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Evaluation of Various Tack Coat Materials Using Interface Shear Device and Recommendations on a Simplified Device

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16. Abstract

The performance of pavement interface bonds affects the integrity of pavement structures. In current practice, tack coats are used to ensure sufficient bonding between asphalt concrete (AC) layers as well as AC and concrete or aggregate base layers. A tack coat is a light application of bituminous materials to an existing surface using a distributor to provide sufficient bonding between pavement layers (Asphalt Institute, 1989). In the past, several research studies were conducted at the Illinois Center for Transportation to evaluate the effectiveness of tack coats between two AC layers and AC and Portland Cement Concrete (PCC) surfaces. In this study, the shear strength of seven types of tack coat materials were evaluated, four of which were hot-applied tack coat products. The results show that hot-applied products have superior shear strength as compared to emulsion type products. A simplified shear testing configuration was also acquired and preliminary testing was completed to provide some recommendations for its future use by the Illinois Department of Transportation.

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Members of the Technical Review panel were the following:

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EXECUTIVE SUMMARY

It is well known that interface bonding affects the integrity of pavement structures. In the current practice, tack coats are used to ensure sufficient bonding between hot mix asphalt (HMA)-HMA, HMA-Base or Portland Cement Concrete (PCC)-HMA layers to prevent premature occurrences of distresses and improve lifetime. A tack coat is a light application of bituminous materials to an existing surface using a distributor to provide sufficient bonding between pavement layers (Asphalt Institute, 1989). The most common tack coats on the market are hot asphalt cements, and emulsified asphalts. Emulsified asphalts (emulsion) are products made of asphalt cement, emulsifying agent, and water.

In the past, several research studies were conducted at the Illinois Center for Transportation to evaluate the effectiveness of tack coats. Various tack coat materials have been investigated as part of their use at the HMA-PCC interfaces (Leng et al., 2008) and HMA-HMA interfaces (Al-Qadi et al., 2012). A new direct shear interface testing device was also developed as part of the recent ICT study. The Interface Shear Testing Device (ISTD) developed for the ICT R27-100 study is a multi-axial interface testing system. The previous study demonstrated that shear strength obtained from this test is a good indicator for performance of tack coats. The objective of this study is to evaluate the properties of various tack coat materials using the ISTD and provide recommendations for a simplified shear testing device that can be integrated to the testing frames at IDOT. Shear strength of seven tack coat materials were evaluated using the ISTD. The materials included three of the commonly used emulsion type tack coats and four hot-applied products. Asphalt Mixture and Portland Cement Concrete (PCC) specimens were prepared for shear testing by gyratory compacting HMA over PCC cylinders. PCC was used as the base material to avoid measuring shear strength effects of aggregate texture. One type of asphalt mixture was used on top of the concrete cores obtained from a slab. Tack coats were applied at a base application rate of 0.05 lb/ft^2 (0.244 kg/m^2). The application rate was increased to 0.15 lb/ft^2 (0.732 kg/m^2) only for one of the hot-applied products.

It was found that emulsion type of products including SS-1h, SS-1h (QS) and SS-1hp (QS) resulted in shear strength in between 38 and 73 psi. The polymer modified type of emulsion product (SS-1hp [QS]) resulted in the highest strength in this range. The results for emulsion products were consistent with the previous ICT studies. Hot-applied products including the longitudinal joint seal materials had significantly higher shear strength than the emulsion type products ranging from 98 to 189 psi.

A simplified shear testing device was acquired and some preliminary testing was completed. The device is easy to use and has the potential to fulfill the requirements. The simplified shear testing device can be integrated to the screw-driven type loading frames. Normal load is not controlled in the simplified device as is the case with many of simplified shear testing devices. According to the preliminary testing conducted using this device, it was noticed that normal pressure build up can be significant. Therefore, the importance of reducing the normal loads building during the preliminary testing using this device is highlighted. Recommendations were made for future modifications and implementation of this device.

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CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

It is well known that interface bonding affects the integrity of pavement structures. In the current practice, tack coats are used to ensure sufficient bonding between hot mix asphalt (HMA)-HMA, HMA-Base or Portland Cement Concrete (PCC)-HMA layers to prevent premature occurrences of distresses and improve service life. As a result, to ensure durable pavements, selection of tack coat materials and rate of application is critical to withstand the shear forces imposed at the interface due to traffic and environmental loadings.

A tack coat is a light application of bituminous materials to an existing surface using a distributor to provide sufficient bonding between pavement layers (Asphalt Institute, 1989). The most common tack coats on the market are hot asphalt cements, and emulsified asphalts. Emulsified asphalts (emulsion) are products made of asphalt cement, emulsifying agent, and water. Upon application, the water evaporates allowing the asphalt to settle over the surface.

In the past, several research studies were conducted at the Illinois Center for Transportation to evaluate the effectiveness of tack coats. Various tack coat materials have been investigated to examine their use at HMA-PCC interfaces (Leng et al., 2008). The research scope included laboratory investigation of various types of tack coats using laboratory shear testing and accelerated field testing of the HMA overlays placed after the application of the tack coats used in the study. The ultimate goal was to find the optimum tack coat application rate to use as part of the overlay application. The second study was about the interfaces between HMA layers with an addition of hot-applied tack coat materials (Al-Qadi et al., 2012). In this study, the effect of the tack coat type, along with several other factors, were evaluated with an ultimate goal of finding the optimum application rate and cleaning method. A new direct shear interface testing device was also identified and further developed as part of this study.

