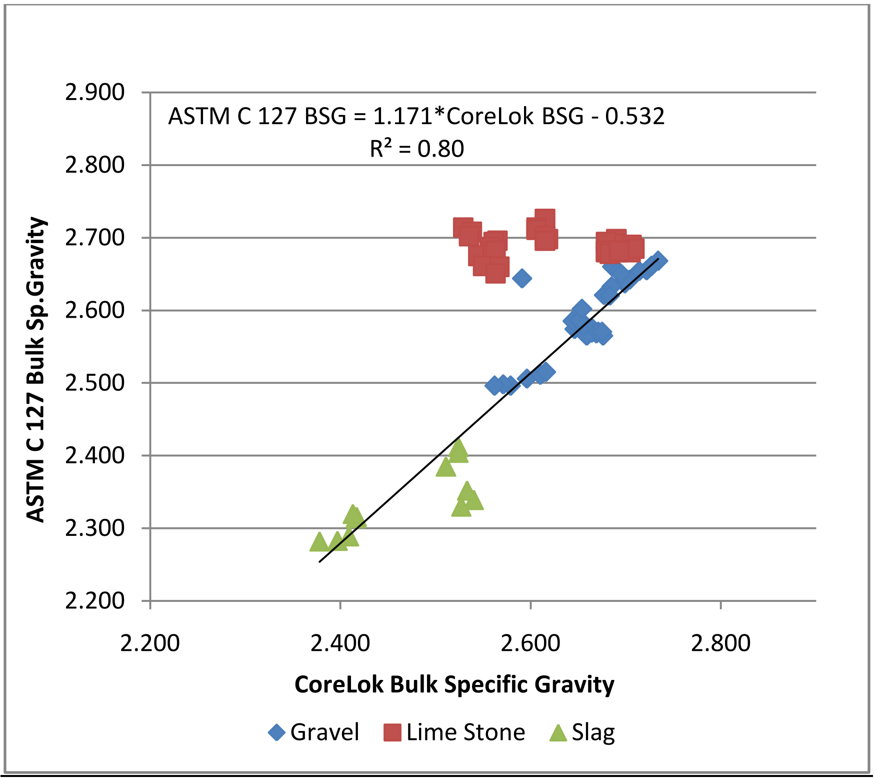
Table 3. Paired t-Test on G_{sb} Values of Coarse Aggregates

	CoreLok G_{sb}	**ASTM C 127 G_{sb}**
Number of Samples	78	78
Mean	2.643	2.564
Variance	0.008	0.013
p-value	0.000	
Is the difference statistically significant?	**Yes**	

A detailed analysis of the data was performed to determine if variables such as aggregate type (gravel, lime stone, slag), % crushed material (0, 40, 100%) and absorption levels (low, medium, high) have an influence on the results. In all the cases, the t-tests returned a p-value close to 0.000. The analysis suggested that regardless of the material type and their physical characteristics, difference between two test procedures do exist and that they are statistically significant.

Figure 2 shows a scatter plot of G_{sb} values determined from ASTM C 127 and CoreLok procedures. A regression analysis was performed to explore a relationship between the two test values. The linear regression model obtained is presented in Figure 2. The coefficient of determination R^2 is 0.8, indicating a very strong correlation between the G_{sb} values obtained from the two test procedures. The R^2 value indicates that approximately 80% of the variation is explained by the model. In other words, the model cannot account for 20% of the variation. Higher values of the coefficient serve as a justification for the existence of a linear relationship between the test procedures.

Figure 2. CoreLok vs. ASTM C 127 Scatter Plot of G_{sb} Values



It was apparent that higher R^2 can be achieved, if needed, by separating the data according to material type and performing regression analysis for each material type.

It is important to recognize that separating the data according to material type before hypothesis testing and regression will sometimes drastically reduce the sample size. In statistical analysis, small or inadequate sample size may be one of the reasons why a parameter estimate may be found not significant. In this study, many comparative analyses have been performed. Each analysis first considered all the data regardless of material type. When the R^2 value was found to be low to moderate, a detailed analysis for each material type has been performed with intent to evaluate the effect of material type.

5.2.2 Coarse Aggregate Apparent Specific Gravity (G_{sa}) Test Results

The G_{sa} values for all the samples are tabulated in Table 1-3 of Appendix 1. A graphic illustration can be seen in Figure 3. The differences between the two test procedures are smaller for gravel, a low absorptive material. When water absorption increases as in the case of lime stone and slag, the difference also increases. Table 4 shows the descriptive statistics and Table 5 presents details of the statistical analysis.

Figure 3. CoreLok vs. ASTM C 127 - Variation in G_{sa}

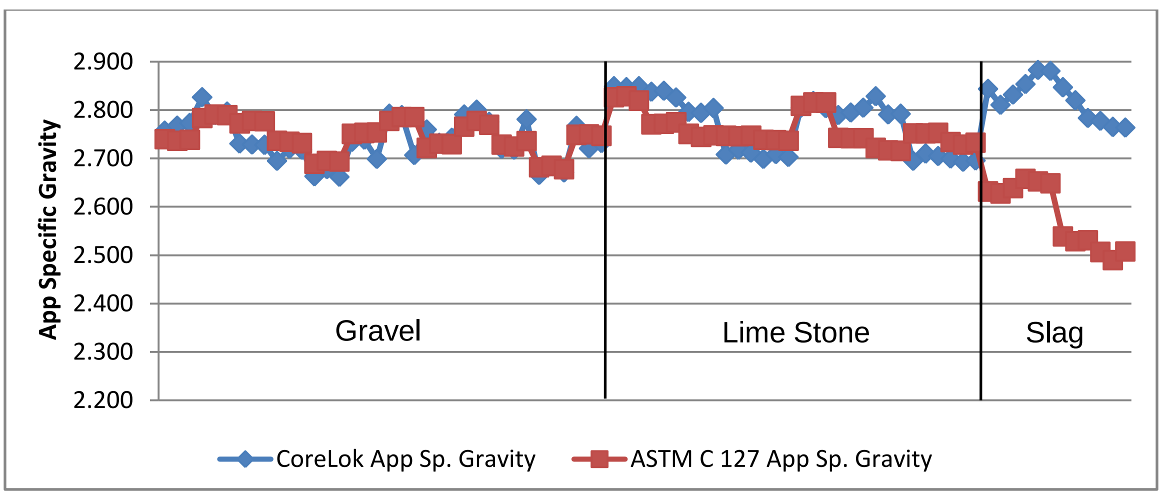


Table 4. Descriptive Statistics for Coarse Aggregate G_{sa} Values

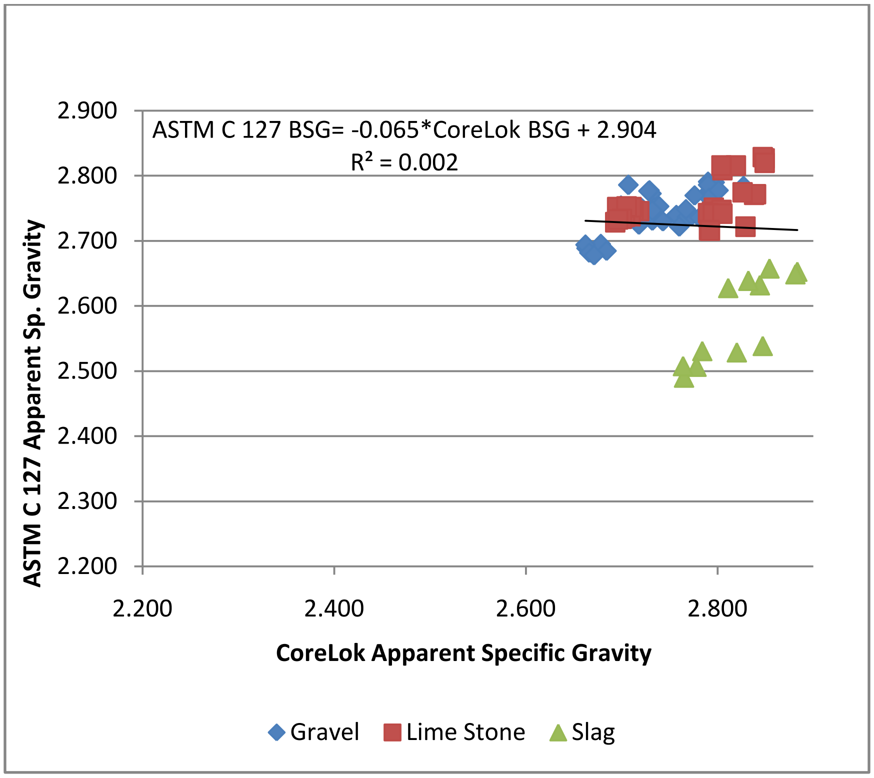
	CoreLok G_{sa}	ASTM C 127 G_{sa}
Number of samples	78	78
Minimum value	2.662	2.490
Maximum value	2.883	2.829
Mean	2.763	2.724
Standard deviation	0.057	0.073
Coefficient of Variation, %	2.1	2.7

Table 5. Paired *t*-Test on G_{sa} Values of Coarse Aggregates

	CoreLok	ASTM C 127
Number of Samples	78	78
Mean	2.763	2.724
Variance	0.003	0.005
p-value	0.000	
Is the difference statistically significant?	**Yes**	

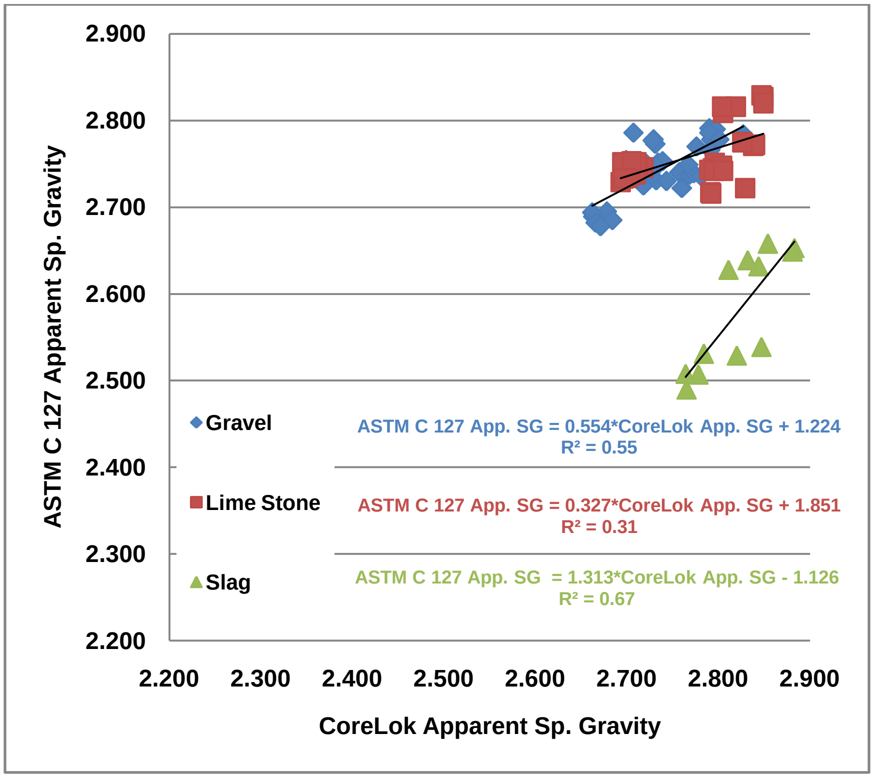
As in the case of G_{sb} values, the *p*-value is 0.000, which means the difference is statistically significant. The scatter plot (Figure 4) of G_{sa} values displays poor relationship between the two test procedures which is evident by a very low R^2 value.

Figure 4. CoreLok vs. ASTM C 127 - Scatter Plot of G_{sa} Values



The data was then grouped according to the material type and regression analysis was repeated. As it can be seen in Figure 5, there was a significant improvement in the R^2 values, with 0.31, 0.55 and 0.67 for Lime Stone, Gravel, and Slag respectively.

