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Measuring the Specific Gravities of Fine Aggregates: An Automated Procedure

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Abstract: The objective of the research described in this paper was to evaluate the use of the new automated SSDetect in determining the specific gravities of fine aggregates in Michigan. Currently, the American Association of State Highway and Transportation Officials (AASHTO) Standard, AASHTO T-84, *Standard Method of Test for Specific Gravity and Absorption of Fine Aggregate,* is used in determining the specific gravity of fine aggregates in Michigan. This test procedure basically utilizes a standard frustum cone and tamping rod to find the saturated surface-dry (SSD) state of the fine aggregate; after 15hrs of soaking in water. In addition to its time consuming nature, the AASHTO T-84 is problematic with angular and rough textured fine aggregate because they do not readily slump. The new SSDetect is proposed as a viable alternative in accurately and efficiently finding specific gravities using the scientific laws of reflection of infra-red light rays. Results of the research indicate statistical similarity between the AASHTO T-84 and SSDetect for specific gravity measurement.

***Key words**: AASHTO T-84; Fine aggregate; Specific gravity; SSDetect.*

Introduction

The American Association of State Highway and Transportation Officials (AASHTO) Standard T-85 defines the *specific gravity* of an aggregate as the ratio of the density of a material to the density of distilled water at a stated temperature, the values being dimensionless. Specific gravity is determined at bulk and apparent conditions. In the bulk state, denoted *Gsb*, both the permeable and impermeable voids on the surface on the aggregate are considered in the volume calculations. Conversely, the apparent specific gravity (*Gsa*) calculates the specific gravity excluding the permeable voids of the aggregate. The water absorption (*Wa* %) of an aggregate is the increase in mass of aggregate due to water penetration into the pores of the particles during a prescribed period of time, but not including water adhering to the outside surface of the particles, expressed as a percentage of the dry mass. *Gsb* (saturated surface-dry, SSD) is used when the fine aggregates are considered to be wet at the time of use. The accurate determination of the specific gravity of aggregate for use in the volumetric design of hot mix asphalt is critical [1]. In particular the voids in the mineral aggregate (VMA) and thus the voids filled with asphalt (VFA) are directly affected by the aggregate specific gravity values. Further challenges exist when using specific gravity values, directly or indirectly, from mixture designs for evaluating hot mix asphalt (HMA) volumetric qualities during and/or after construction. The allowable multi-laboratory precision values for fine aggregate in AASHTO T-84 [2], are greater than the comparable ones for coarse aggregate in AASHTO T-85, *Standard Method of Test for Specific Gravity and Absorption of Coarse Aggregate*. These multi-laboratory precision properties are summarized in Table 1. Thus, the determination of fine aggregate specific gravity and absorption could contribute to some amount of error in VMA and VFA calculations.

The National Stone, Sand, and Gravel Association's Aggregate Handbook [3] defines fine aggregate as a material that passes a 9.55*mm* sieve (3/8*inch* square opening), and essentially all of which passes a 0.75*mm* sieve (0.187*inch* square opening) and is predominantly retained on the 0.075*mm* sieve (0.0029*inch* square opening). Examination of fine aggregate for this study followed this aforementioned definition of fine aggregate.

Newer measurement systems of aggregate specific gravity have been more recently developed including the SSDetect. The SSDetect relies on the principle of the transition of light rays from a laser being reflected to being refracted, a condition which depends on the moisture coating on the aggregate surface. Seventeen different fine aggregates of varying gradation, geologic history, and method of processing were tested by AASHTO T-84 and an SSDetect device for comparison.

Table 1. AASHTO T-84 and T-85 Multi-Laboratory Precision (Standard Deviation, 1S).

Characteristic	T-84 (Fine Aggregate)	T-85 (Coarse Aggregate)
Gsb (dry)	0.023	0.013
Gsb (SSD)	0.020	0.011
Gsa	0.020	0.011
Wa, %	0.230	0.145

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Background and Literature Review

Among the early attempts at bulk specific gravity and absorption of fine aggregates was the work undertaken to find the specific gravity of non-homogenous fine aggregates [4]. Rea's approach found the apparent specific gravity by coating sand materials with kerosene before finding the volume of the sand. The rationale behind coating the fine aggregates is to prevent the penetration of water into the voids. The American Society of Testing Materials (ASTM) Committee C-9 on Concrete and Concrete Aggregates revised this early method, of which the details were carried out in the 1920's ASTM Proceedings report [5].

Further development of a method to find the specific gravity and absorption of sand was shown by Pearson. The method involved finding how dampened grains of sand adhered to the sides of an Erlenmeyer flask [6]. Pearson reported that this proposed method underestimated the true absorption value due to incomplete saturation.

Pearson's titration method was modified slightly, and accepted by the ASTM for use as the standard practice for specific gravity and absorption determination [7]. The sand was saturated with water and dried back to SSD state based on the operator's visual inspection. 500*g* of the SSD sample was placed in a 1-qt glass jar, and water added in drops to ascertain whether the material sticks to the sides of the jar. The SSD state condition of this method according to Pearson was highly subjective and thus unreliable.

The use of color change in sand SSD determination has proved to be unreliable and unrepeatable [8]. To further increase the usefulness of the colimetric method of SSD and specific gravity determination, calcium chloride was used to dry the sand for a period of time [9]. The drying process, it was found unduly removed substantial amounts of water from the SSD sand material.

Additional research worth noting is that of Myers in 1935. Myers found the free moisture in the aggregate using gravimetric, displacement, dilution, colimetric, and electrical-resistance principles. All the four methods were not promising due to the fact that visual inspection was used in finding the SSD state of the fine aggregates during testing [10]. There have been a number of research advances towards the modification of how the SSD condition of fine aggregate is determined to make the test less prone to error. These advances have also aimed at reducing the test time from about 24hrs to only a few hours.

AASHTO T-84 is currently used to determine the fine aggregate specific gravity and absorption. The method dates back to 1935 when the kerosene method, ASTM tentative method, cone method, and visual inspection method were evaluated in order to rank them in terms of which was the most promising. Results from this research showed that the cone method (AASHTO T-84) was the most favorable among the four test methods. The T-84 procedure requires approximately 1*kg* of the fine aggregate be immersed in water or soaked in at least 6% moisture and allowed to stand undisturbed for about 15hrs. The rationale behind the soaking of the fine aggregate is to enable the full water absorption potential of the aggregate pore surfaces to be satisfied before the specific gravity and absorption are measured in the laboratory. After soaking, the sample is decanted and spread flat on a nonabsorbent surface exposed to a gentle current of warm air, constantly stirred until surface dry, and a cone and tamp rod used to determine its SSD state. The subjectivity of the test in part is when a tester determines when the fine aggregate just slumps after removal of the cone and that in fact the slumped sample is uniformly representative of the approximately 1*kg* sample.

Attempts at measuring fine aggregate specific gravity based on thermodynamic principles were initiated by the Arizona Department of Transportation (ADOT) (Dana and Peters, [11]). Dana and Peters had sought to establish the SSD state of fine aggregates by soaking the sample and placing it in a small rotating drum. As the aggregates were rotated uniformly, hot air was issued through one end to dry it. An attached thermocouple, an electronic device that converted the temperature gradient into an electronic signal, was used to convey data to a digital recorder or sensor. The attainment of the SSD condition caused a sudden drop in the thermal gradient between the incoming and outgoing air. Their work established that the concept of monitoring the temperature gradient of incoming and outgoing air or the relative humidity of the outgoing air had positive results on a wide range of fine aggregates.

Further research on the initiative taken by Dana and Peters added the measurement of the humidity of the outgoing air to the temperature gradient principle [12]. The research demonstrated that the humidity of the outgoing air predicts the SSD condition more accurately than the temperature gradient. A significant recommendation of this work was the improved automation of the thermodynamic device to enable the operation to be stopped immediately after the SSD state is found, and also measuring the final mass of fine aggregate during the process. The device received enhanced modification by the National Center for Asphalt Technology (NCAT) but the repeatability and reproducibility of test results was poor.