The Interface Shear Testing Device (ISTD) developed for the ICT R27-100 study is a multi-axial interface testing system. It has a vertical axis used to apply shear pressure and a horizontal axis used to apply confining pressure. The device can be placed into a servo-hydraulic system with an environmental chamber where the temperature and loading rate can be controlled. The test can be performed either in cyclic or monotonic mode. The monotonic test with a constant shear rate of 0.005 in/sec (0.127mm/sec) proved to be sufficient to obtain a shear load versus displacement curve. The previous study demonstrated that shear strength obtained from this test is a good indicator for performance of tack coat. There is currently a need to evaluate additional tack coat materials recently produced by various manufacturers and to identify a simplified device that Illinois Department of Transportation (IDOT) can utilize for product approval and quality assurance purposes.

1.2 RESEARCH OBJECTIVES

The objectives of this special study are to: (1) Evaluate the properties of various tack coat materials using the ISTD; and (2) Evaluate the current ISTD and provide design recommendations for a simplified shear testing device and assist IDOT in integrating this device in an available testing frame at IDOT.

CHAPTER 2: METHODOLOGY

An experimental plan was developed to evaluate the performance of seven tack coats based on interface shear strength of HMA-PCC interlayers. The tests were performed using a custom-designed shear fixture device previously referred to in this report as Interlaken Shear Test Device (ISTD) (Al-Qadi et al. 2012).

2.1 TACK COAT SHEAR TEST DEVICES

2.1.1 Interlaken Shear Test Device (ISTD)

The Interlaken Shear Test Device (ISTD) used in this study is shown in Figure 2.1. This device was designed at the Illinois Center of Transportation. It has the load capacity to characterize the bond strength between HMA-HMA and HMA-PCC pavement layers by applying monotonic or cyclic one-dimensional shear force directly to the interlayer. The device can measure the shear force, the normal (confining) force, the dilation, and the shear displacement during the test. The dilation refers to the enlargement of the specimen at an axis perpendicular to the shear load direction (normal force axis).

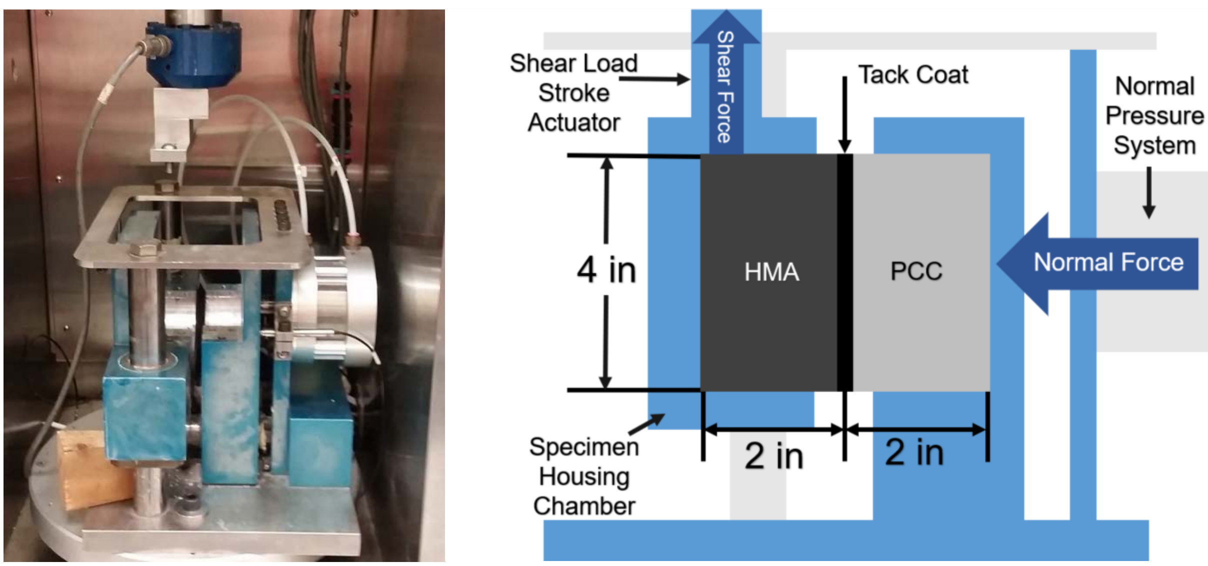


Figure 2.1. Interlaken Shear Test Device (ISTD).

The test fixture is composed of the shear load stroke actuator, the normal pressure system, and the specimen housing chamber. The shear load hydraulic actuator has two load cells of 10 and 22 kips (44 kN and 97.8 kN) capacity. The normal pressure system consists of an air-pressure actuator connected to a miniature load cell with a capacity of 2 kips (8.9 kN). The normal pressure simulates the confinement occurring due to tire contact pressure on the pavement. In this study, a normal pressure of 1 psi (0.0069 MPa) was applied to ensure minimum confinement of the specimen. In both directions, two linear variable differential transducers (LVDTs) were used to measure both the shear displacement and the dilation. Finally, the housing chamber supports the specimen fixed during the test. The fixture can accommodate 3.93 and 5.90 in (100 and 150 mm) diameter specimens with total heights of the specimen ranging from 3.7 to 4.3 in (94 to 109 mm). During this study, the specimen diameter was kept constant at 4 in (101.6 mm) (diameter of the HMA compactor mold) and heights of 3.77 to 4.01 in (96 to 102 mm). The test temperature was controlled at 77°F (25°C) using an environmental chamber where the fixture was placed that can maintain temperatures ranging from -20°F to 86°F (–29°C to 30°C). During the test, the specimen layer next to the normal load pressure system was held stationary while the other layer was moved to induce shear in the interface of both layers at a monotonic displacement controlled testing rate of 0.005 in/s (0.127 mm/s). The shear load, the shear displacement, and the dilation were recorded from the actuators and LVDTs using a data acquisition system. Figure 2.2 shows a typical shear load-displacement curve for a typical tack coat specimen.