Figure 5. CoreLok vs. ASTM C 127 - Revised Scatter Plot of G_{sa} Values



5.3 Comparing Absorption Test Results from CoreLok and ASTM C 127 procedures

The results of absorption tests are tabulated in Appendix 1, Table 1-3. A graphic illustration is provided in Figure 6. The CoreLok absorption values are in general lower than the corresponding ASTM C 127 values except for two slag samples which exhibited considerably higher values. Table 6 shows the descriptive statistics and Table 7 presents details of the statistical analysis.

Figure 6. CoreLok vs. ASTM C 127 - Variation in Coarse Aggregate Absorption

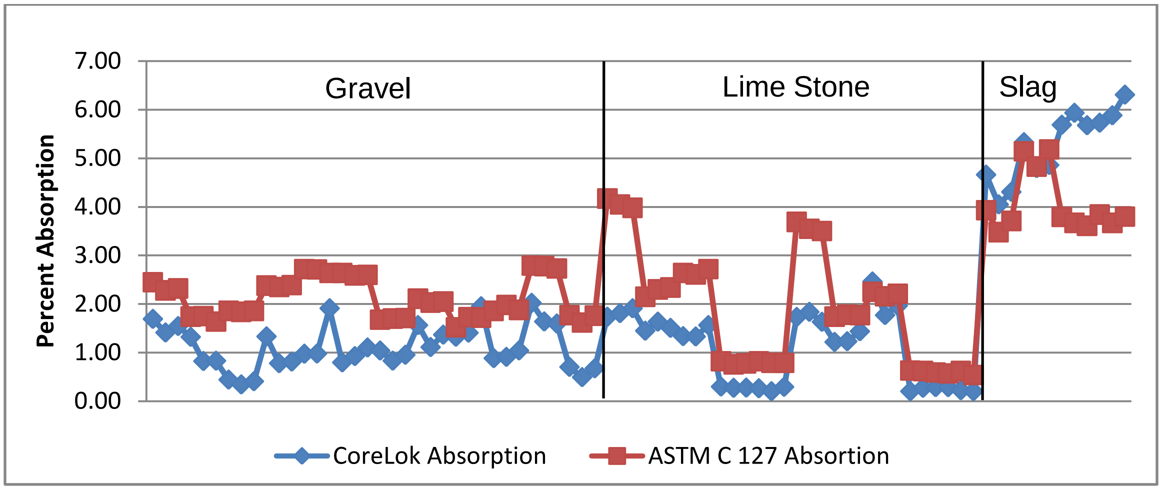


Table 6. Descriptive Statistics for Coarse Aggregate Absorption Values

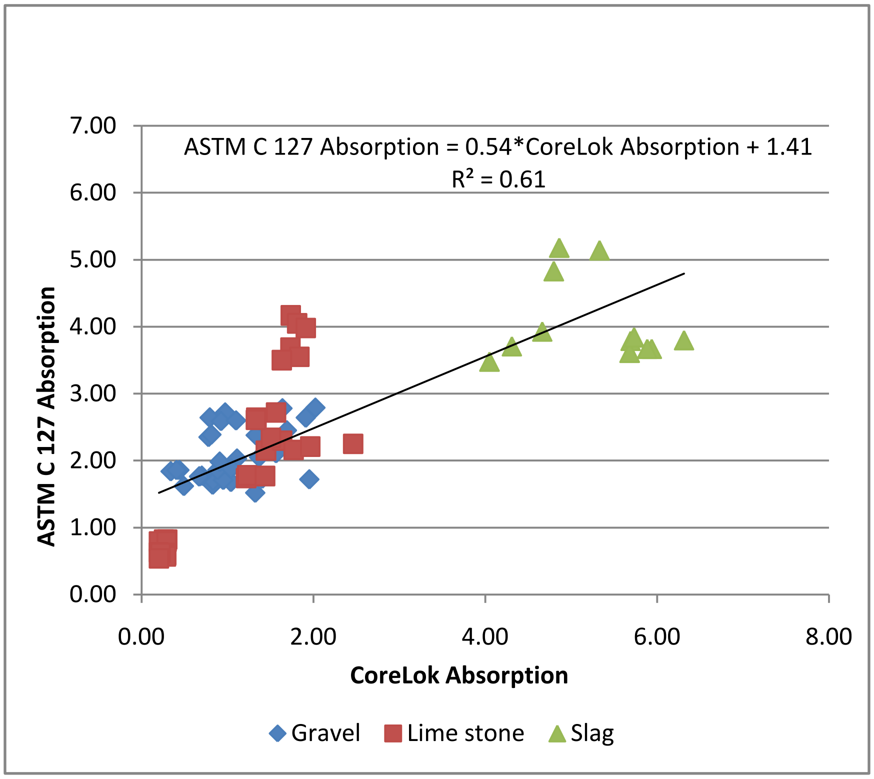
	CoreLok Absorption	ASTM C 127 Absorption
Number of samples	78	78
Minimum value	0.20	0.54
Maximum value	6.31	5.18
Mean	1.74	2.34
Standard deviation	1.63	1.11
Coefficient of Variation, %	93.7	47.4

Table 7. Paired *t*-Test on Coarse Aggregate Absorption Values

	CoreLok	**ASTM C 127**
Number of Samples	78	78
Mean	1.739	2.343
Variance	2.658	1.231
p-value	0.008	
Is the difference statistically significant?	**Yes**	

The CoreLok device uses a computational method to determine absorption of aggregates without having to dry the saturated aggregates. As a result, the absorption and specific gravity values can be obtained in a short time. The CoreLok absorption values are generally lower compared to ASTM C 127 values, except for highly porous and absorptive material like slag. The statistical analysis yielded a *p*-value of 0.008, indicating that the difference in absorption values is statistically significant at 95% confidence interval. The R^2, as seen in Figure 7, value of 0.61 represents good correlation between the absorption values from the two test procedures. It is interesting to note that while the coefficient of variation of CoreLok and ASTM specific gravities are extremely small (less than 5%), the corresponding values for absorption are very high - 93% and 43% for CoreLok and ASTM respectively. The variation in ASTM procedure may be expected because of the subjectivity in the SSD determination. However, the CoreLok procedure, which is supposed to be more objective, has produced more dispersed data. This fact has been further reviewed and presented in Chapter 7.

Figure 7. CoreLok vs. ASTM C 127 - Scatter Plot of Absorption Values



5.4 Repeatability of ASTM C 127 and CoreLok Test Procedures

To verify the repeatability of CoreLok test results, three materials were selected. Specific gravity and absorption tests were conducted on representative samples from each of the material using the CoreLok test procedure. The three samples were then dried and retested nine more times. Thus, a total of ten repetitive tests were conducted on the same physical sample. After completing the CoreLok tests, the same samples were tested using the ASTM C 127 procedure. The results for the G_{sb}, G_{sa}, and absorption values are presented in Figures 8, 9, 10, and 11.