In other fine aggregate research developments, the idea of establishing the SSD condition of fine aggregates by examining their flow under gravity off a tilted masonry trowel has been exploited [13]. This approach defines the SSD condition to be the state when the aggregates are capable of flowing off freely as discrete individual particles. A second proposed method by Krugler [13] involved placing the fine aggregate samples adjacent to oven-dry ones; and the SSD condition determined as the point where the test materials have the same color as the oven-dry aggregate. Another technique considered by Krugler was based upon sliding test samples along the bottom of a tilted pan. When the test sample failed to stick to the bottom and flowed freely, the SSD state was judged to have been reached.

The use of water-soluble glue to detect whether fines aggregates have achieved SSD or not was also developed, and compared to earlier methods at specific gravity measurement [13]. Krugler employed a strip of packaging tape (Supreme Super standard gummed paper tape, 5.08*cm* medium duty), attached it to a small block of wood and placed the wood with glue on the fine aggregate material. The proposition was that if for two trials not more than one test-sample particle adheres to the tape, the sample was judged to have attained the SSD condition.

Fine aggregates have been known to undergo color transformations with the presence of water on the particle's surfaces. This colimetric idea of establishing the SSD condition of fine aggregates has been studied and investigated by some researchers

[14]. The process basically uses a special chemical dye to achieve the same SSD requirements of the AASHTO T-84 procedure. The fine aggregate is first soaked in water containing the dye. When removed from the water, the aggregate which has now taken the color of the dye begins to dry. SSD is said to be reached when the aggregate changes from this color status after receiving dry current from a fan. Lee and Kandhal [14] noted that the dyes never showed well on dark-colored aggregates, exhibited non-uniform mixing when the fine aggregates were being dried, and the color change was highly subjective. These notable and problematic observations made this proposition impracticable and difficult.

Some important successes in specific gravity research worth mentioning are Saxer's absorption curve procedure [15], Hughes and Bahramain's saturated air-drying method [16], and Martin's wet and dry bulb temperature method [17]. These test methods required a high level of expertise to perform and to improve their practicability, extensive modifications were suggested.

Quite recently, automated equipments such as the SSDetect, AggPlus, and the Langley system have been developed to address the aforementioned limitations of AASHTO T-84. For example, the SSDetect, which is more scientific in nature, has been known to have statistically similar results with AASHTO T-84 according to research conducted on Oklahoma fine aggregates [18]. Cross [18] also demonstrated that the new SSDetect could have better repeatability than the traditional fine aggregate specific gravity and has great potential in replacing AASHTO T-84. Cross reported that this electronic innovation had great potential in specific gravity measurement since the vacuum sealed results were comparable to that of the AASHTO T-84.

Another significant scientific input towards improvement in specific gravity determination is the use of the vacuum sealing approach – a single test method [19]. The method measures specific gravity by using electronic vacuum sealing procedure to expel fine aggregates packed in standard polythene bags. Hall [19] observed also that tests of aggregate blends do not appear to be sensitive to nominal maximum aggregate size, gradation, nor mineralogy.

At Michigan Technological (Tech) University, researchers investigated the applicability of the automated helium pycnometer in fine aggregate specific gravity analysis in geotechnical engineering [1]. Current specific gravity test methods require soaking for close to 24hrs to satisfy most of the absorption potential. However, it is recognized that for some highly absorptive aggregates, not all of the effective pore space may be saturated after 24hrs. Helium gas, on the other hand, can more easily absorb into a material's effective pore space. The helium pycnometer uses the ideal gas law, $PV = nRT$, to determine the volume of a material based on pressure measurements of helium gas. By knowing the dry mass of a soil, the specific gravity of the aggregate can be determined.

Michigan Tech researchers explored another alternative [1] - the automated envelope density analyzer. This device determines the bulk volume or envelope volume of a sample by measuring the volume of a fine-grained material in a cylinder, and then again measuring the volume of the fine-grained material plus the sample. By finding the difference in volume between the two measurements, the bulk volume of the sample can be calculated and the bulk specific gravity determined. The findings concluded that the helium pycnometer can be used to automate the testing of aggregate to determine

Table 2. Techniques in Specific Gravity and Absorption Measurement (Literature Review).

Researcher(s)	Principle of Operation	Advantages	Disadvantages
Rea (1917)	Aggregate voids sealing with kerosene	Simple and inexpensive	Problematic with clayey and finer aggregates
Pearson (1929)	Ability of damp sand to stick to sides of Erlenmeyer flask	Simple and inexpensive	Underestimates water absorption
Pearson (1933)	Titration method	Simple and inexpensive	SSD state is difficult to judge
Myers (1935)/ AASHTO T 84	Aggregate slump in cone to measure SSD state	Test equipment is less expensive	Less scientific, time consuming
Dana and Peters(1974)	Thermodynamics; Thermal gradient analysis to find SSD	Showed great promise	Expensive equipment, skilled personnel required
Kandhal et al(2000)	Humidity and temperature to predict the SSD state	More accurate than thermodynamics approach	Less automation, requires skilled labor
Krugler et al(1992)	Discrete particle flow under gravity colimetric approach; water-glue property	Correlates well with aggregate physical and chemical properties	Subjective method, operator dependent, limited aggregate tested
Vitton (et al. (1999)	Helium pycnometry	Test is easy to operate and equipment is inexpensive	Limited range of aggregates tested
Saxer(1956)	Absorption curve procedure	Test is easy to operate and is inexpensive	Less automated
Hughes and Bahramain (1967)	Saturated air-drying method	Test is easy to operate and equipment are inexpensive	Less automated
Martin(1950)	Wet and dry bulb temperature approach	Inexpensive equipment	Highly skilled personnel required
Cross et al.(2006) You et al. (2008)	Reflection of light rays	Method is highly automated and reliable	Limited range of aggregates tested
Prowell and Baker 2005	Vacuum sealing of fine aggregate material	Method is highly automated and reliable, reproducible and accurate	May need possible calibration, limited range of aggregates tested

apparent specific gravity. A combination of the helium pycnometer and the envelope density analyzer can be used to calculate the absorption and bulk specific gravity (SSD).

In Michigan Technological University, You et al. [20] conducted research on the fine aggregate specific gravity by comparing the SSDetect and AASHTO T-84. It was found that the SSDetect and AASHTO T-84 had very good correlation in specific gravity. This paper is based upon the existing work and expanded tested materials.

There are some other methods such as a gamma-ray method (Core Reader), Paraffin-Coated test, and other methods used in HMA and Portland cement concrete (PCC) materials testing. The CoreLok (vacuum sealing) method has been evaluated further by a number of state transportation agencies and many universities [21]. Table 2 is a summary of some of the research work conducted for fine aggregate specific gravity testing. In coarse aggregate specific gravity testing, studies were shown in a number of research projects such as the vacuum saturation approach proposed by Mills-Beale et al. [22] for several of aggregates and Mills-Beale and You [23] for steel slag and recycled concrete. The coarse aggregates work is not discussed further in this paper since the focus of this paper is in fine aggregates.

SSDetect Test Principle

The SSDetect device works on the basic principle of the laws of reflection. Objects can be seen by their characteristic nature of reflecting light rays that fall on them. The reflected light rays conform to the scientific law of reflection, which in simpler terms proves that the angle of reflection is equal and opposite to that of the angle of incidence. The law of reflection is represented pictorially in Fig. 1.

Some objects however exhibit scattering of light rays - a phenomenon which occurs when light rays are reflected at a number of angles after the incident rays fall on uneven or granular surfaces. Fine aggregates, like most materials, obey the law of reflection when viewed on the microscopic level but since the irregularities on its surface are larger than the wavelength of light, the light is reflected in many directions. The SSDetect operates on this principle to ascertain the SSD state of the fine aggregates when thin films of moisture are coated on the particles. The surface moisture causes diffusive reflection of the rays which are then picked up by the laser system in the SSDetect unit.

In the automated SSDetect procedure, the characteristic wetting curve of the fine aggregate material has to be established. This value, defined by Barnstead International, manufacturers of the SSDetect, as the Film Coefficient, is obtained by the Baseline Test, and was derived empirically as the minimum amount of water needed to wet the surface of the fine aggregate. The pre-determined Film Coefficient value is used as a parameter in the SSDetect, and with a 500*g* sample in the SSDetect bowl, the test operation commences to find the SSD state of the fine aggregate. The final step involves the determination of the mass of the SSDetect bowl plus SSD sample, from which the computation of the specific gravity and absorption is done.