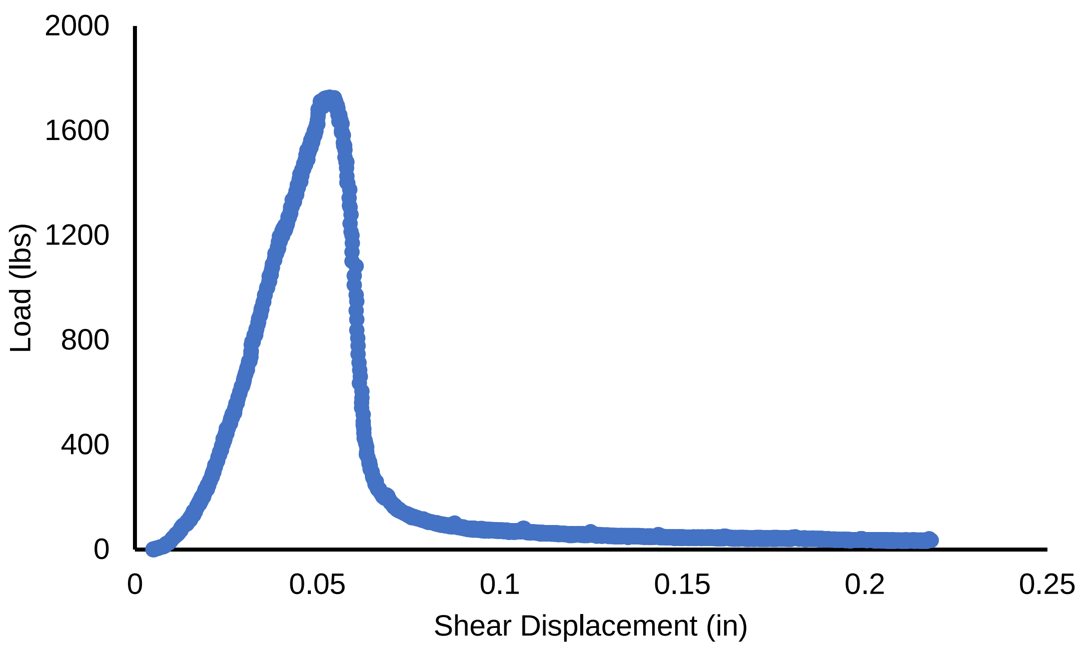


Figure 2.2. Typical load-displacement curve obtained from a test conducted using the ISTD (1 in = 25.4 mm; 1 lb = 0.453 kg).

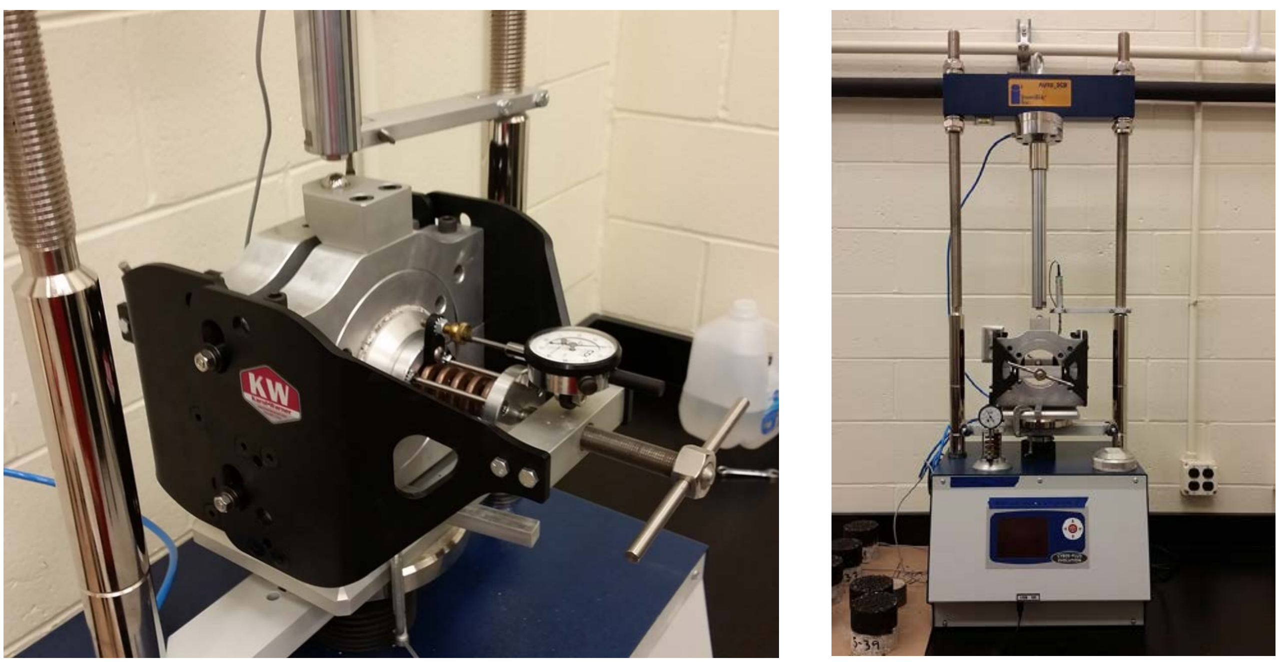
The interface shear strength is calculated using the equation below:

$$Interface\ Shear\ Strength\ (psi) = \frac{Maximum\ Load\ (lbs)}{Interfacial\ Area\ (sq.in)} \quad \text{Equation 2.1}$$

where Interfacial Area can be calculated using the diameter of the specimens used.