Figure 8. Repeatability of CoreLok Bulk Specific Gravity

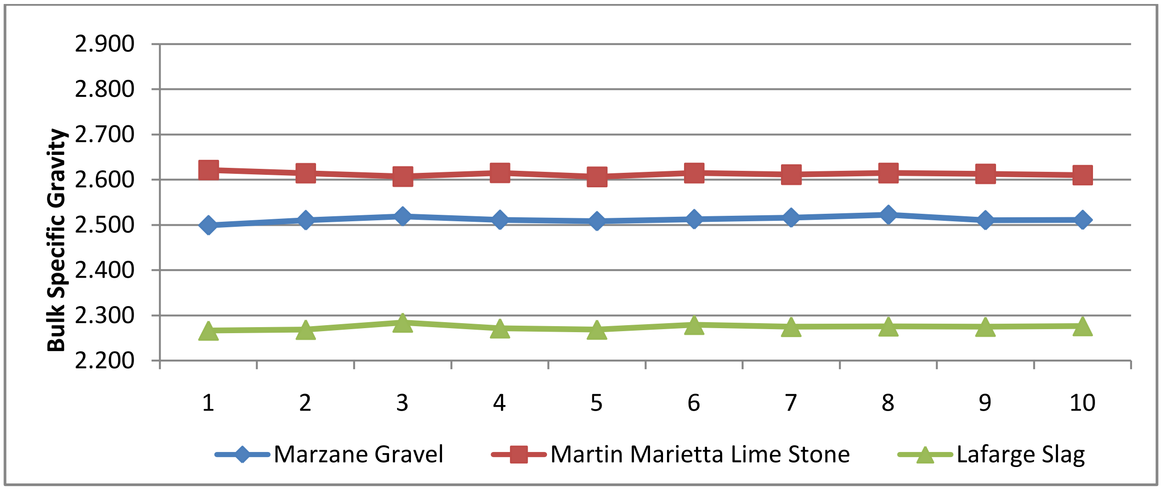


Figure 9. Repeatability of ASTM C 127 Bulk Specific Gravity

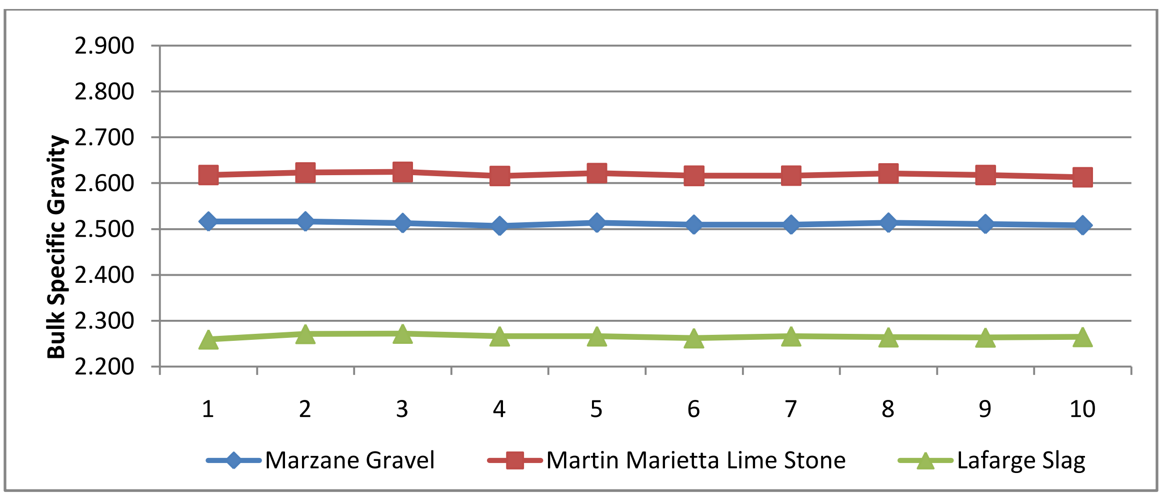


Figure 10. Repeatability of CoreLok Absorption

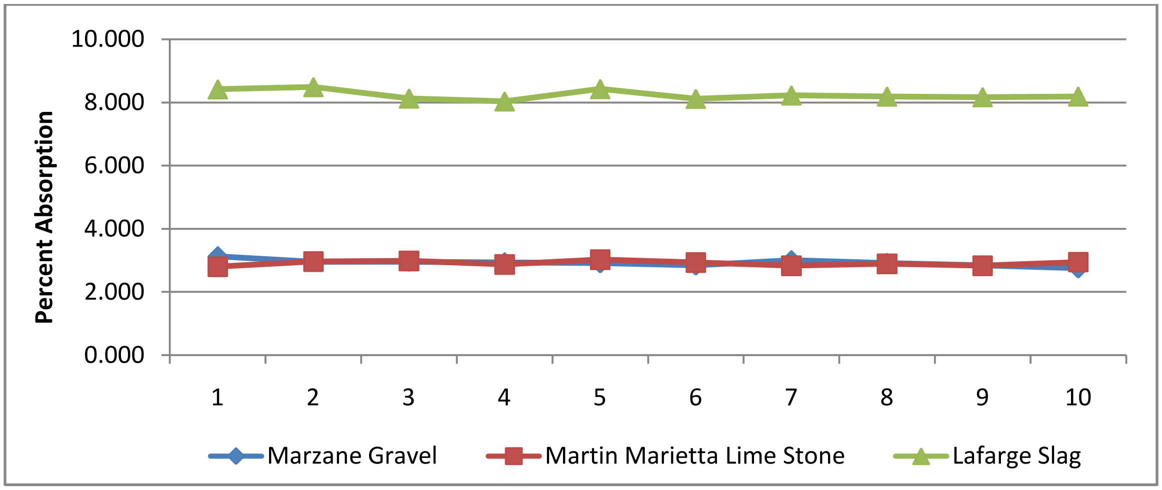
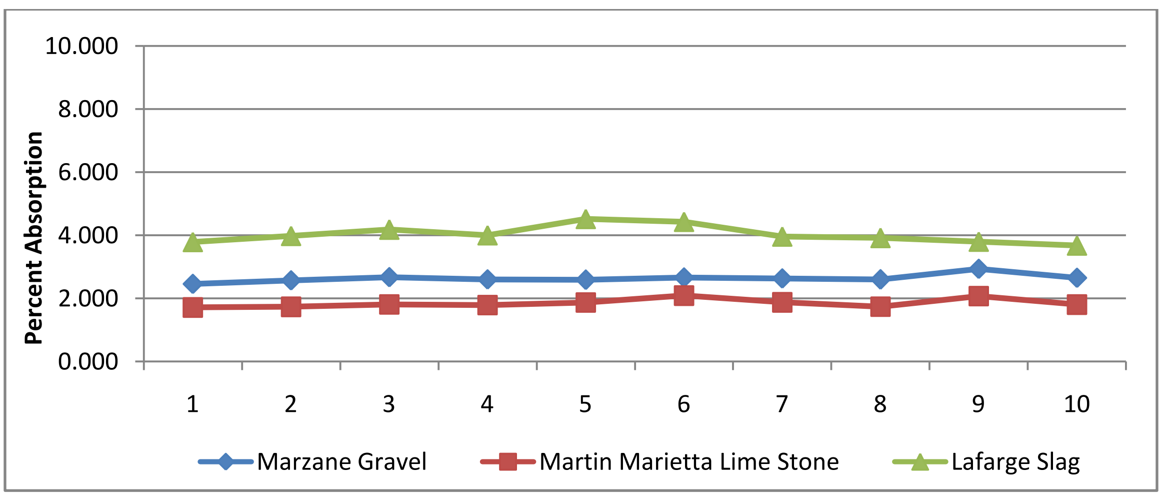


Figure 11. Repeatability of ASTM C 127 Absorption



One sample *t*-test was performed on both CoreLok and ASTM C 127 test procedures to determine the statistical significance of repeatability tests. At 95% confidence interval, the one sample *t*-test provides the upper and lower limits for the data range and tests whether the mean of a single variable differs from a specified constant. The results of the *t*-test are shown in Table 8.

Table 8. Statistical Verification for Repeatability of CoreLok and ASTM C 127 Tests

Specific Gravity	Test	Type of Material	Mean	Lower Limit	Upper Limit	Std. Dev.	*p*-value	Comments
Bulk Specific Gravity	CoreLok	Marzane Gravel	2.512	2.508	2.517	0.006	0.924	Repeatable
	ASTM C 127	Marzane Gravel	2.512	2.509	2.514	0.003	0.849	Repeatable
	CoreLok	Martin Marietta Lime Stone	2.613	2.610	2.616	0.005	1.000	Repeatable
	ASTM C 127	Martin Marietta Lime Stone	2.619	2.616	2.622	0.004	0.934	Repeatable
	CoreLok	Lafarge Slag	2.274	2.271	2.278	0.005	0.820	Repeatable
	ASTM C 127	Lafarge Slag	2.266	2.263	2.268	0.004	0.690	Repeatable
App. Specific Gravity	CoreLok	Marzane Gravel	2.712	2.705	2.718	0.009	0.857	Repeatable
	ASTM C 127	Marzane Gravel	2.690	2.685	2.696	0.008	0.909	Repeatable
	CoreLok	Martin Marietta Lime Stone	2.828	2.825	2.831	0.004	0.884	Repeatable
	ASTM C 127	Martin Marietta Lime Stone	2.752	2.745	2.759	0.010	0.924	Repeatable
	CoreLok	Lafarge Slag	2.799	2.793	2.805	0.008	0.971	Repeatable
	ASTM C 127	Lafarge Slag	2.514	2.479	2.549	0.049	1.000	Repeatable
Absorption	CoreLok	Marzane Gravel	2.926	2.852	3.000	0.103	0.933	Repeatable
	ASTM C 127	Marzane Gravel	2.640	2.554	2.727	0.121	0.994	Repeatable
	CoreLok	Martin Marietta Lime Stone	2.908	2.856	2.960	0.073	0.997	Repeatable
	ASTM C 127	Martin Marietta Lime Stone	1.853	1.757	1.949	0.134	1.000	Repeatable
	CoreLok	Lafarge Slag	8.242	8.133	8.351	0.152	0.995	Repeatable
	ASTM C 127	Lafarge Slag	4.028	3.832	4.225	0.274	0.997	Repeatable

The *p*-values in each case, from Table 8, are greater than 0.05, which means the difference within the test results is statistically not significant. Hence, both ASTM C 127 and CoreLok are deemed repeatable.

6. TESTS ON FINE AGGREGATES

6.1 Materials

A list of the fine aggregate materials tested is given in Table 2-1 of Appendix 2. The fine aggregate samples were collected from 9 sources in Ohio and included three aggregate types namely, Lime Stone Sand (LSSD, 4 sources), Natural Sand (NTSD, 3 sources) and Slag Sand (2 sources). Water absorption of these aggregates varied from 0.20% to 4.2%.

6.2 Comparative Evaluation of ASTM C 128, CoreLok, and SSDetect Test Procedures

Three tests were conducted on each of the 9 sources. The 27 samples, in all, were tested for determining the specific gravity values and absorption using the ASTM C 128, CoreLok, and SSDetect test procedures. The following sections present the results of bulk specific gravity, apparent specific gravity, and absorption tests.

6.2.1 Fine Aggregate Bulk Specific Gravity (G_{sb}) Test Results

Results of G_{sb} from ASTM C 128, CoreLok and SSDetect are tabulated in Table 2-2 of Appendix 2. Figure 12 depicts a graphical illustration of the variation in G_{sb} values.

Comparatively, the SSDetect G_{sb} values appear to follow ASTM C 128 values more closely. However, it is difficult to establish a definite pattern from this figure. The CoreLok G_{sb} values are higher than the ASTM and SSDetect values in approximately 50% cases. The maximum difference between the ASTM G_{sb} and CoreLok G_{sb} is 5.36%, while it is 4.24% with respect to SSDetect. Table 9 provides descriptive statistics. Values of coefficient of variation indicate consistent data from all the three test procedures.

Figure12. CoreLok vs. SSDetect vs. ASTM C 128 - Variation in G_{sb} Values

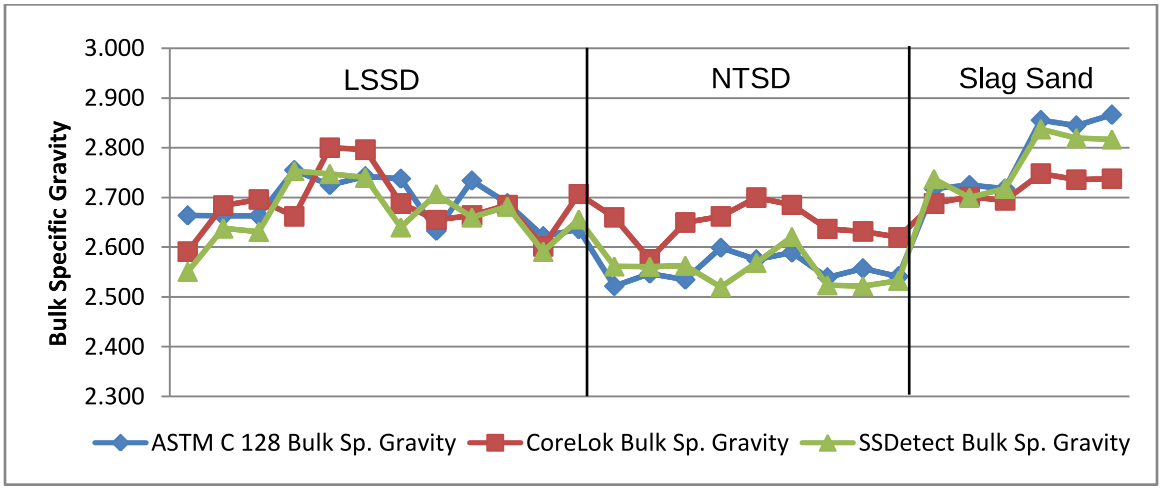


Table 9. Descriptive Statistics for Fine Aggregate G_{sb} Values

	CoreLok G_{sb}	**SSDetect G_{sb}**	**ASTM C 128 G_{sb}**
Number of samples	27	27	27
Minimum value	2.576	2.520	2.522
Maximum value	2.800	2.837	2.866
Mean	2.680	2.652	2.666
Standard deviation	0.054	0.097	0.100
Coefficient of Variation, %	2.0	3.7	3.8

6.2.1.1 Fine Aggregate G_{sb} Test Results – CoreLok vs. ASTM C 128

The results of the statistical *t*-test between CoreLok and ASTM C 128 are shown in Table 10. The *t*-test returned a *p*-value of 0.542 at 95% confidence interval. Since the *p*-value is greater than 0.05, it can be concluded that the difference in results between the two test procedures is statistically not significant.

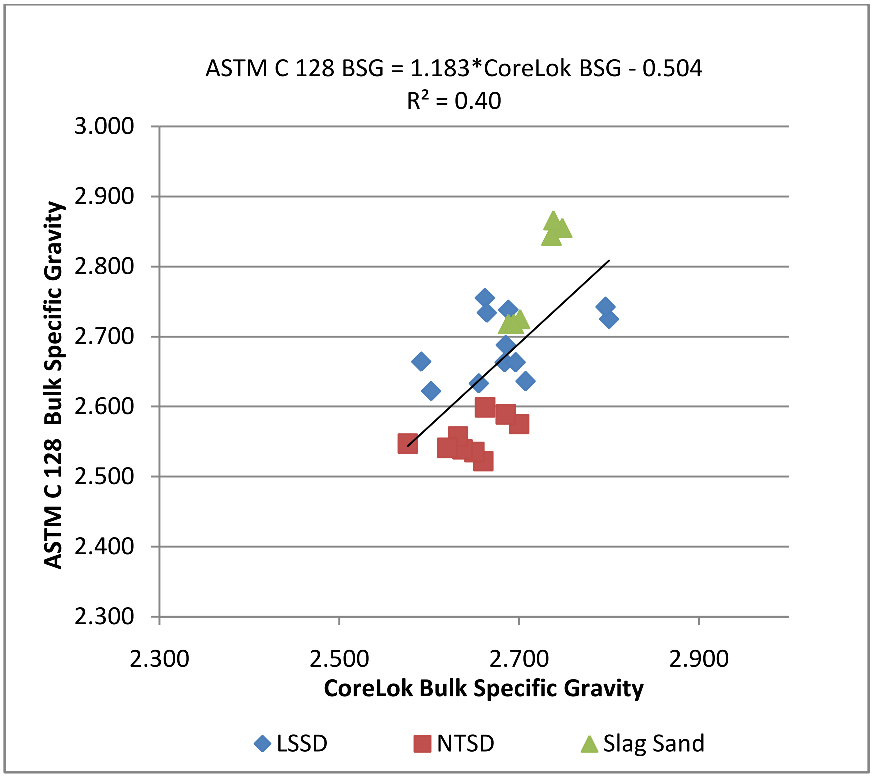
Table 10. CoreLok vs. ASTM C 128 - Paired *t*-Test on G_{sb} Values of Fine Aggregates

	CoreLok	**ASTM C 128**
Number of Samples	27	27
Mean	2.680	2.666
Variance	0.003	0.010
p-value	0.542	
Is the difference statistically significant?	**No**	

Figure 13 shows a scatter plot of G_{sb} values determined from CoreLok and ASTM C 128 procedures along with the linear regression model. The coefficient of determination, R^2 is 0.40 indicating a moderate correlation between the G_{sb} values obtained from the two test procedures.