Scope of Materials

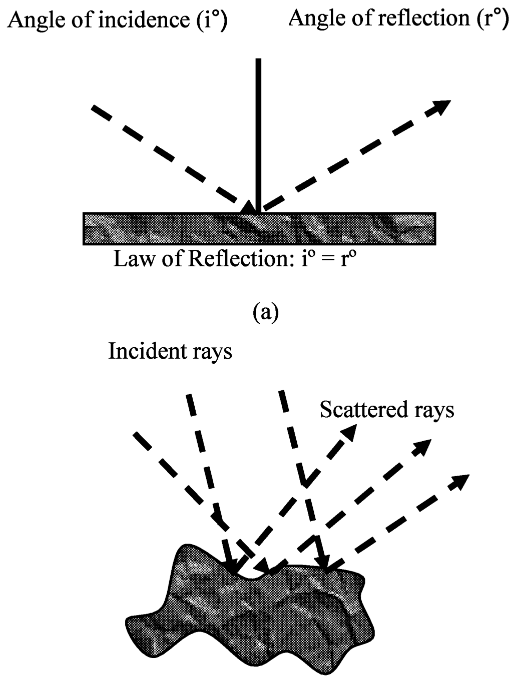


Fig. 1. (a) The Law of Reflection of Light on an Even Surface, (b) Scattering of Light Rays on an Uneven Surface (Fine Aggregate).

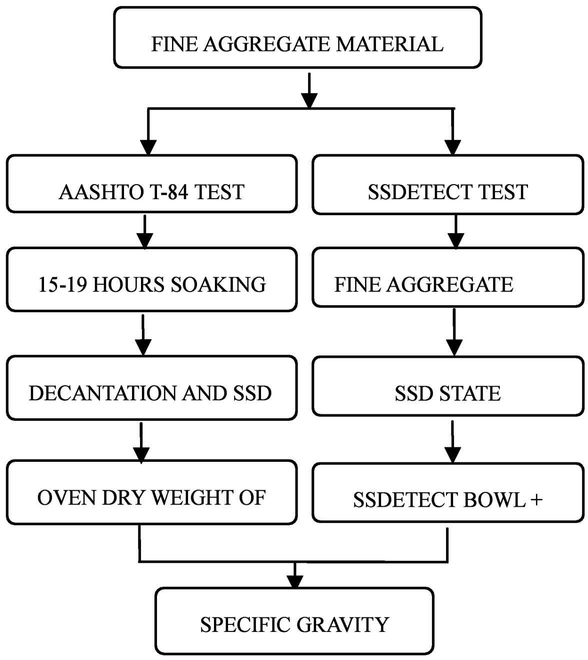


Fig. 2. Flow Chart Indicating the Processes Carried out in the Research.

The aggregates used in the research work were typical of those found in the state of Michigan. Sand and gravel are two of the most important sources of fine aggregates commonly found throughout the northern part of the United States due to glacial deposits and occur in other parts of the United States from old lake or river beds.

The research considered a range of fine aggregate source materials with varying gradations to determine if they were comparable to

Table 3. (a) Single Gradation and 'as Received' Fine Aggregate Materials Tested, (b) Blended Fine Aggregates Tested (MDOT Designation).

(a)

Material	Gradation Retained (*mm*)
RJH (Crushed Natural Gravel)	2.360
MHL (Crushed Limestone)	1.180
RJH (Crushed Steel Slag)	0.600
Ross 2006 (Natural Sand)	0.300
FMS 2324-2006 (Fine Manufactured Sand)	0.150
FMS 2354-2006 (Fine Sand)	2.360
	1.180
	0.600
FMS 2370-2006 (Manufactured Sand)	2.360
	1.180
	0.600
	0.300
	0.150
	0.075
HMA 5E10-MKF (Sand/Gravel Blends)	as Received Fine Aggregate
HMA 5E10-MKF (Sand/Gravel Blends)	as Received Fine Aggregate
HMA 5E10-AIF (Sand/Gravel Blends)	as Received Fine Aggregate
HMA 5E10-NLF (Sand/Gravel Blends)	as Received Fine Aggregate
HMA 4E10-ARF (Sand/Gravel Blends)	as Received Fine Aggregate
HMA 3E10-APF (Sand/Gravel Blends)	as Received Fine Aggregate
HMA 2E10-APF (Sand/Gravel Blends)	as Received Fine Aggregate
HMA 5E3 GMF (Sand/Gravel Blends)	as Received Fine Aggregate
HMA 2E10-SLF (Sand/Gravel Blends)	as Received Fine Aggregate
HMA 3E3-GMF (Sand/Gravel Blends)	as Received Fine Aggregate

(b)

Material	MDOT Blend Designation	Total Percent Passing					
		# 4	# 8	# 16	# 30	# 50	# 100
Natural Sand, Fine and Manufactured Sand, Limestone, Gravel, and Slag Fines	2NS	100	65	35	20	10	0
	2SS	100	80	50	25	15	0
	2MS	100	5	0	0	30	0

AASHTO T-84. Fine materials that have been used in this study are listed in Table 3. The four source materials shown with the various sieve sizes were tested for specific gravity and absorption values measured by the SSDetect each sieve fraction as indicated, while the last 10 source materials in the table were tested as "as Received" gradation ranging in sieve size from the 4.75 to 0.075*mm* sieve. The Ross 2006, FMS 2354-2006, FMS 2370-2006, and FMS 2324-2006 fine aggregates had 44, 58, 51, and 50% carbonate minerals respectively. Siliceous and other minerals contained in the Ross, 2354, 2370, and 2324 were 56, 42, 49, and 50%, respectively. In addition to the blended "as Received" fine aggregate blend, a number of the aggregates were blended to attain Michigan Department of Transportation (MDOT) specifications, namely gradations. These materials were tested with the SSDetect device. The MDOT blended gradations that were used in this analysis are shown in Table 3.

Methodology

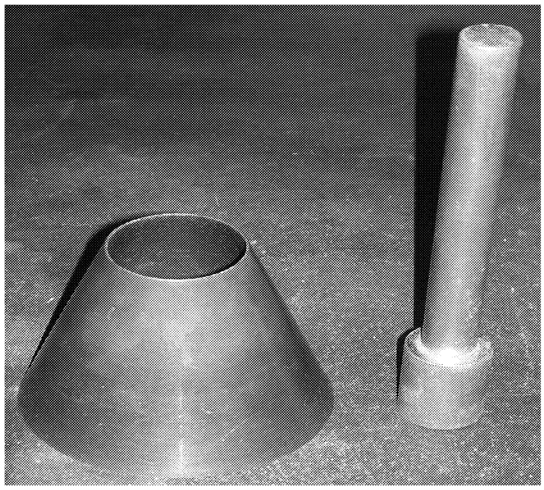


Fig. 3. The Frustum Cone and Tamp Rod.

The research methodology involved obtaining the specific gravities and absorption percentages of the fine aggregate materials using the AASHTO T-84 and SSDetect methods.

The experimental plan involved carrying out three replicate tests on the individual gradations of each material. The calculated average specific gravity and absorption for the three replicate tests were taken as the specific gravity and absorption values respectively for the tested gradation. Fig. 2 is a flow chart that summarizes the test procedure in a sequential order.

Standard AASHTO T-84 Test Method

The fine aggregates were initially tested according to AASHTO T-84, *Standard Test Method of Test for Specific Gravity and Absorption of Fine Aggregate*. About 1000*g* of the fine aggregate, sampled using the AASHTO T-248 Test Procedure, *Reducing Field Samples of Aggregates to Testing Sizes*, was dried at a constant temperature of 110 ± 5°C. Upon cooling to handling temperature, the material was immersed in 6% moisture and allowed to stand overnight for 15hrs. The water was decanted and spread on a flat non-absorbent surface. With the aid of moving current from a hair drier, the fine aggregates were continuously dried and stirred. Within intervals, portions of the partially dried fine aggregates were put in the frustum cone, and made to heap above the top of the mold. 25 light blows of the tamping rod are applied to the fine aggregate, and into the mold. The slight slump of the tested aggregates gave an indication of the SSD state. The frustum cone and tamping rod used is shown in Fig. 3. The mathematical calculations of the specific gravities were conducted according to the formulae in the Appendix of the AASHTO T-84 test procedure.