2.1.2 MS-43 Asphalt Tack Bond Shear Strength Apparatus

The MS-43 Asphalt Tack Bond Shear Strength Apparatus was developed by the Karol Warner Soil Testing System, as shown in Figure 2.3, to evaluate the interlayer tack coat bonding. The device was integrated to the Instrotek Auto-SCB load frame. The device is composed of a heavy steel frame that holds the specimen fixed and moveable shear plates, which are used to apply uniform normal confining pressure. The normal pressure on the specimen is applied using a calibrated spring with a dial indicator displays the dilation of the specimen. Using the spring constant, the resulting normal pressure can be computed from the spring reading. The steel frame has adapters that allow users two specimen diameter sizes to be tested: 4 in (101.6 mm) or 6 in (152 mm). Each specimen used in preliminary testing of this equipment has a thickness of 2 ± 0.2 in (50± 5 mm). Tolerances for dimensions of specimens that can be used with this equipment were not provided by the manufacturers. The major difference between the ISTD and MS-43 systems is the way normal pressure is controlled. Contrary to the ISTD, the MS-43 does not allow automated normal pressure control. As the specimen dilates, normal pressure can build up depending on the spring's stiffness. However, one of the advantages of this device is the capability to integrate it with a screw-driven machine like the Instrotek's Auto-SCB. Some preliminary testing was completed using this device.



a) b)

Figure 2.3. The simplified MS-43 asphalt tack bond shear strength apparatus installed in Instrotek's Auto-SCB.

2.2 MATERIALS

The materials and specimen preparation parameters were selected based on the 2016 IDOT Standard Specifications and in the results of Al-Qadi et al. 2012. The parameters that control the interface bonding and which could affect the shear strength are: the HMA mix type, the PCC interface texture, the tack coat application rate and temperature, and the curing time. Therefore, these variables were carefully selected to enable comparison of only the influence of tack coat material to interface shear strength.

2.2.1 AC Mixture

A surface AC mixture was chosen for this study. The mix was a N90 3/8 in (9.5-mm) NMAS surface mix. The mix was sampled from a plant as part of the ongoing ICT study R27-175. Table 2.1 shows the final aggregate gradation and key volumetric properties for the mixtures. The job mix formula is provided in Appendix A.

Table 2.1. AC Mix Formula

Property			Passing Ratio %
Aggregate Gradation	Sieve Size		
	(mm)	(in)	
	25.4	1	100
	19	3/4	100
	12.5	1/2	100
	9.5	3/8	97
	4.75	#4	61
	2.36	#8	35
	1.18	#16	21
	0.6	#30	14
	0.3	#50	8
	0.15	#100	6
	0.075	#200	4.7
Asphalt Cement Grade			PG 70-22
Asphalt Content (%)			6.2
Maximum Specific Gravity			2.455

2.2.2 PCC Specimens

The PCC layer was prepared from un-milled non-trafficked field cores obtained from a previous study at the Illinois Center for Transportation (Popovics, 2016). Concrete specimens with 4 in (101.6 mm) diameter were cored from the slabs shown in figure 2.4. Then the cores were cut into individual specimens with 2 in (50.8 mm) thickness. After the cut, a smooth un-milled surface was obtained consistently for all the specimens to be tested. Table 2.2 shows the mix design for the PCC cores, and the complete aggregate gradation is given in Appendix A.

A) B)

Figure 2.4. PCC Slabs for extracting the cores at the Illinois Center for Transportation (ICT).

Table 2.2. Mixture Design Nominal Proportions

Components	Content per yd^3 (m^3) of concrete
CM16 -Kankakee, lb. (kg)	364 (216)
FA-Mid-America-Mahomet, lb. (kg)	1227 (728)
CM11- Kankakee, lb. (kg)	1450 (860)
Fly Ash - C-MRT Labadie, lb. (kg)	145 (86)
Portland cement type I, lb. (kg)	435 (258)
Water, gal (L)	29.2 (145)
Admix. content per 100 lb. (kg) of cementitious material	
Air-entraining admixture, oz. (mL)	1.9 to 2.0 (56 to 59)
Water reducer Pozzolith 80, oz. (mL)	4.0 (118.3)

2.2.3 Tack Coats

Seven tack coats were provided by the Illinois Department of Transportation's Central Bureau of Materials including hot-applied and emulsion type tack coats. The properties for these materials are presented in Table 2.3. One residual application rate was considered throughout the study. The base rate for comparison is 0.05 lb/ft^2 (0.244 kg/m^2) based on the 2016 IDOT Standard Specifications. In addition, for only the Longitudinal Joint Seal (LJS-II) type of hot-applied tack coat, six additional specimens were produced using a residual application rate of 0.15 lb/ft^2 (0.244 kg/m^2).