A detailed analysis of the data was performed to determine the effect of aggregate type (LSSD, NTSD, and Slag Sand) on the results, although this meant smaller sample size for each material type. In case of LSSD and Slag Sand, the *t*-tests returned a *p*-value higher than 0.05, meaning the material type does not have a significant effect on the two test procedures for these two materials. However, the *t*-test for NTSD returned a *p*-value of <0.05, which means the difference between two test types is statistically significant. This could be because the deviation of test results for NTSD between the test procedures. Linear regression was performed for each material type. There was no improvement in R^2 except for slag. The results are shown in Figure 14.

Figure 13. CoreLok vs. ASTM C 128 - Scatter Plot for G_{sb} Values



6.2.1.2 Fine Aggregate G_{sb} Test Results – SSDetect vs. ASTM C 128

In order to determine if the differences in the test results between ASTM C 128 and SSDetect are statistically significant, similar statistical tests were performed. The results of the *t*-test are shown in Table 11. The *t*-test yielded a *p*-value of 0.590 at 95% confidence interval. Since the *p*-value is greater than 0.05, it can be concluded that the difference in results between the two test procedures is statistically not significant.

Figure 14. CoreLok vs. ASTM C 128 - Revised Scatter Plot for G_{sb} Values

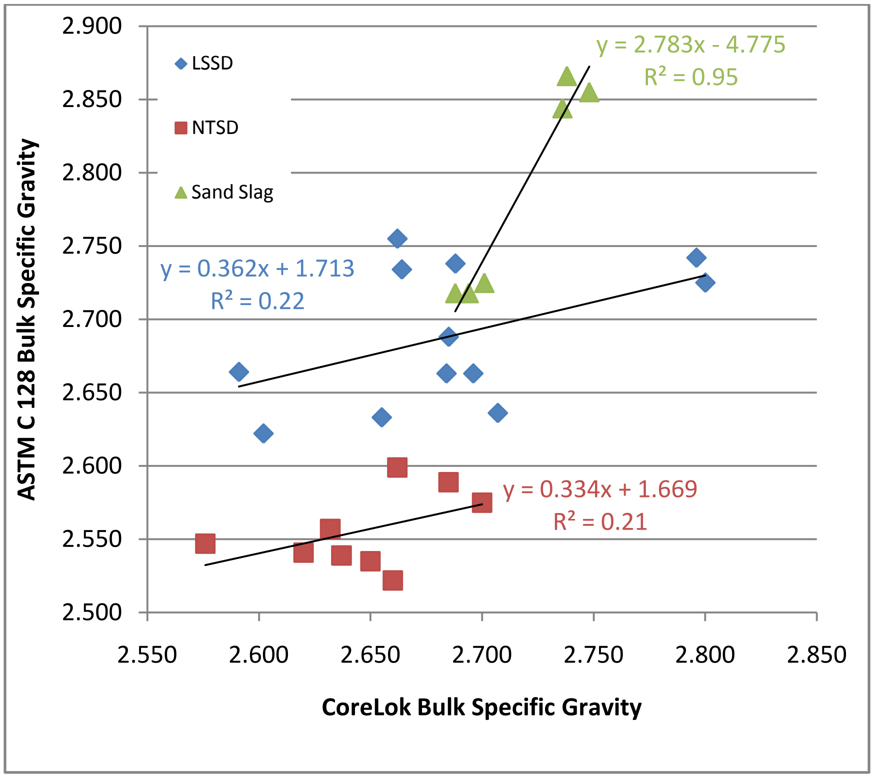


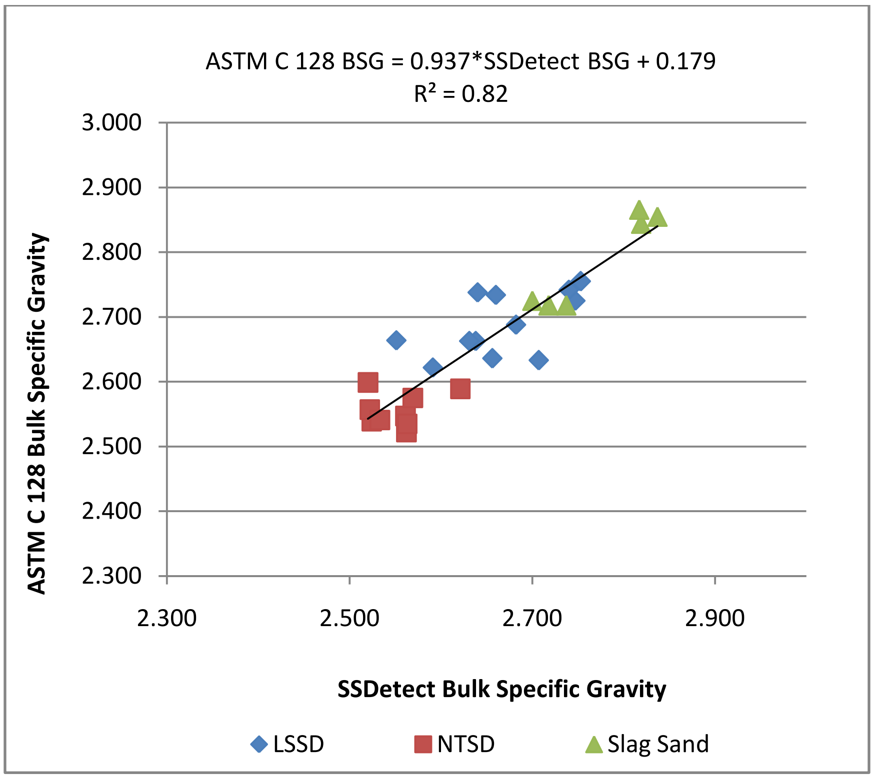
Table 11. SSDetect vs. ASTM C 128 - Paired *t*-Test on G_{sb} Values of Fine Aggregates

	SSDetect	**ASTM C 128**
Number of Samples	27	27
Mean	2.652	2.666
Variance	0.009	0.010
p-value	0.590	
Is the difference statistically significant?	**No**	

Similar statistical analysis on each material type (LSSD, NTSD, and Slag Sand) suggested that regardless of the material type, the difference between the SSDetect and ASTM C 128 test procedures is statistically not significant.

Figure 15 shows a scatter plot of G_{sb} values determined from ASTM C 128 and SSDetect procedures along with a linear regression model. The coefficient of determination R^2 is 0.82, indicating a strong correlation between the G_{sb} values obtained from the two test procedures, SSDetect and ASTM C 128. As a result, regression analysis was not performed for individual material type.

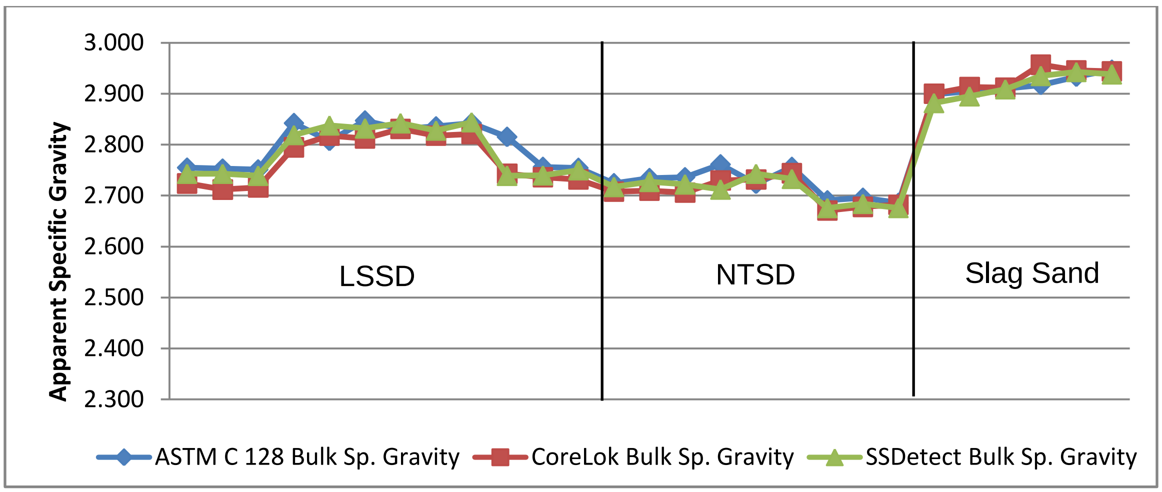
Figure 15. SSDetect vs. ASTM C 128 - Scatter Plot for G_{sb} Values



6.2.2 Apparent Specific Gravity (G_{sa}) Test Results

The results of G_{sa} are tabulated in Appendix 2 (Table 2-2). A graphic illustration is provided in Figure 16.

Figure 16. CoreLok vs. SSDetect vs. ASTM C 128 - Variation in G_{sa} Values



It is interesting to see that the G_{sa} values from all the three test procedures are nearly identical. The variations between ASTM G_{sa} and CoreLok G_{sa} ranged from 0% to 2.55%, while the variation between ASTM G_{sa} and SSDetect G_{sa} varied from 0.03% to 2.66%. Table 12 provides descriptive statistics.

6.2.2.1 Fine Aggregate G_{sa} Test Results – CoreLok vs. ASTM C 128

The results of the *t*-test are shown in Table 13. The *t*-test led to a *p*-value of 0.510 at 95% confidence interval. With the *p*-value being more than 0.05, it can be concluded that the difference in results between CoreLok specific gravity and ASTM C 128 specific gravity is statistically not significant.

Table 12. Descriptive Statistics for Fine Aggregate G_{sa} Values

	CoreLok G_{sa}	**SSDetect G_{sa}**	**ASTM C 128 G_{sa}**
Number of samples	27	27	27
Minimum value	2.671	2.676	2.686
Maximum value	2.957	2.943	2.947
Mean	2.785	2.790	2.800
Standard deviation	0.091	0.085	0.080
Coefficient of Variation, %	3.3	3.0	2.9

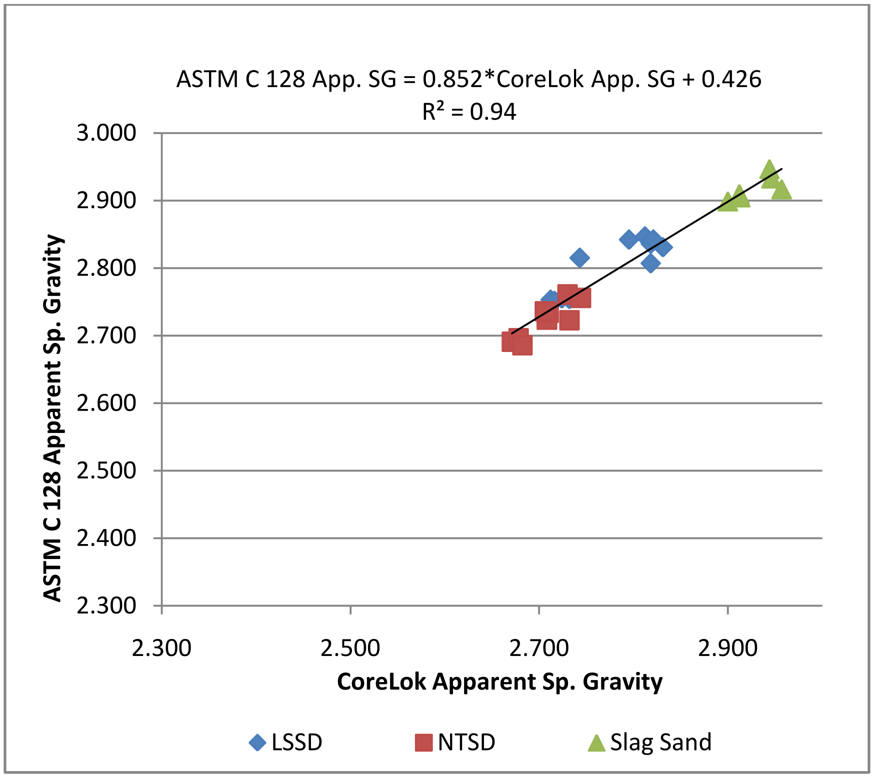
Table 13. CoreLok vs. ASTM C 128 - Paired *t*-Test on G_{sa} Values of Fine Aggregates

	CoreLok	**ASTM C 128**
Number of Samples	27	27
Mean	2.785	2.800
Variance	0.008	0.006
p-value	0.510	
Is the difference statistically significant?	**No**	

Similar conclusions were drawn based on an analysis of the data according to material type (LSSD, NTSD, and Slag Sand). Thus the difference between the ASTM C 128 and CoreLok is statistically not significant regardless of material type.