SSDetect Test Method

The new SSDetect basically involves a 2-step procedure: determination of the film coefficient and infra-red detection of the SSD condition of the fine aggregate sample. Figs. 4(a) and 4(b) show the SSDetect chamber with the Automated Vacuum Unit (AVU), and the internal components of the SSDetect Chamber, respectively.

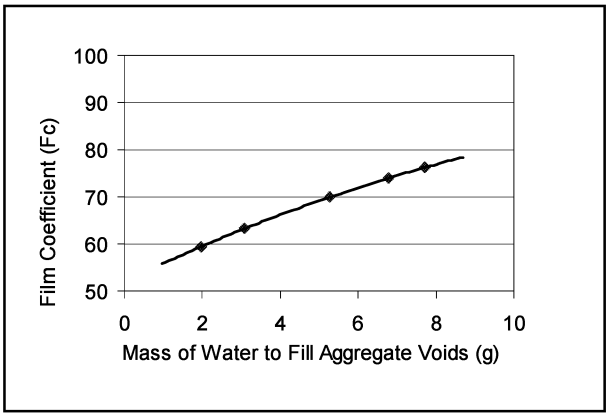


Fig. 5. Film Coefficient Curve for the Fine Sand Aggregate.

Film Coefficient Determination

The film coefficient or "Baseline" test was conducted to determine the minimum amount of water needed to form an effective film coating on a unit fine aggregate particle. 500*g* of the fine aggregate and 250*ml* of water was put into a pycnometer, and water filled to the calibration line before the final total mass was found. After vacuum agitating the pycnometer with contents using the Automated Vacuum Unit (AVM), water was refilled back to the calibration line and total mass of pycnometer plus contents determined. This film coefficient value, which is empirical and increases as aggregate size increases, was calculated by the following formula:

$$F_c = 52 + 4x - (0.11x^2) \quad (1)$$

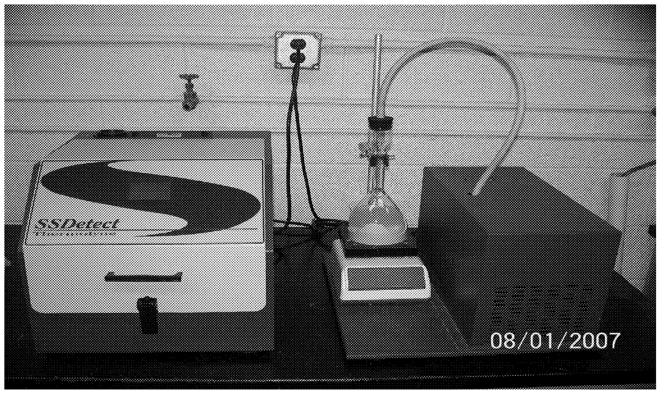
Where:
F_c is the film coefficient value and x is the difference between the initial and final mass of the pycnometer and its contents.

A plot of the film coefficient of a characteristic film coefficient curve for the fine sand aggregate material used in this research is shown is Fig. 5.

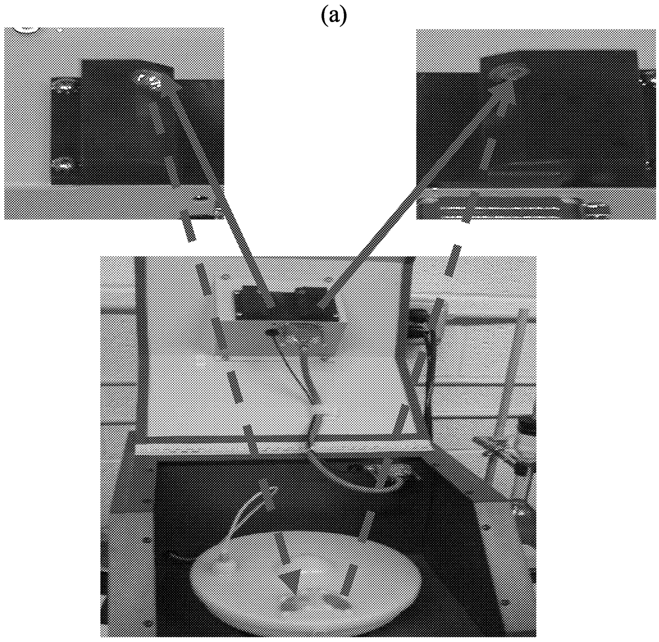
Infra-Red Detection of SSD Condition of Fine Aggregates

A second 500*g* of the fine aggregate was put into the special SSDetect bowl and the film coefficient value entered into the system input screen. The special SSDetect bowl has been designed specifically, in terms of dimensions and style, to ensure the complete orbital mixing of the fine aggregate material before it attains the SSD state. Once initiated, the SSDetect unit injected water through a nozzle mounted on the lid of the test bowl into the flow of the material. The SSDetect mixes the fine aggregate inside the bowl by using an orbital motion. Through capillary action and hysteresis, the water is absorbed into the pores of the aggregate. The forces of capillary and hysteresis act very strongly to pull water into the aggregate pores quickly. Upon satisfying the optimum water potential of the fine aggregate pores, the water begins to gather on the surface of the aggregate.

As the process continued, infra-red rays were transmitted through a transparent lens on the top of the bowl unto the fine aggregate surface. The reflected infra-red rays then indicated the SSD state of the fine aggregate. The test duration is approximately 2hrs. After the test, the mass of the SSD sample was determined, and the difference between the 500*g* fine aggregate and final SSD mass calculated as the water absorbed during the SSDetect test.



(a)



(b)

Fig. 4. (a) The SSDetect with Automated Vacuum Unit (AVU), (b) Internal Components of the SSDetect.

SSDetect Mathematical Relationships

Finding the specific gravity and percent absorption with the SSDetect of the fine aggregate involves the following mathematical computations:

$$Gsb\ (Dry) = A/(A+B-C+D) \quad (2)$$

$$Gsb\ (SSD) = (A+D)/(A+B-C+D) \quad (3)$$

$$Gsa = E/(E+B-C) \quad (4)$$

$$Wa\% = (D/A) \times 100 \quad (5)$$

Where:
A is the dry sample mass in SSDetect bowl in grams,

Table 4. *Gsb* (Dry) and Standard Deviation Results for T-84 and SSDetect.

		Bulk Specific Gravity (Dry)			
Material	Gradation	T-84 Average	SSDetect Average	T-84 St. Dev.	SSDetect St. Dev.
Ross 2006 (Natural Sand)	2.36*mm* (No. 8)	2.595	2.623	0.014	0.002
	1.18*mm* (No. 16)	2.547	2.574	0.073	0.004
	0.600*mm* (No. 30)	2.596	2.618	0.010	0.003
	0.300*mm* (No. 50)	2.613	2.628	0.055	0.006
	0.150*mm* (No. 100)	2.637	2.669	0.022	0.011
FMS 2324 - 2006 (Fine Manufactured Sand)	2.36*mm* (No. 8)	2.583	2.615	0.004	0.015
	1.18*mm* (No. 16)	2.562	2.564	0.011	0.019
	0.600*mm* (No. 30)	2.582	2.584	0.007	0.012
	0.300*mm* (No. 50)	2.615	2.602	0.006	0.017
	0.150*mm* (No. 100)	2.658	2.663	0.021	0.005
FMS 2354 - 2006 (Fine Sand)	0.0937 (2.36)	2.586	2.594	0.003	0.004
	0.0467 (1.18)	2.572	2.594	0.005	0.003
	0.0234 (0.600)	2.578	2.588	0.008	0.016
FMS 2370 - 2006 (Manufactured Sand)	2.36*mm* (No. 8)	2.609	2.637	0.007	0.003
	1.18*mm* (No. 16)	2.581	2.592	0.016	0.006
	0.600*mm* (No. 30)	2.583	2.578	0.007	0.001
	0.300*mm* (No. 50)	2.590	2.563	0.023	0.004
	0.150*mm* (No. 100)	2.595	2.624	0.030	0.019
	0.075*mm* (No. 200)	2.526	2.565	0.007	0.013
RJH1 - 2006 (Crushed Natural Gravel)	2.36*mm* (No. 8)	2.644	2.659	0.011	0.021
	1.18*mm* (No. 16)	2.606	2.615	0.007	0.017
	0.600*mm* (No. 30)	2.596	2.607	0.004	0.025
	0.300*mm* (No. 50)	2.565	2.581	0.007	0.028
	0.150*mm* (No. 100)	2.519	2.541	0.027	0.028
MHL-2006 (Crushed Limestone)	2.36*mm* (No. 8)	2.703	2.726	0.006	0.016
	1.18*mm* (No. 16)	2.695	2.670	0.003	0.017
	0.600*mm* (No. 30)	2.728	2.740	0.022	0.014
	0.300*mm* (No. 50)	2.668	2.654	0.011	0.008
	0.150*mm* (No. 100)	2.620	2.627	0.003	0.015
MHL-2006 (Crushed Steel Slag)	2.36*mm* (No. 8)	2.788	2.775	0.008	0.006
	1.18*mm* (No. 16)	2.784	2.771	0.008	0.019
	0.600*mm* (No. 30)	2.776	2.763	0.020	0.013
	0.300*mm* (No. 50)	2.739	2.725	0.012	0.009
	0.150*mm* (No. 100)	2.734	2.724	0.010	0.002
HMA 5E10 - MLK1	Blended	2.657	2.656	0.016	0.009
HMA 5E10 - MKF2	Blended	2.659	2.643	0.015	0.004
HMA 5E10 - AIF	Blended	2.671	2.646	0.008	0.002
HMA 5E10 - NLF	Blended	2.671	2.656	0.031	0.002
HMA 4E10 - ARF	Blended	2.660	2.689	0.018	0.001
HMA 3E10 - APF	Blended	2.662	2.629	0.004	0.012
HMA 2E10 - APF	Blended	2.628	2.635	0.027	0.032
HMA 5E3 - GMF	Blended	2.615	2.630	0.009	0.003
HMA 4E3 - SLF	Blended	2.619	2.599	0.043	0.008
HMA 3E3 - GMF	Blended	2.631	2.622	0.013	0.004