Table 2.3. Tack Coat Properties

Source	Type	ID	Production Date	Details	Residual Application Rate in lb/ft^2 (kg/m^2)	Application Temperatures (°F) (°C)
Asphalt & Wax Innovations	Hot-Applied	DOT-C LT	Unknown	Drive on Tack Coat ILDOT Can be applied at relatively low temperatures (230-250 °F)	0.05 (0.244)	311 (155)
Asphalt Materials, Indianapolis	Hot-Applied	LJS-I	6/1/2017		0.05 (0.244)	300 (149)
Asphalt & Wax Innovations	Hot-Applied	DOT-C10	Unknown	Non-Tracking Tack Coat	0.05 (0.244)	311 (155)
Emulsicoat in Urbana, Il	Hot-Applied LJS	LJS-II	5/19/2017	T 4010	0.05 (0.244)	330 (165.5)
Emulsicoat in Urbana, Il	Emulsion	SS-1h	8/23/2017		0.05 (0.244)	77 (25)
Tristate Asphalt Morris, Il	Emulsion	SS-1hp QS	7/20/2017	Polymer Modified	0.05 (0.244)	77 (25)
Tristate Asphalt Morris, Il	Emulsion	SS-1h QS	8/22/2017		0.05 (0.244)	77 (25)

Asphalt emulsions consists of liquefied asphalt binder mixed with water using an emulsifying agent. The emulsifying agent allows to dilute the asphalt binder with water. The emulsion product is labeled to describe the characteristics of the emulsion. First, emulsions labels starting with a letter “C” describes that the ionic charge of the emulsion is cationic and the absence of “C” indicates that the emulsion is anionic. It is followed by two letters the describes how fast the emulsifying agents evaporates and the emulsion sets to a continuous asphalt residue. This is identified using RS (Rapid Set), MS (Medium Set), SS (Slow Set), and QS (Quick Set). Emulsions bearing the letter “h” indicates a High Float emulsion. Finally, emulsions bearing a “P” indicate that the emulsion uses a polymer while an “L” indicates the use of a latex polymer.

2.3 SPECIMEN PREPARATION

The preparation of composite specimens consisted of the three main stages: PCC coring, tack coat application, and curing/compaction.

The first stage consisted of extracting 4 in (101.6 mm) diameter PCC cores at the Illinois Center for Transportation. A 4 in (101.6 mm) diameter core drill was used to core the samples as shown in Figure 2.4. Then the cores were cut to 2 in (50.8 mm) using a water-cooled thick mechanical saw with a 0.2 in (5 mm) thick blade. The surfaces were cleaned to remove any leftover materials from the surface due to saw cutting and were dried at least overnight.

Figure 2.5. PCC driller.

After the preparation of the PCC cores, the tack coats were applied. The weight of the tack coat to be applied was computed to achieve a 0.05 lb/ft^2 (0.244 kg/m^2) residual rate as required from the 2016 Illinois Department of Transportation Standard Specifications (IDOT, 2016). Approximately, 0.004 lbs (2 grams) of tack coat materials were applied on each surface.

The hot-applied tack coats were heated to the application temperature designated by the manufacturer, while the emulsified tack coat was applied at room temperature. Then, the PCC cores were placed on a balance and the tack coats were applied using a spatula. The applied tack coat was distributed evenly to achieve uniform thickness. The cores were removed from the balance and stored on shelves, at room temperature (77^{O}F, 25^{O}C), 50 % humidity, for the curing period (24 hr).

After curing was complete, the HMA mix was compacted on top of the existing PCC layer (with a portable gyratory compactor) to reach target air voids. Before compacting, the mixture obtained in bags from the plant was divided into individual buckets for each compaction to avoid segregation. Then, the mixes were heated to the compaction temperature of 302^{o}F (150^{o}C). This process is different from previous studies where the PCC cores with the tack coats were heated to compaction temperature approximately 30 min before compaction. This was only applied to the second round of specimens compacted to 10% air voids. The PCC cores were then placed inside the gyratory compactor molds and the target weight of asphalt mix was poured on top of concrete for compaction as shown in Figure 2.5. Then, the samples were taken out of the mold and cooled at room temperature for shear testing.

a)

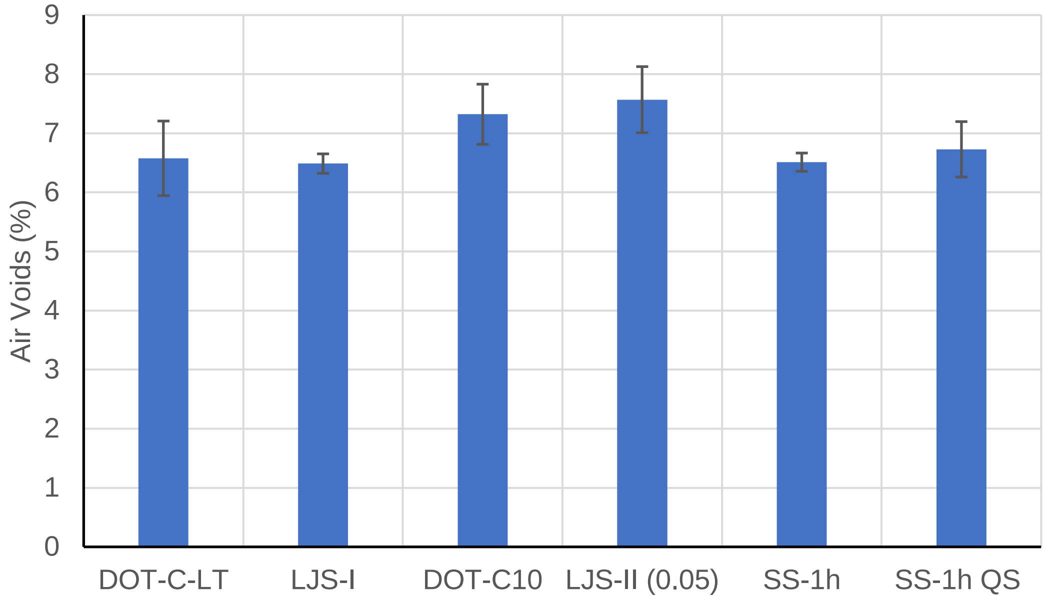
b)

c)