Figure 17 shows a scatter plot of G_{sa} values determined from CoreLok and ASTM C 128 procedure along with the linear regression model and R^2 value, with $R^2 = 0.94$. It can be inferred that a strong correlation exists between the data obtained from the two test procedures. As a result it was decided not to perform regression analysis for individual material type.

Figure 17. CoreLok vs. ASTM C 128 - Scatter Plot of G_{sa} Values



6.2.2.2 Fine Aggregate G_{sa} Test Results – SSDetect vs. ASTM C 128

From the statistical *t*-test, shown in Table 14, *p*-value is found to be 0.672, which means the difference in results between the two test procedures is statistically not significant.

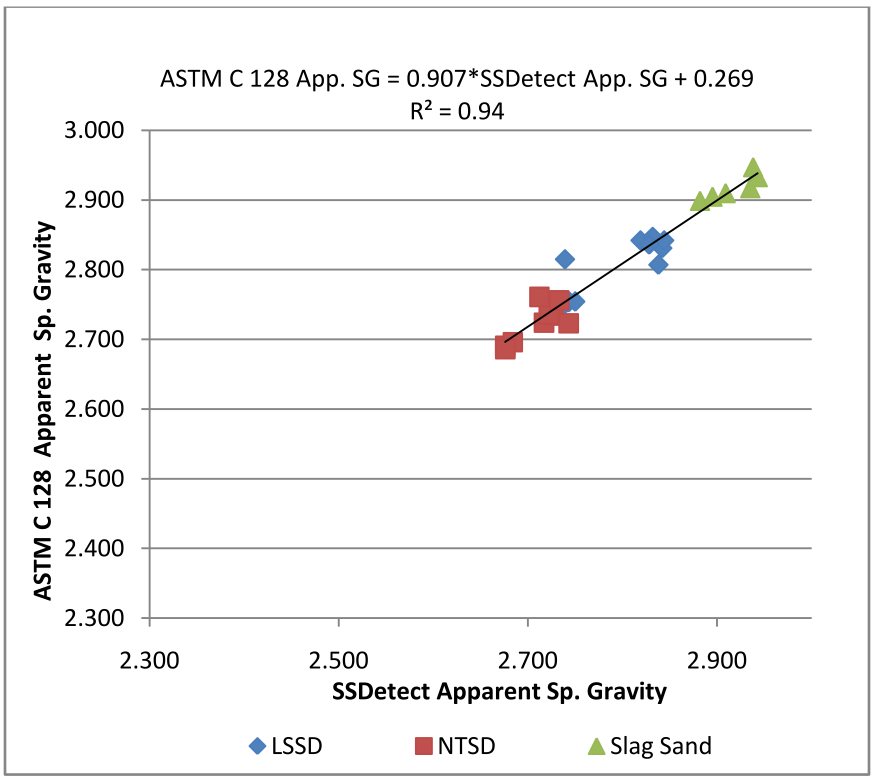
Table 14. Paired *t*-Test on G_{sa} Values of Fine Aggregates

	SSDetect	**ASTM C 128**
Number of Samples	27	27
Mean	2.790	2.800
Variance	0.007	0.006
p-value	0.672	
Is the difference statistically significant?	**No**	

A analysis of the data was performed to determine if the aggregate type (LSSD, NTSD, and Slag Sand) has an influence on the results. The *t*-tests returned a *p*-value higher than 0.05. Hence, the analysis suggested that regardless of the material type, the difference between two test procedures is statistically not significant.

Figure 18 shows a scatter plot of G_{sa} values determined from SSDetect and ASTM C 128 procedure along with the linear regression model and R^2 = 0.94. It can be inferred that a strong correlation exists between the data obtained from the two test procedures.

Figure 18. SSDetect vs. ASTM C 128 - Scatter Plot of G_{sa} Values

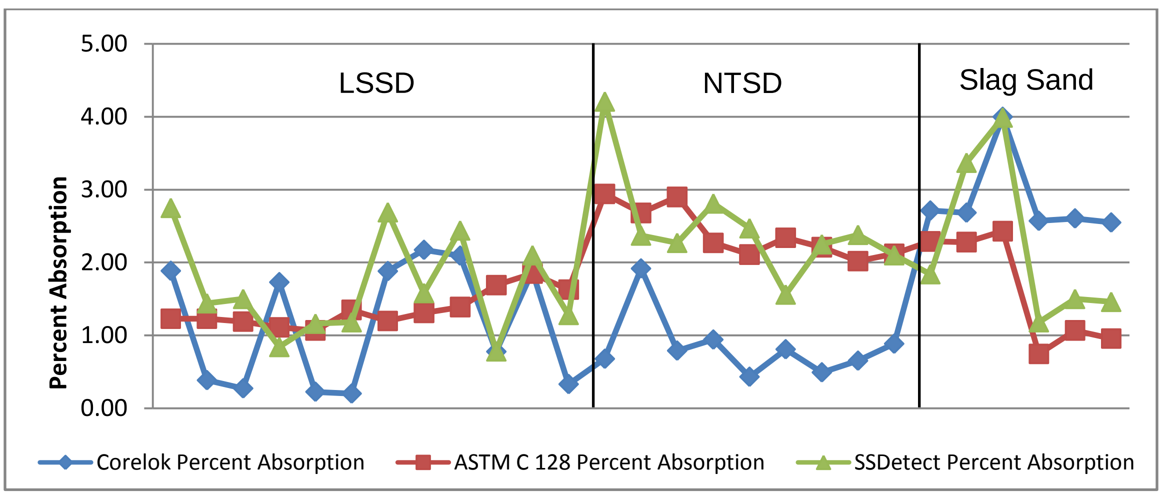


6.3 Comparing Absorption Test Results from ASTM C 128, CoreLok, and SSDetect procedures

The results of absorption are presented in Table 2-2 of Appendix 2. A graphic illustration can be seen in Figure 19. Table 15 shows the descriptive statistics, and Table 16 and Table 17 present details of the statistical analysis.

The *t*-tests returned a *p*-value of 0.153 and 0.168 for CoreLok vs. ASTM C 128 and SSDetect vs. ASTM C 128 respectively at 95% confidence interval. With the *p*-value being greater than 0.05, it can be concluded that the difference in results between the respective test procedures is statistically not significant.

Figure 19. CoreLok vs. ASTM C 128 vs. SSDetect - Variation in Absorption



As in the case of coarse aggregates, it is interesting to see that the coefficient of variation of absorption values is high for the CoreLok values (71%). It is also interesting to note the traditional ASTM procedure displayed least dispersion of test results closely followed by SSDetect.

Table 15. Descriptive Statistics for Fine Aggregate Absorption Values

	CoreLok Absorption	**SSDetect Absorption**	**ASTM C 128 Absorption**
Number of samples	27	27	27
Minimum value	0.200	0.780	0.748
Maximum value	4.000	4.210	2.940
Mean	1.428	2.055	1.764
Standard deviation	1.021	0.879	0.634
Coefficient of Variation, %	71.5	42.3	35.9

Table 16. Paired *t*-Test on Absorption Values for Fine Aggregates

	CoreLok	**ASTM C 128**
Number of Samples	27	27
Mean	1.428	1.764
Variance	1.043	0.401
p-value	0.153	
Is the difference statistically significant?	**No**	

Figure 20 and Figure 21 show scatter plots, linear regression model, and R^2 values of absorption values determined from CoreLok vs. ASTM C 128 and SSDetect vs. ASTM C 128 procedures. A very weak correlation (R^2 = 0.005) exists between the CoreLok and ASTM C 128 absorption values while a moderate correlation (R^2 = 0.39) exists between SSDetect and ASTM C 128 test procedures.

Table 17. Paired *t*-Test on Absorption Values for Fine Aggregates

	SSDetect	**ASTM C 128**
Number of Samples	27	27
Mean	2.055	1.764
Variance	0.772	0.401
p-value	0.168	
Is the difference statistically significant?	**No**	

Figure 20. CoreLok vs. ASTM C 128 – Scatter Plot for Absorption Values

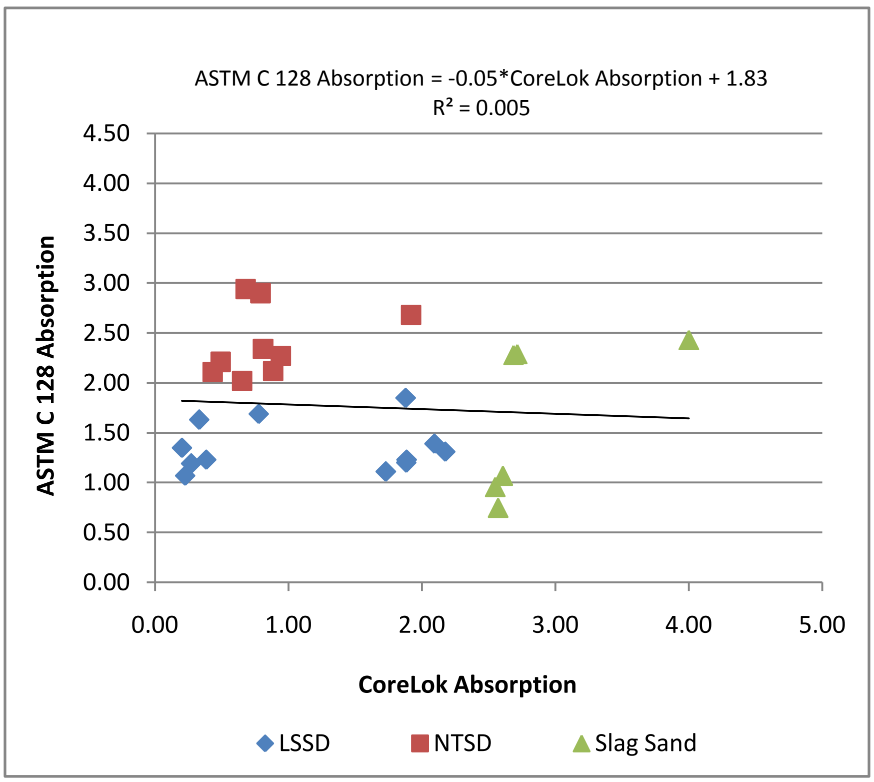
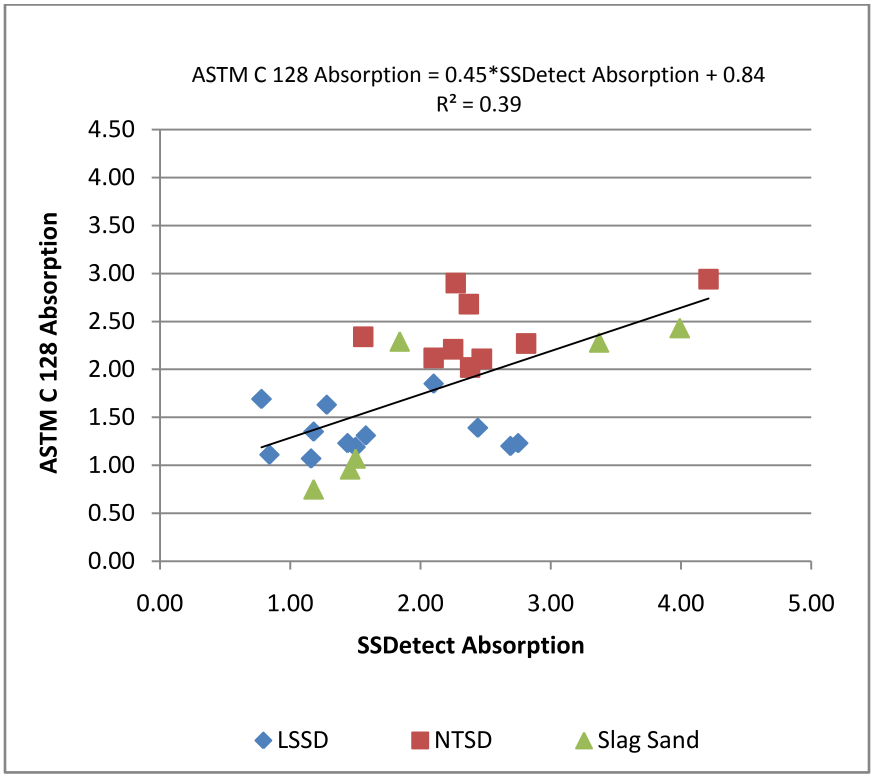