B is the mass of volumetric flask filled with water in grams,

C is the final mass in grams of flask with contents in film coefficient determination,

D is the water absorbed by the 500*g* fine aggregate in the SSDetect bowl, and

E is the mass in grams of dry aggregate in film coefficient determination test.

Blended Specific Gravity and Calculated Specific Gravity

In the standard AASHTO T-84 specific gravity and absorption testing, blended fine aggregates are tested in two ways: testing the blended fine aggregate together or using the proportionate formula to find a calculated blended specific gravity and absorption value.

The calculated specific gravity is obtained using the formula below:

$$Gsb_c = 1/[(Pb_1/Gsb_1) + (Pb_2/Gsb_2) + (Pb_3/Gsb_3) + ...] \quad (6)$$

Where:

Gsb_c is the specific gravities at either dry, SSD, or apparent conditions, Gsb_1, Gsb_2, and Gsb_3 are the specific gravities of the first, second, and third individual fine aggregates used in the total blend, and Pb_1, Pb_2, and Pb_3 are the percentage contributions of the first, second, and third individual fine aggregates used in the total blend.

Table 5. *Gsb* (SSD) and Standard Deviation Results for T-84 and SSDetect.

		Bulk Specific Gravity (SSD)			
Material	Gradation	T-84 Average	SSDetect Average	T-84 St. Dev.	SSDetect St. Dev.
Ross 2006 (Natural Sand)	2.36*mm* (No. 8)	2.660	2.670	0.010	0.001
	1.18*mm* (No. 16)	2.613	2.624	0.043	0.002
	0.600*mm* (No. 30)	2.650	2.656	0.006	0.002
	0.300*mm* (No. 50)	2.660	2.666	0.028	0.002
	0.150*mm* (No. 100)	2.676	2.687	0.016	0.006
FMS 2324 - 2006 (Fine Manufactured Sand)	2.36*mm* (No. 8)	2.642	2.654	0.005	0.009
	1.18*mm* (No. 16)	2.626	2.618	0.011	0.010
	0.600*mm* (No. 30)	2.634	2.627	0.006	0.007
	0.300*mm* (No. 50)	2.650	2.634	0.007	0.012
	0.150*mm* (No. 100)	2.701	2.691	0.008	0.005
FMS 2354 - 2006 (Fine Sand)	0.0937 (2.36)	2.650	2.654	0.003	0.004
	0.0467 (1.18)	2.648	2.653	0.002	0.003
	0.0234 (0.600)	2.648	2.651	0.008	0.012
FMS 2370 - 2006 (Manufactured Sand)	2.36*mm* (No. 8)	2.667	2.677	0.005	0.004
	1.18*mm* (No. 16)	2.652	2.643	0.011	0.003
	0.600*mm* (No. 30)	2.649	2.636	0.004	0.001
	0.300*mm* (No. 50)	2.642	2.696	0.024	0.002
	0.150*mm* (No. 100)	2.652	2.662	0.030	0.015
	0.075*mm* (No. 200)	2.577	2.599	0.007	0.011
RJH1 - 2006 (Crushed Natural Gravel)	2.36*mm* (No. 8)	2.702	2.691	0.008	0.017
	1.18*mm* (No. 16)	2.667	2.660	0.006	0.012
	0.600*mm* (No. 30)	2.663	2.654	0.002	0.021
	0.300*mm* (No. 50)	2.633	2.619	0.004	0.025
	0.150*mm* (No. 100)	2.586	2.592	0.034	0.025
MHL-2006 (Crushed Limestone)	2.36*mm* (No. 8)	2.769	2.760	0.006	0.016
	1.18*mm* (No. 16)	2.761	2.724	0.003	0.017
	0.600*mm* (No. 30)	2.773	2.776	0.022	0.014
	0.300*mm* (No. 50)	2.726	2.718	0.011	0.008
	0.150*mm* (No. 100)	2.682	2.704	0.003	0.015
MHL-2006 (Crushed Steel Slag)	2.36*mm* (No. 8)	2.813	2.794	0.002	0.005
	1.18*mm* (No. 16)	2.810	2.794	0.004	0.018
	0.600*mm* (No. 30)	2.803	2.813	0.006	0.015
	0.300*mm* (No. 50)	2.781	2.789	0.009	0.008
	0.150*mm* (No. 100)	2.781	2.798	0.009	0.001
HMA 5E10 - MLK1	Blended	2.691	2.684	0.014	0.009
HMA 5E10 - MKF2	Blended	2.730	2.707	0.012	0.004
HMA 5E10 - AIF	Blended	2.714	2.687	0.008	0.001
HMA 5E10 - NLF	Blended	2.707	2.696	0.030	0.002
HMA 4E10 - ARF	Blended	2.723	2.731	0.013	0.002
HMA 3E10 - APF	Blended	2.702	2.691	0.008	0.011
HMA 2E10 - APF	Blended	2.679	2.680	0.019	0.037
HMA 5E3 - GMF	Blended	2.667	2.668	0.005	0.002
HMA 4E3 - SLF	Blended	2.684	2.657	0.029	0.005
HMA 3E3 - GMF	Blended	2.682	2.688	0.005	0.002

To determine whether the calculated blend values were comparable to the SSDetect values for the blend, the prepared MDOT blends were tested with the SSDetect and their individual gradation values used to obtain the calculated values.

Test Results

Individual Gradations and "as Received" Fine Aggregates

The results of the source aggregates (individual gradations) and the "as Received" fine aggregates are summarized in this section separately. Table 4, 5, 6, and 7 in the list of tables section gives detailed results of the all the *Gsb* (dry), *Gsb* (SSD), *Gsa*, and *Wa %* tests for both AASHTO T-84 and SSDetect, and their standard deviations values.

Bulk Specific Gravity (Dry)

The plot of bulk specific gravity (dry) relationship between the AASHTO T-84 and SSDetect showed a good relationship with a R^2 of 0.921 and is shown in Fig. 6. A large percentage of the fine aggregates tested, 97.7% (42 of 44), satisfied the AASHTO T-84 acceptable standard specification range (single-operator precision) of 0.032 for any similar given fine aggregate material. The paired t-test for mean *Gsb* (dry) analysis at the 95% significance level showed that there was no significant difference between the two methods. The confidence interval for difference in mean *Gsb* (dry) was found to be (-0.0108, 0.0008) about the mean values.

Table 6. *Gsa* and Standard Deviation Results for T-84 and SSDetect.