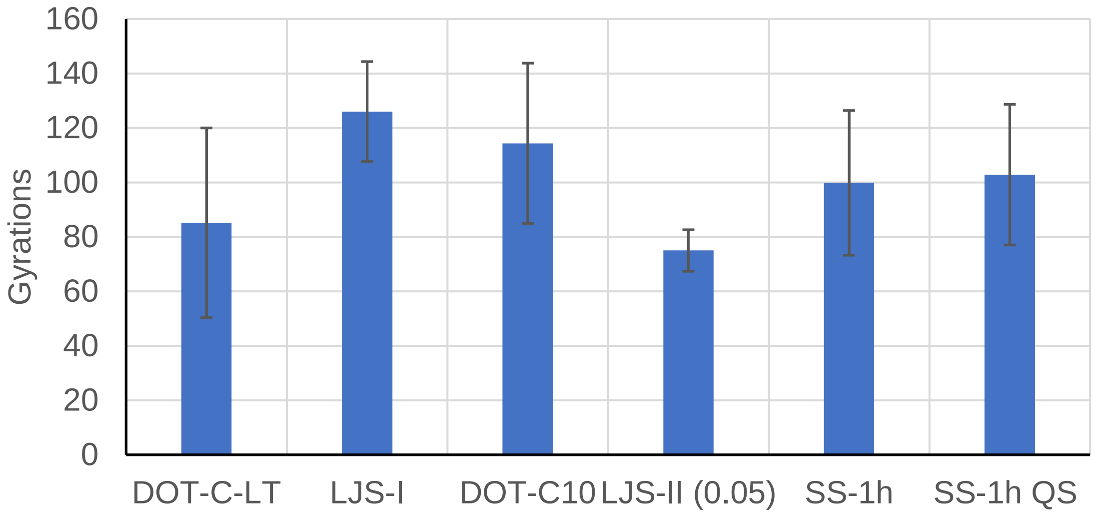
d)

Figure 2.6. Specimen preparations steps: (a) tack coat application, (b) curing process, (c) compaction, and (d) curing before moving to the climatic room.

The AC mixture layer was initially compacted at 7% air void content and 4 in (50.8 mm) thickness. However, after the first round of specimen preparation, it was found that there were significant variations in the number of gyrations, resulting in gyration numbers occasionally over 150. This was due to the small height of the specimen compacted. The compactive effort plays an important role in defining the interface strength. The second round of specimens were prepared with a goal of obtaining a target density (7% air voids) at a consistent and reasonable number of gyrations in accordance with the design number of gyrations for the mix.



a)



b)

Figure 2.7. Air voids (a) and average gyrations (b) per tack coat for the first round of specimen with 7% air voids target (0.05 indicates an application rate of 0.05 lb/ft^2).

To determine the number of gyrations and the weight of the sample required to achieve this condition, compaction curves were produced. This process entails compacting five specimen 4 in (101.6 mm) diameter and 2 in (50.8-mm) high at five target weights (890, 850, 825, 797, 766 g). The compaction curve for the mix are presented in Figure 2.8. We chose to produce specimens with maximum possible density that can be achieved within a consistent and reasonable number of gyrations. Given the fact that the design number of gyrations is 90 to reach 4.0% air voids, the target density (usually at air voids higher than the design air voids) should be achieved at gyrations much smaller than 90. Therefore, target density was changed to 10% air voids that can achieved within an expected number of gyrations to fall between 30 and 40. This is the maximum possible density that can be achieved for the 4 in (100 mm) diameter and 2 in (50.8 mm) thick specimens considering the constraint for number of gyrations. It was determined that 840 g were needed to achieve 10% air voids for the 4 in (100 mm) diameter and 2 in (50.8 mm) high specimen. Because the asphalt mix was compacted over the tack coat and the PCC Core, the volumetric properties of each individual specimen were measured after the specimens were tested (volumetric properties are included in Appendix B).