Figure 21. SSDetect vs. ASTM C 128 - Scatter Plot for Absorption Values



7. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The present study relates to the determination of specific gravity and absorption of aggregate samples. The specific gravity and absorption values are important for many reasons including asphalt, Portland cement concrete mix designs, and quality control. Traditionally, for many decades, highway agencies have used the ASTM C 127 and C 128 procedures for specific gravity and absorption determination of coarse and fine aggregates respectively. These procedures require determination of the Saturated Surface Dry (SSD) weight of the test samples. The inconsistencies in the SSD weight measurements have been a source of debate for a long time. In performing asphalt mix designs, inaccuracies in the determination of SSD values can have serious effects on the resulting job mix formulas. Similarly, in Portland cement concrete applications, the specific gravity and absorption values can influence the computation of solid volume of aggregates and net water-cement ratio.

This study reviewed two automated devices namely CoreLok and SSDetect for the measurement of specific gravity and absorption in order to compare their performance with the traditional ASTM procedures. The primary intent of the study was to investigate if the automated devices have potential applicability to Ohio's conditions based on the capability, precision, repeatability, durability, technician time involved, and cost advantages of the equipment evaluated.

Considering the uncertainties in SSD weight measurements in the ASTM procedures, deployment of automated systems is a welcome sign. The first thing the user agencies normally do before replacing an existing procedure is to compare the performance of the new procedure with the existing one. In doing so, the agencies investigate possible variations between the traditional and new test procedures. In the event of variations, such studies can help to establish factors correlating the two procedures.

The present study involved testing 26 coarse aggregate and 9 fine aggregate samples collected from various sources in Ohio. Specific gravity and absorption tests were conducted on three replicate samples from each source. In addition, tests were carried out to evaluate the repeatability of CoreLok and ASTM C 127 procedures. A thorough statistical analysis of the data was conducted. The test data and the analysis led to the following conclusions:

7.1 Conclusions Regarding Tests on Coarse Aggregates

1. The bulk specific gravity values (G_{sb}) obtained from the CoreLok test procedure is higher than the corresponding ASTM C 127 values. Depending on the material type, the difference varies from 0 to 8%. A statistical analysis conducted using a confidence interval of 95% revealed that the difference in the specific gravity values determined from the two test procedures is statistically significant.
2. A strong correlation (R^2 = 0.8) exists between the CoreLok and ASTM G_{sb} values. Performing such analysis for each material type further improved the strength of correlation.
3. The difference between CoreLok apparent specific gravity (G_{sa}) values and the corresponding ASTM C 127 values varies from 0 to 12%. The statistical analysis at 95% confidence interval revealed that this difference is statistically significant.
4. The regression analysis between CoreLok and ASTM C 127 G_{sa} values for all the values combined resulted in a R^2 value of 0.002. However, when performed on individual

material types (gravel, lime stone and slag), the results showed a considerable improvement with R^2 value ranging from 0.3 to 0.7.

5. The CoreLok absorption values are lower than ASTM values for all material types except for two slag samples. The difference in absorption for individual samples ranged from 1% to 81%. This difference is statistically significant at 95% confidence interval. Difference of this magnitude was also evident from the high coefficient of variation of CoreLok absorption values.

7.2 Conclusions Regarding Tests on Fine Aggregates

1. For low to medium absorption materials such as gravel and lime stone, the CoreLok procedure exhibited a moderately higher G_{sb} values than the corresponding values from ASTM C 128 and SSDetect procedures. However, these differences are not statistically significant at 95% confidence interval.
2. Linear regression analysis between CoreLok and ASTM C 128 test procedures resulted in a R^2 value of 0.40. Further analysis based on material type did not improve the results except for slag (R^2 = 0.95). Indeed, the R^2 value for gravel and lime stone reduced to 0.2 and 0.22 respectively. Higher R^2 for LSSD and NTSD could be achieved by fitting a power curve.
3. A strong correlation (R^2 = 0.82) was noticed in case of SSDetect vs. ASTM C 128 G_{sb} values.
4. The apparent specific gravity test results from the three test procedures closely follow each other. The difference between the ASTM C 128 and CoreLok range from 0 to 2.6% while the range of difference between ASTM C 128 and SSDetect is 0.3 to 2.7%. Low

variations between the test procedures resulted in a strong correlation as evidenced in the regression analysis, which produced R^2 of 0.94 in both the cases.

5. The CoreLok absorption values are considerably lower than the ASTM C 128 values for lime stone and natural sand but higher for slag sand. Although the difference varies from 1.5% to 243.7%, results of *t*-tests show that there is no significant difference between the test procedures. However, regression analysis of absorption implies a weak correlation (R^2 = 0.005) between the two test procedures. High dispersion of CoreLok absorption data as evidenced by high coefficient of variation could be the causal factor.
6. The difference in absorption between SSDetect and ASTM C 128 absorption values range from 0.9% to124.2%, with a moderate correlation (R^2 = 0.39).

7.3 Investigating CoreLok's Theory

In determining the specific gravity, water absorption is the key element. The precision of specific gravity relies on the precision with which absorption can be obtained. The easiest and direct method to determine absorption would use the weight of SSD sample and oven dry sample. However, CoreLok uses a novel theory to determine the absorption value. A report by InstroTek [12] states that "….*with one more density measurement and the apparent gravity, one can calculate aggregate absorption*". Absorption calculation is made using the equation,

$$a = \frac{\rho v - \rho w}{\rho v * \rho u}\ \rho w$$

Where,

a = absorption

ρv= Apparent Specific Gravity

ρu= Apparent Bulk Specific Gravity

ρw= Density of Water

Here, ρ_u is determined using a calibrated pycnometer. The procedure recommends that the measurement involving pycnometer be completed in less than two minutes. During the 2-minute period, the dry aggregate particles, immersed in water, are not expected to absorb water. The procedure notes that there could be some absorption however. Hence, the device includes a factory calibrated parameter to account for the water absorbed during 2-minute soaking. It can be seen here that the absorption value derived from the CoreLok procedure is a function of the 2-minute test in pycnometer.

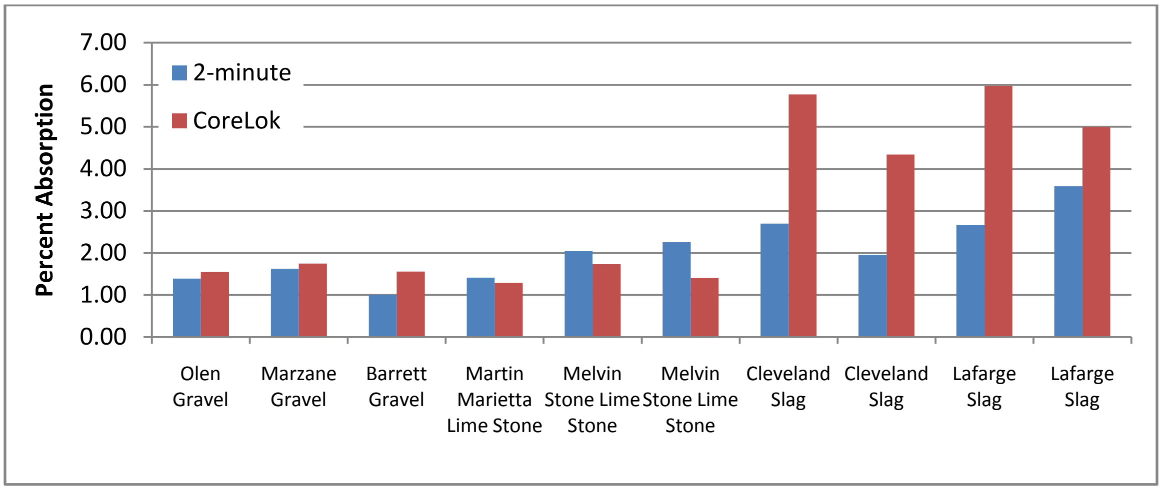
To investigate the reason for wide variation in water absorption, a detailed study was initiated. The primary goal of this study was to investigate the effect of duration of immersion on absorption characteristics of aggregates and to compare with the CoreLok absorption.

7.4 Detailed Study of Absorption vs. Time

A total of ten coarse aggregate sources were selected for this study. Adequate amount of dry material from each source was collected and separated into two batches. Batch 1 was immersed in water for 2-minutes. After two minutes, the aggregate samples were removed and tested for absorption in accordance with the standard ASTM C 127 procedure. Batch 2 aggregate was tested using the CoreLok device. The results are shown in Figure 22.

It is interesting to see that, in two minutes the samples absorb significant amount of water, at times being equal to or greater than CoreLok water absorption. In the case of gravel and lime stone, the amount of 2-minute absorption cannot be classified as "*some absorption*" as stated by InstroTek [12]. Strangely, the 2-minute absorption of all lime stone samples is higher than CoreLok water absorption.

Figure 22. 2-minute Absorption vs. CoreLok Absorption

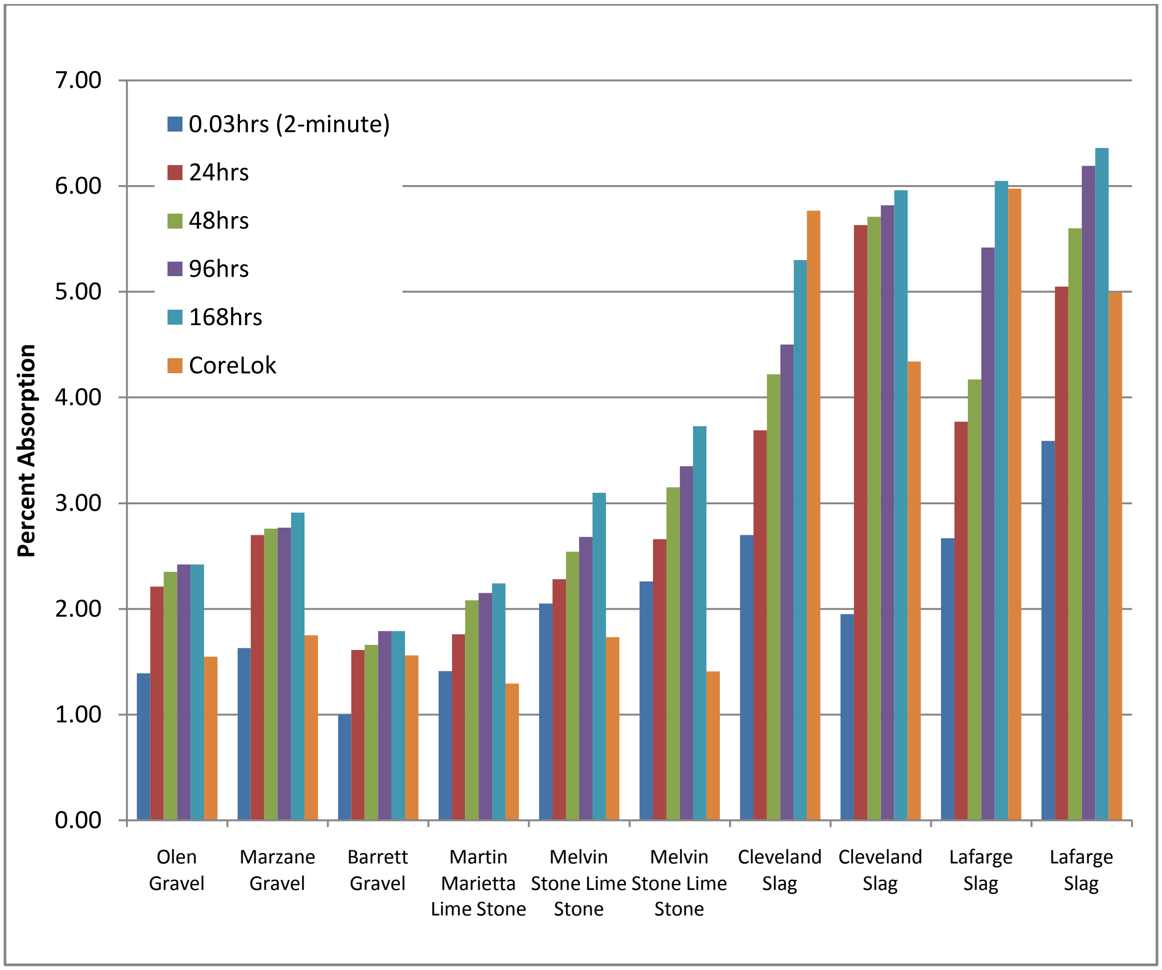


It was then decided to investigate "What does the CoreLok absorption relate to?" The absorption vs. time study was expanded to systematically test the samples at various time periods. The results are tabulated in Table 18 and graphically illustrated in Figure 23.