		Apparent Specific Gravity (*Gsa*)			
Material	Gradation	T-84 Average	SSDetect Average	T-84 St. Dev.	SSDetect St. Dev.
Ross 2006 (Natural Sand)	2.36*mm* (No. 8)	2.773	2.753	0.006	0.002
	1.18*mm* (No. 16)	2.727	2.710	0.049	0.004
	0.600*mm* (No. 30)	2.745	2.721	0.002	0.002
	0.300*mm* (No. 50)	2.742	2.731	0.040	0.006
	0.150*mm* (No. 100)	2.743	2.720	0.006	0.003
FMS 2324 - 2006 (Fine Manufactured Sand)	2.36*mm* (No. 8)	2.746	2.720	0.007	0.002
	1.18*mm* (No. 16)	2.737	2.711	0.012	0.010
	0.600*mm* (No. 30)	2.724	2.702	0.006	0.002
	0.300*mm* (No. 50)	2.709	2.688	0.006	0.017
	0.150*mm* (No. 100)	2.777	2.739	0.031	0.005
FMS 2354 - 2006 (Fine Sand)	0.0937 (2.36)	2.764	2.759	0.003	0.008
	0.0467 (1.18)	2.783	2.756	0.005	0.004
	0.0234 (0.600)	2.774	2.762	0.008	0.009
FMS 2370 - 2006 (Manufactured Sand)	2.36*mm* (No. 8)	2.768	2.747	0.004	0.006
	1.18*mm* (No. 16)	2.779	2.730	0.006	0.002
	0.600*mm* (No. 30)	2.765	2.737	0.002	0.001
	0.300*mm* (No. 50)	2.733	2.787	0.028	0.010
	0.150*mm* (No. 100)	2.754	2.727	0.048	0.009
	0.075*mm* (No. 200)	2.661	2.654	0.007	0.008
RJH1 - 2006 (Crushed Natural Gravel)	2.36*mm* (No. 8)	2.807	2.748	0.006	0.012
	1.18*mm* (No. 16)	2.776	2.737	0.008	0.006
	0.600*mm* (No. 30)	2.782	2.733	0.004	0.016
	0.300*mm* (No. 50)	2.753	2.681	0.015	0.022
	0.150*mm* (No. 100)	2.698	2.677	0.047	0.022
MHL-2006 (Crushed Limestone)	2.36*mm* (No. 8)	2.893	2.821	0.008	0.003
	1.18*mm* (No. 16)	2.887	2.821	0.004	0.006
	0.600*mm* (No. 30)	2.855	2.840	0.009	0.023
	0.300*mm* (No. 50)	2.833	2.837	0.038	0.012
	0.150*mm* (No. 100)	2.794	2.845	0.020	0.002
MHL-2006 (Crushed Steel Slag)	2.36*mm* (No. 8)	2.858	2.831	0.018	0.003
	1.18*mm* (No. 16)	2.858	2.837	0.019	0.016
	0.600*mm* (No. 30)	2.852	2.910	0.011	0.008
	0.300*mm* (No. 50)	2.860	2.910	0.008	0.009
	0.150*mm* (No. 100)	2.870	2.943	0.010	0.001
HMA 5E10 - MLK1	Blended	2.750	2.732	0.014	0.009
HMA 5E10 - MKF2	Blended	2.862	2.822	0.007	0.003
HMA 5E10 - AIF	Blended	2.791	2.759	0.012	0.002
HMA 5E10 - NLF	Blended	2.770	2.768	0.030	0.001
HMA 4E10 - ARF	Blended	2.840	2.809	0.004	0.008
HMA 3E10 - APF	Blended	2.774	2.803	0.006	0.009
HMA 2E10 - APF	Blended	2.769	2.728	0.006	0.005
HMA 5E3 - GMF	Blended	2.758	2.732	0.002	0.001
HMA 4E3 - SLF	Blended	2.801	2.789	0.036	0.052
HMA 3E3 - GMF	Blended	2.772	2.808	0.000	0.001

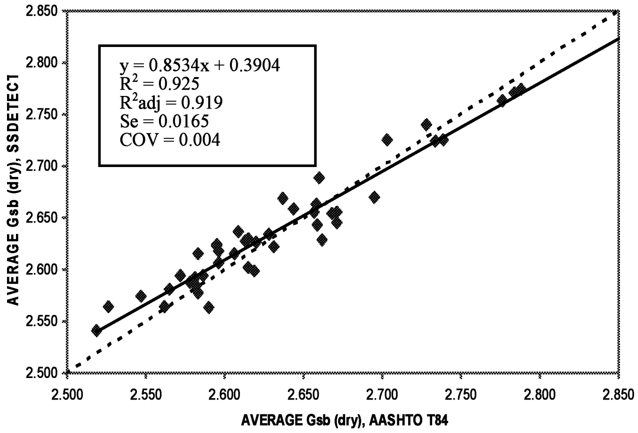


Fig. 6. AASHTO T-84 against SSDetect Bulk Specific Gravity (dry).

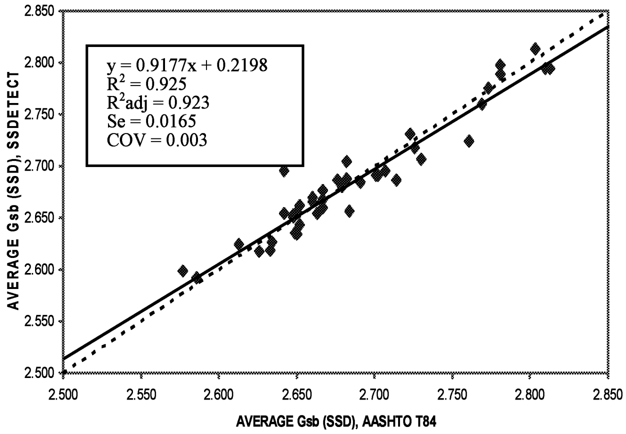


Fig. 7. AASHTO T-84 against SSDetect Bulk Specific Gravity (SSD).

Table 7. *Wa %* and Standard Deviation results for T-84 and SSDetect.

		Water Absorption (*Wa %*)			
Material	Gradation	T-84 Average	SSDetect Average	T-84 St. Dev	SSDetect St. Dev.
Ross 2006 (Natural Sand)	2.36*mm* (No. 8)	2.470	1.793	0.115	0.058
	1.18*mm* (No. 16)	2.586	1.947	0.289	0.046
	0.600*mm* (No. 30)	2.090	1.447	0.170	0.023
	0.300*mm* (No. 50)	1.799	1.440	0.210	0.151
	0.150*mm* (No. 100)	1.455	0.707	0.226	0.196
FMS 2324 - 2006 (Fine Manufactured Sand)	2.36*mm* (No. 8)	2.302	1.473	0.066	0.250
	1.18*mm* (No. 16)	2.496	2.107	0.102	0.284
	0.600*mm* (No. 30)	2.016	1.693	0.082	0.180
	0.300*mm* (No. 50)	1.313	1.240	0.033	0.197
	0.150*mm* (No. 100)	1.602	1.033	0.669	0.031
FMS 2354 - 2006 (Fine Sand)	2.36*mm* (No. 8)	2.494	2.307	0.068	0.115
	1.18*mm* (No. 16)	2.945	2.273	0.103	0.058
	0.600*mm* (No. 30)	2.741	2.440	0.212	0.200
FMS 2370 - 2006 (Manufactured Sand)	2.36*mm* (No. 8)	2.199	1.520	0.082	0.053
	1.18*mm* (No. 16)	2.774	1.953	0.191	0.115
	0.600*mm* (No. 30)	2.542	2.247	0.099	0.012
	0.300*mm* (No. 50)	2.024	1.927	0.103	0.185
	0.150*mm* (No. 100)	2.222	1.440	0.778	0.183
	#200	2.019	1.307	0.038	0.115
RJH1 - 2006 (Crushed Natural Gravel)	2.36*mm* (No. 8)	2.194	1.220	0.142	0.139
	1.18*mm* (No. 16)	2.347	1.707	0.116	0.232
	0.600*mm* (No. 30)	2.578	1.767	0.106	0.194
	0.300*mm* (No. 50)	2.663	1.440	0.280	0.122
	0.150*mm* (No. 100)	2.628	1.993	0.222	0.122
MHL-2006 (Crushed Limestone)	2.36*mm* (No. 8)	2.438	1.240	0.183	0.200
	1.18*mm* (No. 16)	2.473	2.007	0.074	0.170
	0.600*mm* (No. 30)	1.627	1.287	0.359	0.990
	0.300*mm* (No. 50)	2.181	2.427	0.436	0.061
	0.150*mm* (No. 100)	2.376	2.907	0.294	0.221
MHL-2006 (Crushed Steel Slag)	2.36*mm* (No. 8)	0.875	0.713	0.309	0.042
	1.18*mm* (No. 16)	0.929	0.847	0.300	0.050
	0.600*mm* (No. 30)	0.949	1.840	0.274	0.200
	0.300*mm* (No. 50)	1.537	2.340	0.158	0.020
	0.150*mm* (No. 100)	1.729	2.740	0.108	0.040
HMA 5E10 - MLK1	Blended	1.275	1.040	0.108	0.002
HMA 5E10 - MKF2	Blended	2.668	2.400	0.127	0.020
HMA 5E10 - AIF	Blended	1.612	1.547	0.124	0.042
HMA 5E10 - NLF	Blended	1.345	1.520	0.078	0.020
HMA 4E10 - ARF	Blended	2.382	1.593	0.212	0.115
HMA 3E10 - APF	Blended	1.523	2.367	0.006	0.070
HMA 2E10 - APF	Blended	1.937	1.707	0.306	0.220
HMA 5E3 - GMF	Blended	1.991	1.420	0.147	0.020
HMA 4E3 - SLF	Blended	2.484	2.213	0.779	0.142
HMA 3E3 - GMF	Blended	1.930	2.533	0.189	0.061