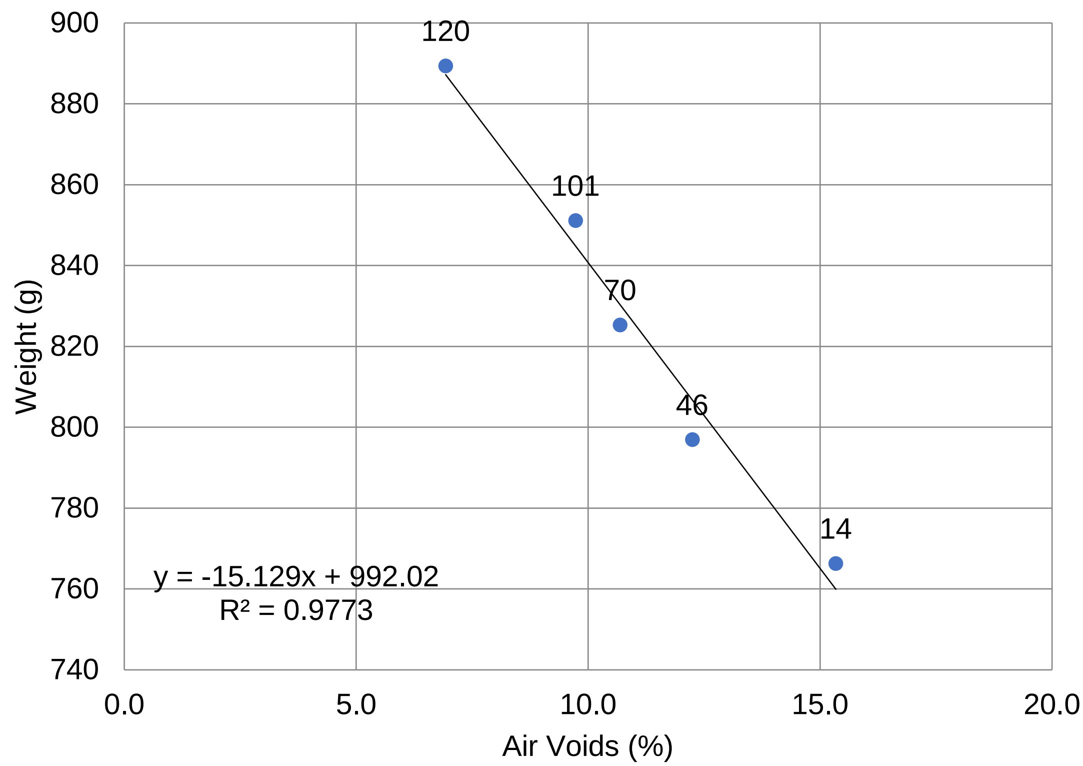
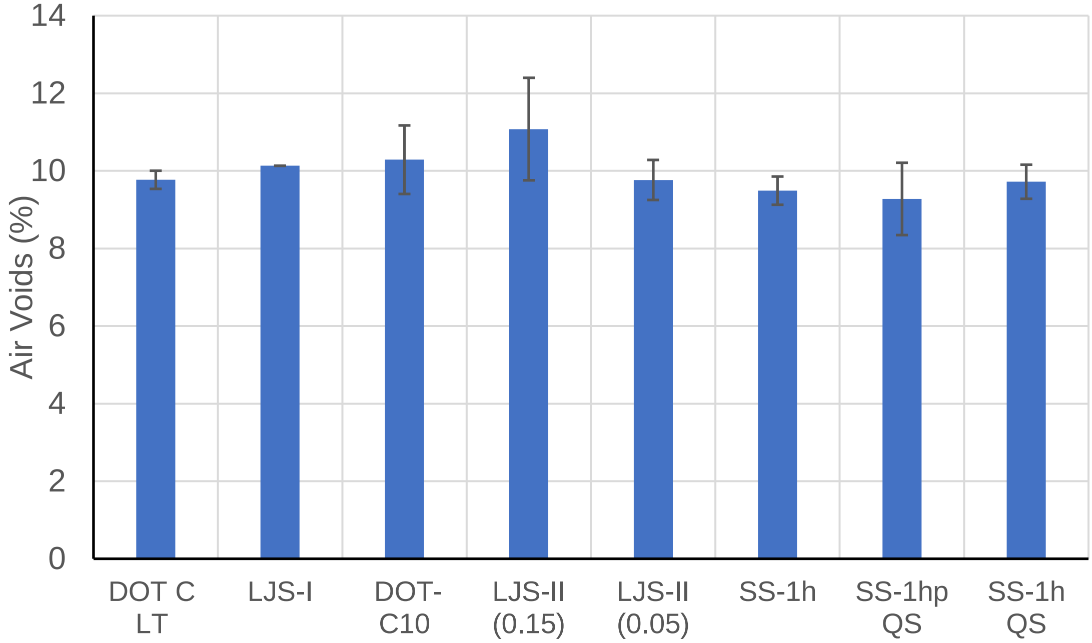
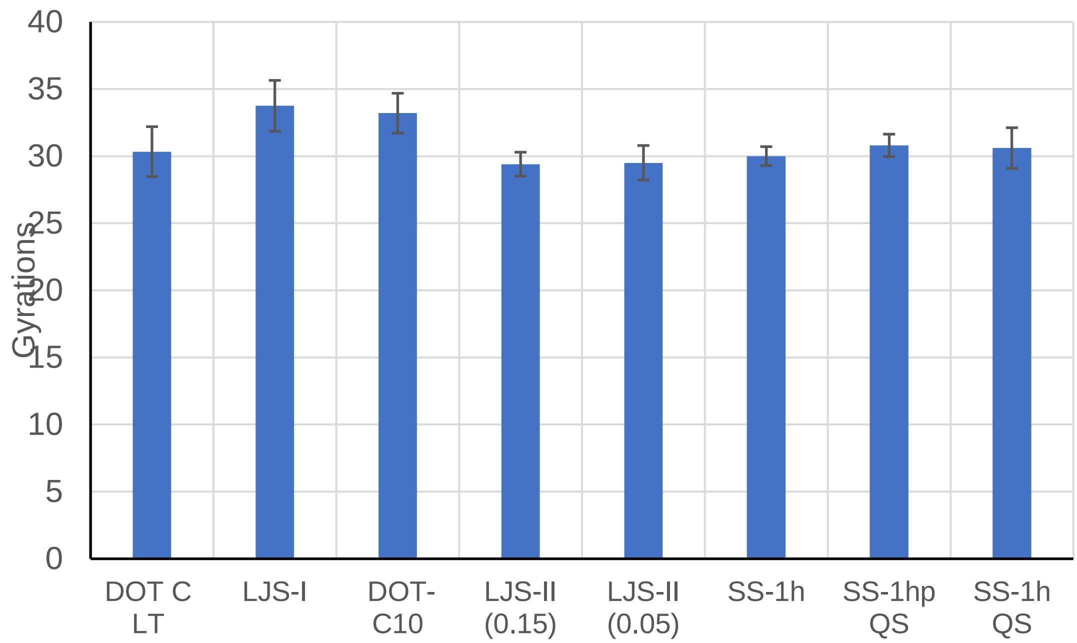


Figure 2.8. Weight determination plot for the N90 mix (point labels defining the number of gyrations).



a)



b)

Figure 2.9. Air voids (a) and average gyrations (b) per tack coat for specimens with 10% air voids target (0.05 and 0.15 indicates an application rate of 0.05 and 0.15 lb/ft^2).