Table 18. Absorption vs. Time

Aggregate Producer	Type	Size	Crushed	2-min	24hrs	48hrs	96hrs	168hrs	CoreLok
Olen Corporation	Gravel	#8	0%	1.39	2.21	2.35	2.42	2.42	1.55
Marzane	Gravel	#57	40%	1.63	2.70	2.76	2.77	2.91	1.75
Barrett	Gravel	#57	0%	1.00	1.61	1.66	1.79	1.79	1.56
Martin Marietta	Lime Stone	#57	100%	1.41	1.76	2.08	2.15	2.24	1.29
Melvin Stone	Lime Stone	#57	100%	2.05	2.28	2.54	2.68	3.10	1.73
Melvin Stone Co.	Lime Stone	#8	100%	2.26	2.66	3.15	3.35	3.73	1.41
Cleveland Slag	Slag	#57	100%	2.70	3.69	4.22	4.50	5.30	5.77
Cleveland Slag	Slag	#8	100%	1.95	5.63	5.71	5.82	5.96	4.34
Lafarge	Slag	#57	100%	2.67	3.77	4.17	5.42	6.05	5.98
Lafarge	Slag	#8	100%	3.59	5.05	5.60	6.19	6.36	5.00

Figure 23. Graphical Illustration Absorption vs. Time



This figure leads to a conclusion that the CoreLok absorption does not consistently relate to either 2-minute or 24 hours or any other absorption value depicted in the figure. This data was further processed (Table 19) to relate the CoreLok absorption value of each sample to the nearest absorption value from the immersion tests.

Table 19. Relating CoreLok Absorption to Immersion Test

Aggregate Producer	Type	Size	Crushed	CoreLok Absorption	Nearest Absorption Value
Olen Corporation	Gravel	#8	0%	1.55	1.39 (2-minute)
MarZane	Gravel	#57	40%	1.75	1.63 (2-minute)
Barrett	Gravel	#57	0%	1.56	1.61 (48-hours)
Martin Marietta	LS	#57	100%	1.29	1.41 (2-minute)
Melvin Stone	LS	#57	100%	1.73	2.05 (2-minute)
Melvin Stone Co	LS	#8	100%	1.41	2.26 (2-minute)
Cleveland Slag	Slag	#57	100%	5.77	5.3 (168-hours)
Cleveland Slag	Slag	#8	100%	4.34	5.63 (24-hours)
Lafarge	Slag	#57	100%	5.98	6.05 (168-hours)
Lafarge	Slag	#8	100%	5.00	5.05 (24-hours)

Ideally, the CoreLok absorption is expected to closely follow the 24-hour absorption with or without a constant difference. In many instances, the CoreLok derived absorption is in the vicinity of 2-minute absorption. In reality, the table above suggests that there is no such pattern and hence the CoreLok theory requires a thorough review.

It should be recognized that the above conclusion was based on tests on coarse aggregates. No such studies were made with fine aggregates.

7.5 Can the CoreLok Device be specified in Ohio?

Conventional Procedure (ASTM) has two aspects that are time consuming and/or subjective in nature, namely:

1. Saturation of a given sample of aggregates requires 24 hours of immersion in water;
2. The concept of Saturated Surface dry sample is subjective in nature, as there is no means of quantifying the surface dry condition.

The CoreLok procedure claims to alleviate these two problems. Firstly, a vacuum is used to accelerate the process of saturation. This process requires just a few minutes instead of 24 hours to achieve full saturation. Then the measurement of SSD density is altogether eliminated by using a pycnometer procedure to measure the total volume of aggregates.

On reviewing the procedures employed by CoreLok, it is observed that the whole procedure hinges upon the computation of volume of aggregates by pycnometer test. In this test, a desiccated sample is immersed in water to compute the volume. It is recommended by the manufacturers that this task be completed in 2-minutes. Here it is assumed that the amount of water absorbed into pores in this 2-minute is negligible. An average correction is built in the device for the small amount of water absorption. From several tests on aggregates from different sources in Ohio, it is observed that the 2-minute absorption is neither small nor constant. It is perhaps even more subjective than the saturated surface dry procedure used conventionally in that the amount of water absorbed in 2-minute for some coarse aggregate materials is as high as 50% of pore volume. Thus, the premise that the CoreLok procedure is more rational and accurate is dubious.

As a result, it is recommended not to use the CoreLok device in its current format, and instead continue with the traditional ASTM procedure for the determination of specific gravity and water absorption values of coarse and fine aggregates.

7.6 Efficacy of SSDetect Device

In recent times, use of infrared for water detection has become a common practice in the building industry. Water absorbs specific wavelengths as do other fluids. By using an infrared filter, it is possible to create an automated system to detect the presence of water. The SSDetect device uses this principle to deliver fine aggregate samples at SSD condition. In short, the device utilizes infrared thermography for detecting presence of water on fine aggregate samples once their pores are completely saturated.

The specific gravity test results on aggregates, collected from nine different sources in Ohio, closely follow ASTM C 128 test results. However, the absorption results between the two test procedures have varied considerably from 1.5% to 243%.

Those who have been using the *cone and tamp* method, as described in the ASTM C 128 procedure, to determine the SSD condition of fine aggregates can testify the level of subjectivity in the process. Use of SSDetect device would essentially bypass the need for the cone and tamp to produce SSD samples. Once the SSD sample is produced in the SSDetect device, the material is used with pycnometer as in the case of traditional procedure. It is thus assumed that samples from SSDetect do relate to SSD condition. To investigate whether the samples really related to SSD condition, some samples were tested with the *cone and tamp*. It was interesting to note that all of the lime stone samples passed the cone and tamp test while 80% of the natural sand samples did not pass the test. This may explain some inconsistencies in the test results, particularly with NTSD samples.

The question now is: "Is the SSDetect device ready for acceptance?" Based on a review of its theoretical principle of development, the test results and the experience gained during the study, it appears that the device has potential application for specific gravity and water absorption determination of fine aggregates. However, it is necessary to resolve the aforementioned issues before recommending its routine use in Ohio.

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APPENDIX 1

Table 1-1

Aggregate Producer	Location	Type	Size	% Crushed
Olen Corporation	Columbus	GR	#8	0
Barrett	Fairborn	GR	#8	100
Barrett	Fairborn	GR	#8	0
Olen Corporation	Columbus	GR	#8	40
MarZane	Barberton	GR	#8	40
Olen Corporation	Columbus	GR	#8	100
Barrett	Fairborn	GR	#68	100
Olen Corporation	Columbus	GR	#57	0
Barrett	Fairborn	GR	#57	0
Olen Corporation	Columbus	GR	#57	40
MarZane	Barberton	GR	#57	40
Olen Corporation	Columbus	GR	#57	100
Melvin Stone Co.	Plano	LS	#8	100
Martin Marietta	Phillipsburg	LS	#8	100
Melvin Stone Co.	Melvin	LS	#8	100
Hanson	Winchester	LS	#8	100
Hanson	Fairview	LS	#8	100
Melvin Stone Co.	Plano	LS	#57	100
Martin Marietta	Phillipsburg	LS	#57	100
Melvin Stone Co.	Melvin	LS	#57	100
Hanson	Winchester	LS	#57	100
Hanson	Fairview	LS	#57	100
Cleveland Slag	Cleveland	SL	#8	100
Lafarge	Warren	SL	#8	100
Cleveland Slag	Cleveland	SL	#57	100
Lafarge	Warren	SL	#57	100

Table 1-2. Gradation of Aggregates

Sieve Size (mm)	#57	#8	Natural Sand / Manufactured Sand
37.5	100		
25	95 - 100		
12.5	25 - 60	100	
9.5		85- 100	
4.75	0 - 10	10-30	100/100
2.360	0- 5	0 - 10	95-100/95-100
1.180		0 - 5	
0.300			10-40/20-40
0.150			0-15/10-25
0.075			0-5/0-10

Table 1-3. Specific Gravity and Absorption Values for Coarse Aggregates

Aggregate Producer	Location	Type	Size	% Crushed	CoreLok Bulk Sp. Gravity	ASTM C 127 Bulk Sp. Gravity	CoreLok App Sp. Gravity	ASTM C 127 App Sp. Gravity	CoreLok Absorption	ASTM C 127 Absorption
Olen Corporation	Columbus	GR	#8	0	2.669	2.568	2.757	2.740	1.69	2.45
Olen Corporation	Columbus	GR	#8	0	2.664	2.576	2.768	2.737	1.41	2.28
Olen Corporation	Columbus	GR	#8	0	2.660	2.576	2.773	2.739	1.54	2.32
Barrett	Fairborn	GR	#8	100	2.722	2.655	2.827	2.784	1.32	1.74
Barrett	Fairborn	GR	#8	100	2.727	2.661	2.790	2.791	0.82	1.75
Barrett	Fairborn	GR	#8	100	2.734	2.668	2.797	2.790	0.83	1.64
Barrett	Fairborn	GR	#8	0	2.699	2.637	2.731	2.773	0.44	1.86
Barrett	Fairborn	GR	#8	0	2.704	2.642	2.729	2.778	0.34	1.84
Barrett	Fairborn	GR	#8	0	2.698	2.641	2.728	2.777	0.41	1.86
Olen Corporation	Columbus	GR	#8	40	2.669	2.569	2.695	2.737	1.33	2.38
Olen Corporation	Columbus	GR	#8	40	2.664	2.569	2.720	2.735	0.78	2.35
Olen Corporation	Columbus	GR	#8	40	2.659	2.565	2.718	2.732	0.81	2.39
MarZane	Barberton	GR	#8	40	2.596	2.506	2.663	2.689	0.97	2.72
MarZane	Barberton	GR	#8	40	2.610	2.511	2.678	2.695	0.98	2.71
MarZane	Barberton	GR	#8	40	2.616	2.515	2.662	2.694	1.91	2.64
Olen Corporation	Columbus	GR	#8	100	2.676	2.565	2.734	2.751	0.79	2.64
Olen Corporation	Columbus	GR	#8	100	2.671	2.570	2.739	2.753	0.92	2.59
Olen Corporation	Columbus	GR	#8	100	2.675	2.570	2.699	2.754	1.10	2.60
Barrett	Fairborn	GR	#68	100	2.714	2.654	2.792	2.778	1.04	1.68
Barrett	Fairborn	GR	#68	100	2.727	2.661	2.790	2.786	0.83	1.70
Barrett	Fairborn	GR	#68	100	2.686	2.660	2.707	2.786	0.95	1.71
Olen Corporation	Columbus	GR	#57	0	2.646	2.574	2.760	2.722	1.56	2.11
Olen Corporation	Columbus	GR	#57	0	2.651	2.588	2.732	2.731	1.11	2.03