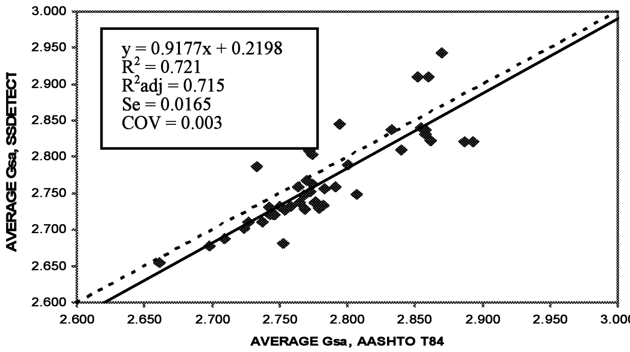


Fig. 8. AASHTO T-84 against SSDetect Bulk Specific Gravity (*Gsa*). Bulk Specific Gravity (SSD).

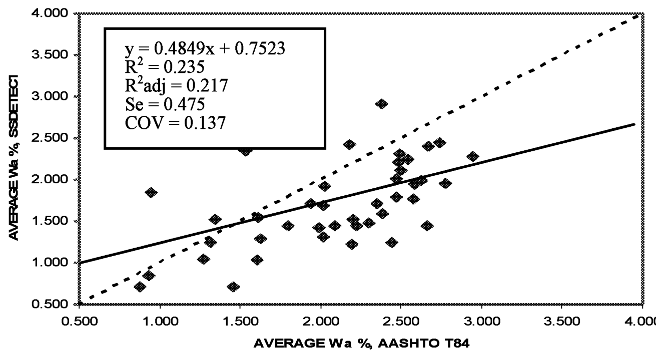


Fig. 9. AASHTO T-84 against SSDetect Water Absorption (*Wa %*).

The coefficient of correlation for the *Gsb* (SSD) was good with a R^2 of 0.925 and is shown in Fig. 7. For the *Gsb* (SSD), 97.7% of the results satisfied the acceptable standard specification range (single-operator precision) of 0.027 representing 42 out of the 44 results. The results also showed no statistical difference at the 95% level of significance with a confidence range of between -0.0039 and 0.0059 about the mean values.

Apparent Specific Gravity (Gsa)

Approximately two thirds, 28 out of the 43 results, satisfied the mean difference range of between 0.0056 and 0.0264, the paired AASHTO T-84 range (single-operator precision) of 0.027 with a R^2 coefficient of 0.721 and is summarized in Fig. 8. With a t-test showed a significant difference between the measurements of the two methods at a 95% level of significance.

Water Absorption (Wa %)

The coefficient of determination was poor with a R^2 of 0.235 and is shown in Fig. 9. 14 of the 44 results (97.7%) satisfied the acceptable standard specification range (single-operator precision) of 0.31. The results also showed statistical difference at the 95% level of significance with a confidence range of between 0.634 and 0.310 about the mean values.

Spearman Correlation Coefficients

Table 8 summarizes the correlation coefficients between AASHTO T-84 and the SSDetect methods for determining the *Gsb* (dry), *Gsb* (SSD), *Gsa*, and *Wa %*. The correlation coefficients are high for *Gsb* (dry), *Gsb* (SSD), and *Gsa* for the two different methods; with all of the values greater than 0.80. However, the correlation coefficient between the two methods is rather low, 0.405, for the *Wa %*.

Table 8. Spearman Correlation Coefficients.

TEST METHOD / RESULT		AASHTO T84			
		Gsb (dry)	Gsb (SSD)	Gsa	Wa %
SSDETECT	Gsb (dry)	0.894			
	Gsb (SSD)		0.899		
	Gsa			0.801	
	Wa %				0.405

Table 9. Summary of (a) LSD and (b) Tukey Means Testing.

(a)

Sieve Comparison	AASHTO T-84				SSDetect			
	Gsb, dry	*Gsb*, ssd	*Gsa*	*Wa*	*Gsb*, dry	*Gsb*, ssd	*Gsa*	*Wa*
#8 vs. #16	Yes	Yes	No	No	Yes	Yes	No	Yes
#8 vs. #30	No	No	Yes	No	Yes	No	No	Yes
#8 vs. #50	No	Yes	Yes	No	Yes	No	No	Yes
#8 vs. #100	No	Yes	Yes	No	Yes	No	No	Yes
#8 vs. #200	Yes	Yes	Yes	No	Yes	Yes	Yes	No
#16 vs. #30	No	No	No	Yes	No	No	No	No
#16 vs. #50	No	No	Yes	Yes	No	No	No	No
#16 vs. #100	No	No	Yes	Yes	No	Yes	Yes	No
#16 vs. #200	Yes	Yes	Yes	No	Yes	Yes	Yes	No
#30 vs. #50	No	No	No	No	No	No	No	No
#30 vs. #100	No	No	No	No	No	No	No	No
#30 vs. #200	Yes	Yes	Yes	No	Yes	Yes	Yes	No
#50 vs. #100	No	No	No	No	No	No	No	No
#50 vs. #200	Yes	Yes	Yes	No	Yes	Yes	Yes	No
#100 vs. #200	Yes	Yes	Yes	No	Yes	Yes	Yes	No

(b)

Sieve Comparison	AASHTO T-84				SSDetect			
	Gsb, dry	*Gsb*, ssd	*Gsa*	*Wa*	*Gsb*, dry	*Gsb*, ssd	*Gsa*	*Wa*
#8 vs. #16	No	No	No	No	Yes	Yes	No	No
#8 vs. #30	No	No	No	No	No	No	No	No
#8 vs. #50	No	No	Yes	No	Yes	No	No	No
#8 vs. #100	No	No	Yes	No	No	No	No	No
#8 vs. #200	Yes	Yes	Yes	No	Yes	Yes	Yes	No
#16 vs. #30	No	No	No	No	No	No	No	No
#16 vs. #50	No	No	No	Yes	No	No	No	No
#16 vs. #100	No	No	No	No	No	No	No	No
#16 vs. #200	Yes	Yes	Yes	No	Yes	Yes	Yes	No
#30 vs. #50	No	No	No	No	No	No	No	No
#30 vs. #100	No	No	No	No	No	No	No	No
#30 vs. #200	Yes	Yes	Yes	No	Yes	Yes	Yes	No
#50 vs. #100	No	No	No	No	No	No	No	No
#50 vs. #200	Yes	Yes	Yes	No	Yes	Yes	Yes	No
#100 vs. #200	Yes	Yes	Yes	No	Yes	Yes	Yes	No

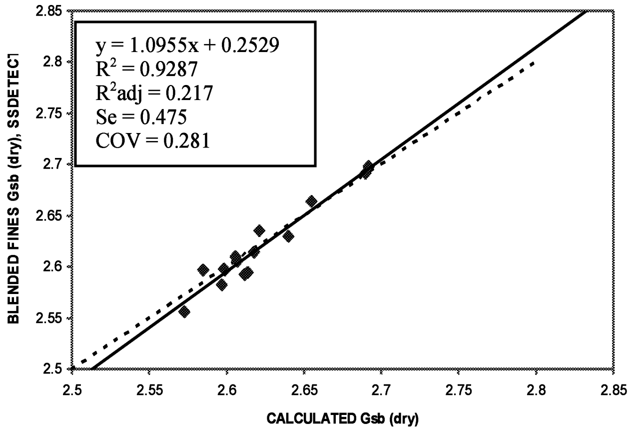


Fig. 10. Blended-Calculated against SSDetect *Gsb* (dry).