Aggregate Producer	Location	Type	Size	% Crushed	CoreLok Bulk Sp. Gravity	ASTM C 127 Bulk Sp. Gravity	CoreLok App Sp. Gravity	ASTM C 127 App Sp. Gravity	CoreLok Absorption	ASTM C 127 Absorption
Olen Corporation	Columbus	GR	#57	0	2.644	2.585	2.743	2.730	1.37	2.05
Barrett	Fairborn	GR	#57	0	2.692	2.654	2.791	2.766	1.32	1.52
Barrett	Fairborn	GR	#57	0	2.695	2.650	2.801	2.778	1.41	1.73
Barrett	Fairborn	GR	#57	0	2.591	2.644	2.776	2.770	1.95	1.72
Olen Corporation	Columbus	GR	#57	40	2.656	2.579	2.720	2.729	0.88	1.86
Olen Corporation	Columbus	GR	#57	40	2.651	2.586	2.718	2.725	0.91	1.98
Olen Corporation	Columbus	GR	#57	40	2.654	2.602	2.781	2.736	1.04	1.88
MarZane	Barberton	GR	#57	40	2.579	2.496	2.666	2.682	2.02	2.79
MarZane	Barberton	GR	#57	40	2.571	2.498	2.684	2.685	1.64	2.78
MarZane	Barberton	GR	#57	40	2.562	2.496	2.671	2.678	1.59	2.73
Olen Corporation	Columbus	GR	#57	100	2.677	2.621	2.767	2.749	0.70	1.77
Olen Corporation	Columbus	GR	#57	100	2.685	2.633	2.721	2.750	0.49	1.62
Olen Corporation	Columbus	GR	#57	100	2.683	2.620	2.732	2.747	0.67	1.76
Melvin Stone Co.	Plano	LS	#8	100	2.714	2.529	2.849	2.827	1.73	4.17
Melvin Stone Co.	Plano	LS	#8	100	2.708	2.538	2.847	2.829	1.81	4.05
Melvin Stone Co.	Plano	LS	#8	100	2.702	2.535	2.849	2.820	1.91	3.98
Martin Marietta	Phillipsburg	LS	#8	100	2.726	2.615	2.838	2.771	1.45	2.15
Martin Marietta	Phillipsburg	LS	#8	100	2.714	2.606	2.840	2.772	1.63	2.30
Martin Marietta	Phillipsburg	LS	#8	100	2.711	2.606	2.826	2.775	1.50	2.34
Melvin Stone Co.	Melvin	LS	#8	100	2.696	2.565	2.796	2.751	1.33	2.64
Melvin Stone Co.	Melvin	LS	#8	100	2.694	2.561	2.794	2.745	1.33	2.61
Melvin Stone Co.	Melvin	LS	#8	100	2.687	2.557	2.804	2.748	1.56	2.72
Hanson	Winchester	LS	#8	100	2.686	2.686	2.708	2.747	0.30	0.82
Hanson	Winchester	LS	#8	100	2.698	2.690	2.718	2.746	0.27	0.76
Hanson	Winchester	LS	#8	100	2.692	2.690	2.712	2.747	0.27	0.78

Aggregate Producer	Location	Type	Size	% Crushed	CoreLok Bulk Sp. Gravity	ASTM C 127 Bulk Sp. Gravity	CoreLok App Sp. Gravity	ASTM C 127 App Sp. Gravity	CoreLok Absorption	ASTM C 127 Absorption
Hanson	Fairview	LS	#8	100	2.680	2.679	2.699	2.739	0.26	0.82
Hanson	Fairview	LS	#8	100	2.694	2.679	2.709	2.738	0.20	0.79
Hanson	Fairview	LS	#8	100	2.682	2.679	2.703	2.737	0.29	0.79
Melvin Stone Co.	Plano	LS	#57	100	2.675	2.545	2.805	2.809	1.73	3.69
Melvin Stone Co.	Plano	LS	#57	100	2.681	2.560	2.819	2.816	1.84	3.55
Melvin Stone Co.	Plano	LS	#57	100	2.682	2.563	2.804	2.816	1.63	3.50
Martin Marietta	Phillipsburg	LS	#57	100	2.698	2.618	2.790	2.743	1.22	1.74
Martin Marietta	Phillipsburg	LS	#57	100	2.702	2.615	2.795	2.742	1.23	1.78
Martin Marietta	Phillipsburg	LS	#57	100	2.696	2.615	2.805	2.742	1.44	1.77
Melvin Stone Co.	Melvin	LS	#57	100	2.661	2.550	2.829	2.722	2.46	2.25
Melvin Stone Co.	Melvin	LS	#57	100	2.660	2.567	2.791	2.717	1.77	2.16
Melvin Stone Co.	Melvin	LS	#57	100	2.651	2.563	2.792	2.716	1.96	2.21
Hanson	Winchester	LS	#57	100	2.680	2.705	2.695	2.752	0.20	0.63
Hanson	Winchester	LS	#57	100	2.690	2.706	2.710	2.752	0.27	0.62
Hanson	Winchester	LS	#57	100	2.685	2.709	2.705	2.753	0.28	0.59
Hanson	Fairview	LS	#57	100	2.680	2.691	2.700	2.734	0.28	0.57
Hanson	Fairview	LS	#57	100	2.678	2.683	2.693	2.729	0.22	0.62
Hanson	Fairview	LS	#57	100	2.682	2.693	2.696	2.733	0.20	0.54
Cleveland Slag	Cleveland	SL	#8	100	2.511	2.385	2.844	2.632	4.66	3.93
Cleveland Slag	Cleveland	SL	#8	100	2.524	2.412	2.811	2.628	4.05	3.48
Cleveland Slag	Cleveland	SL	#8	100	2.524	2.404	2.832	2.639	4.31	3.71
Lafarge	Warren	SL	#8	100	2.540	2.339	2.854	2.658	5.33	5.14
Lafarge	Warren	SL	#8	100	2.533	2.352	2.883	2.653	4.80	4.83
Lafarge	Warren	SL	#8	100	2.527	2.330	2.881	2.649	4.86	5.18
Cleveland Slag	Cleveland	SL	#57	100	2.417	2.316	2.847	2.539	5.69	3.79

Aggregate Producer	Location	Type	Size	% Crushed	CoreLok Bulk Sp. Gravity	ASTM C 127 Bulk Sp. Gravity	CoreLok App Sp. Gravity	ASTM C 127 App Sp. Gravity	CoreLok Absorption	ASTM C 127 Absorption
Cleveland Slag	Cleveland	SL	#57	100	2.416	2.314	2.820	2.529	5.94	3.67
Cleveland Slag	Cleveland	SL	#57	100	2.413	2.320	2.784	2.531	5.68	3.61
Lafarge	Warren	SL	#57	100	2.397	2.283	2.778	2.507	5.73	3.84
Lafarge	Warren	SL	#57	100	2.378	2.282	2.765	2.490	5.89	3.67
Lafarge	Warren	SL	#57	100	2.409	2.289	2.764	2.508	6.31	3.80

APPENDIX 2

Table 2-1

Aggregate Producer	**Location**	**Type**
Hanson	Fairview	LSSD
Martin Marietta	Phillipsburg	LSSD
Melvin	Plano	LSSD
Hanson	Winchester	LSSD
Olen Corporation	Columbus	NTSD
Barrett	Fairborn	NTSD
Marzane	Barberton	NTSD
Cleveland Slag	Cleveland	Slag Sand
Lafarge	Warren	Slag Sand

Table 2-2. Specific Gravity and Absorption Values for Fine Aggregates

Aggregate Producer	Location	Type	ASTM C 128 Bulk Sp. Gravity	CoreLok Bulk Sp. Gravity	SSDetect Bulk Sp. Gravity	ASTM C 128 Apparent Sp. Gravity	CoreLok Apparent Sp. Gravity	SSDetect Apparent Sp. Gravity	ASTM C 128 Percent Absorption	CoreLok Percent Absorption	SSDetect Percent Absorption
Hanson	Fairview	LSSD	2.664	2.591	2.551	2.755	2.724	2.743	1.23	1.89	2.75
Hanson	Fairview	LSSD	2.663	2.684	2.638	2.753	2.712	2.743	1.23	0.38	1.44
Hanson	Fairview	LSSD	2.663	2.696	2.631	2.751	2.716	2.739	1.19	0.27	1.50
Martin Marietta	Phillipsburg	LSSD	2.755	2.662	2.753	2.842	2.795	2.819	1.11	1.73	0.84
Martin Marietta	Phillipsburg	LSSD	2.725	2.800	2.747	2.807	2.818	2.838	1.07	0.22	1.16
Martin Marietta	Phillipsburg	LSSD	2.742	2.796	2.740	2.847	2.812	2.832	1.35	0.20	1.18
Melvin	Plano	LSSD	2.738	2.688	2.640	2.831	2.831	2.842	1.20	1.88	2.69
Melvin	Plano	LSSD	2.633	2.655	2.707	2.836	2.818	2.828	1.31	2.17	1.58
Melvin	Plano	LSSD	2.734	2.664	2.660	2.842	2.821	2.844	1.39	2.09	2.44
Hanson	Winchester	LSSD	2.688	2.685	2.682	2.815	2.743	2.739	1.69	0.78	0.78
Hanson	Winchester	LSSD	2.622	2.602	2.591	2.756	2.736	2.740	1.85	1.88	2.10
Hanson	Winchester	LSSD	2.636	2.707	2.656	2.754	2.732	2.750	1.63	0.33	1.28
Olen Corporation	Columbus	NTSD	2.522	2.660	2.562	2.724	2.708	2.717	2.94	0.68	4.21
Olen Corporation	Columbus	NTSD	2.547	2.576	2.561	2.734	2.710	2.727	2.68	1.92	2.37
Olen Corporation	Columbus	NTSD	2.535	2.650	2.563	2.736	2.706	2.722	2.90	0.79	2.27
Barrett	Fairborn	NTSD	2.599	2.662	2.520	2.761	2.730	2.712	2.27	0.94	2.81
Barrett	Fairborn	NTSD	2.575	2.700	2.569	2.723	2.732	2.743	2.11	0.43	2.47
Barrett	Fairborn	NTSD	2.589	2.685	2.621	2.756	2.744	2.733	2.34	0.81	1.56
Marzane	Barberton	NTSD	2.539	2.637	2.524	2.691	2.671	2.676	2.21	0.49	2.25
Marzane	Barberton	NTSD	2.557	2.632	2.522	2.696	2.678	2.684	2.02	0.65	2.38
Marzane	Barberton	NTSD	2.541	2.620	2.533	2.686	2.682	2.676	2.12	0.88	2.10
Cleveland Slag	Cleveland	Slag Sand	2.718	2.688	2.737	2.899	2.900	2.882	2.29	2.71	1.84
Cleveland Slag	Cleveland	Slag Sand	2.725	2.701	2.700	2.905	2.913	2.895	2.28	2.68	3.37

Aggregate Producer	**Location**	**Type**	**ASTM C 128 Bulk Sp. Gravity**	**CoreLok Bulk Sp. Gravity**	**SSDetect Bulk Sp. Gravity**	**ASTM C 128 Apparent Sp. Gravity**	**CoreLok Apparent Sp. Gravity**	**SSDetect Apparent Sp. Gravity**	**ASTM C 128 Percent Absorption**	**CoreLok Percent Absorption**	**SSDetect Percent Absorption**
Cleveland Slag	Cleveland	Slag Sand	2.718	2.694	2.718	2.910	2.912	2.909	2.43	4.00	3.99
Lafarge	Warren	Slag Sand	2.855	2.748	2.837	2.917	2.957	2.935	0.75	2.57	1.18
Lafarge	Warren	Slag Sand	2.844	2.736	2.819	2.933	2.946	2.943	1.07	2.61	1.50
Lafarge	Warren	Slag Sand	2.866	2.738	2.817	2.947	2.944	2.938	0.96	2.55	1.46