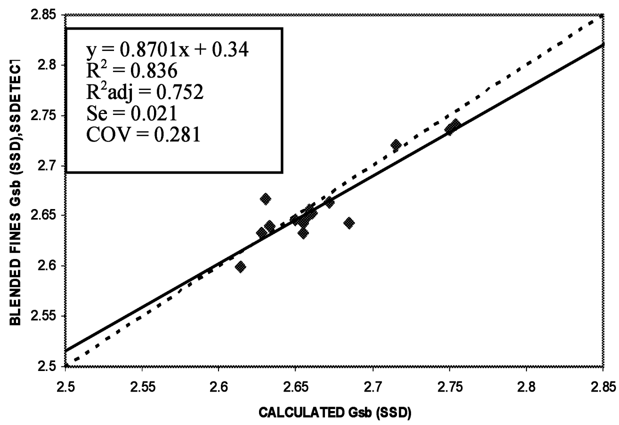


Fig. 11. Blended-Calculated against SSDetect *Gsb* (SSD).

Least Square Difference and Tukey Test

Statistical means testing was conducted to examine if statistical differences exist between the two methods. The three types of specific gravities and water absorption for the sieve sizes were analyzed using means tests. This consisted of determining the difference between the levels of each factor and calculating a 95% confidence interval. The confidence intervals and the significance of the differences were calculated using two methods: Least Squares Difference (LSD) and Tukey. The LSD method controls the Type I comparison wise error rate while the Tukey method controls the Type I experiment wise error rate and results in the LSD method being less conservative in the means testing than the Tukey Method. The outcome of these mean tests is summarized in Table 9 (a) and (b).

120 mean comparisons were done for all sieve size combinations using the LSD and Tukey methods each. 53 mean differences were identified for the LSD method as identified in Table 9(a) with "Yes" whereas 36 mean differences were identified for the Tukey method as shown in Table 9(b). Both methods of determining the three different specific gravities using both types of means comparisons show that the specific gravity values for the sieve sizes (8, 16, 30, 50, and #100) are different from the #200 sieve size.

The results of the means testing for the other sieve size comparisons for the specific gravities were not consistent as some

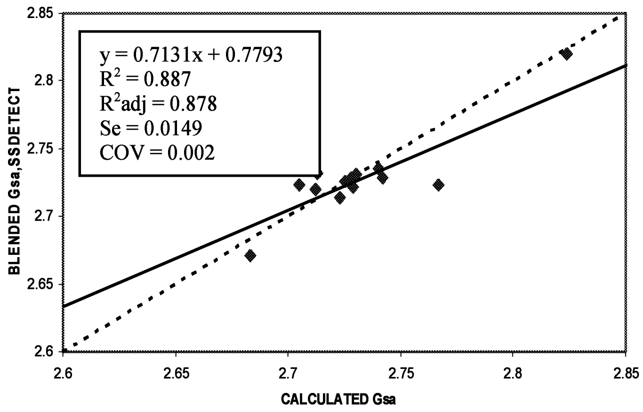


Fig. 12. Blended-Calculated against SSDetect *Gsa.*

means were different and in other instances the means were not different. These results lead to the belief that the SSDetect better determines the three specific gravities for the 8, 16, 30, 50, and #100 sieve sizes than for the #200 sieve. This could be due to the fact that the SSDetect laser beam is not effective in finding the SSD state of a closely-packed #200 particles. The closeness of the particles makes it impossible for the infra-red rays to locate other SSD state particles aside the ones at the surface. There is thus, non-uniformity in SSD determination when the #200 is tested.

The outcomes of the means comparisons for the water absorption for both AASHTO T-84 and the SSDetect were not consistent.

Blended-Calculated Specific Gravities against SSDetect Results for Blended Fine Aggregates

The specific gravities of the blended aggregates are summarized in this section. The AASHTO T-84 and SSDetect methods are compared as well.

Bulk Specific Gravity (Dry)

The R^2 relationship between the calculated and SSDetect-determined blended *Gsb* (dry) is approximately 0.93, which can be described as excellent. The 95% mean confidence interval was found to be (-0.003, 0.009) which suggests statistical similarity between the two approaches. A plot of the linear trend between the two approaches at determining the blended *Gsb* (dry) is shown in Fig. 10.

Bulk Specific Gravity (SSD)

The linear regression relationship between the AASHTO T-84 and SSDetect had a R^2 of 0.84. With a mean confidence interval of (-0.003, 0.016), the relationship between the two methods can be analyzed as having no significance difference at the 95% confidence interval (paired t-test for mean difference). The linear plot between calculated *Gsb* (SSD) and SSDetect-determined *Gsb* (SSD) is given in Fig. 11.

Apparent Specific Gravity (Gsa)

The linear trend between the two results had a R^2 of 0.89 which is very good. In addition, no significant difference occurred between the results of the two methods. This was because the mean confidence interval, (-0.002, 0.021) does includes 0 in the range. The plot of the linear trend is shown in Fig. 12.

Conclusions and Recommendations

The comparison of the SSDetect against the AASHTO T-84 in finding the specific gravities of the tested fine aggregates has led to the following conclusions:

1. For the tested single gradation and "as Received" material, the SSDetect can be confidently used as a replacement for the current AASHTO T-84 in *Gsb* (dry) and *Gsb* (SSD) measurement with desirable time-saving advantages and better accuracy in testing fine aggregates.
2. In terms of standard deviation comparisons between the AASHTO T-84 and SSDetect test results for the tested single gradation and "as Received" material, the SSDetect proved to have lower deviations for the *Gsb* (dry), *Gsb* (SSD), and *Gsa*, and thus has less variability within the test procedure for these properties. With the SSDetect implementation, there is the beneficial assurance that operator errors will be reduced as compared to AASHTO T-84.
3. When mathematical calculations were used for finding the specific gravities of the blended fine aggregates as against using the SSDetect, no statistical differences occurred between results of the two approaches.
4. The SSDetect is insensitive and unaffected by the presence of different aggregate size mixes and can therefore be used to test for blended fine aggregates similar for testing single gradation fine aggregates.
5. Comparing how the SSDetect compares with the AASHTO T-84 when the 8, 16, 30, 50, 100, and #200 sieves were tested, it was observed that SSDetect will work better in testing the 8, 16, 30, 50, and #100 sieves. The SSDetect will however need more validation when used for the #200 sieve-size fine aggregate.

It is believed that the SSDetect can be improved for measuring specific gravity of fine aggregates. One improvement could be achieved by the inclusion of an extra digital measurement system which automatically finds the bowl mass with contents before and after the SSD operation. This improvement would eliminate the inconvenience of the operator having to wait and monitor closely the SSD attainment stage during the process and immediately remove the sample for mass measurement.

Extended research should also be carried out to determine whether empirical relationships can be determined between the water film coefficient and the specific gravity of fine aggregate. This development would greatly aid in using the film coefficient to predict the specific gravity of fine aggregates for various gradations. In addition the device could be modified with a better testing fluid, such as an alcohol which has a higher penetration rate into aggregate voids, and is highly applicable to fine aggregates that experience testing issues with water.

Research work should also be conducted on the automated SSDetect to verify its applicability and feasibility in finding the specific gravity and absorption of a wide range of fine aggregates including recycled, natural, and manufactured aggregates (recycled PCC, recycle asphalt pavement, and slag). Preliminary results of the study have revealed that the SSDetect highly underestimates the absorption potential of highly absorptive fines even though the specific gravity measurements match very well.

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