CHAPTER 3: RESULTS

3.1 TACK COAT COMPARISON AT THE BASE RATE

Seven different tack coats were tested on top of PCC cores: DOT-C LT, LJS-I, DOT-C10, LJS-II, SS-1h, SS-1hp QS, and SS1hp QS. All specimens were conditioned and tested at 77°F (25°C) for 24 hr. Figure 3.1 shows the results of the interface tests conducted using the base application rate of 0.05 lb/ft^2 (0.244 kg/m^2). According to the results, the DOT-C-10 provided the highest shear strength before failure, with an average peak stress of 189 psi. There is a good chance of having repeating results since the calculated coefficients of variation (COVs) did not exceed 30%, as seen in Table 3.1. In general, hot-applied tack coats resulted in higher shear strength as compared to emulsion type. The range of shear strength for emulsions is between 38 and 73 psi with SS-1hp QS highest shear strength. According to the previous study where similar materials were used with the AC-PCC interface, the range was between 44 and 63 psi (Al-Qadi et al., 2008). During those studies, the following tack coats were used: SS-1h, RC-70, SS-1hp, HFE, SS-1vh, and PG 64-22. None of the hot-applied products or virgin asphalt binder were used before with AC-PCC interfaces. Virgin binder (PG64-22) performed similar to the emulsion type of products (HFE and SS-1hp) when tested with HMA-HMA specimens (Al-Qadi et al., 2012).

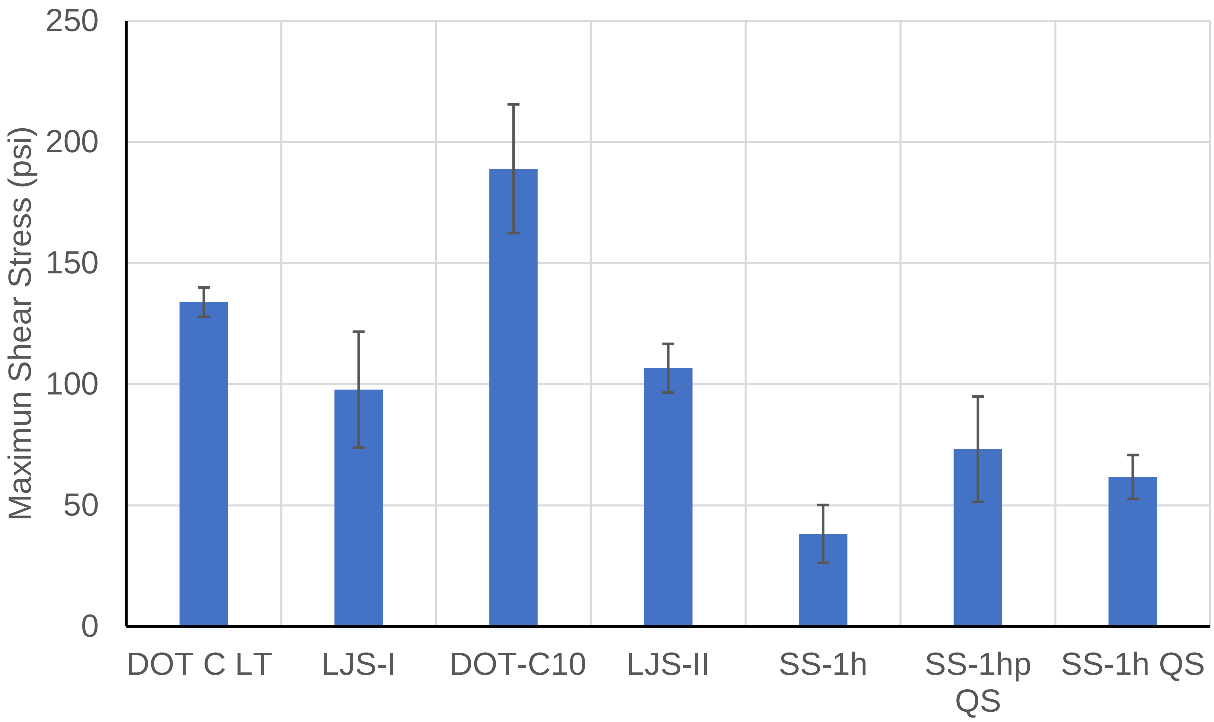


Figure 3.1. Interface shear strength results for the specimens prepared with base tack coat application rate (1 psi = 6.89 kPa) (0.05 and 0.15 indicates an application rate of 0.05 and 0.15 lb/ft^2).

Table 3.1. Interface Shear Strength Results for the Specimens Prepared with Base Tack Coat Application Rate (1 psi = 6.89 kPa)

	ISTD Apparatus		
Name	Shear Strength (psi)	Standard Deviation (psi)	COV
DOT-C LT	133.9	6.1	4.5
LJS-I	97.7	23.9	24.5
DOT-C10	189.0	26.6	14.1
LJS-II (0.15 lb/ft^2)	86.1	20.8	24.2
LJS-II (0.05 lb/ft^2)	106.6	10.1	9.4
SS-1h	38.2	11.9	31.3
SS-1hp QS	73.2	21.8	29.7
SS-1h QS	61.7	9.1	14.7

3.2 EFFECT OF APPLICATION RATE

Application rate was only changed for the LJS-II type. The typical application rate of this product in the field is around 0.12 to 0.20 lb/ft^2(0.586 to 0.976 kg/m^2). Therefore, additional specimens were prepared with 0.15 lb/ft^2 (0.732 kg/m^2). When the application rate was tripled, shear strength reduced by approximately 20 psi. There may be an optimum application rate based on shear strength for this product somewhere between 0.05 and 0.15 lb/ft^2 (0.244 and 0.732 kg/m^2).

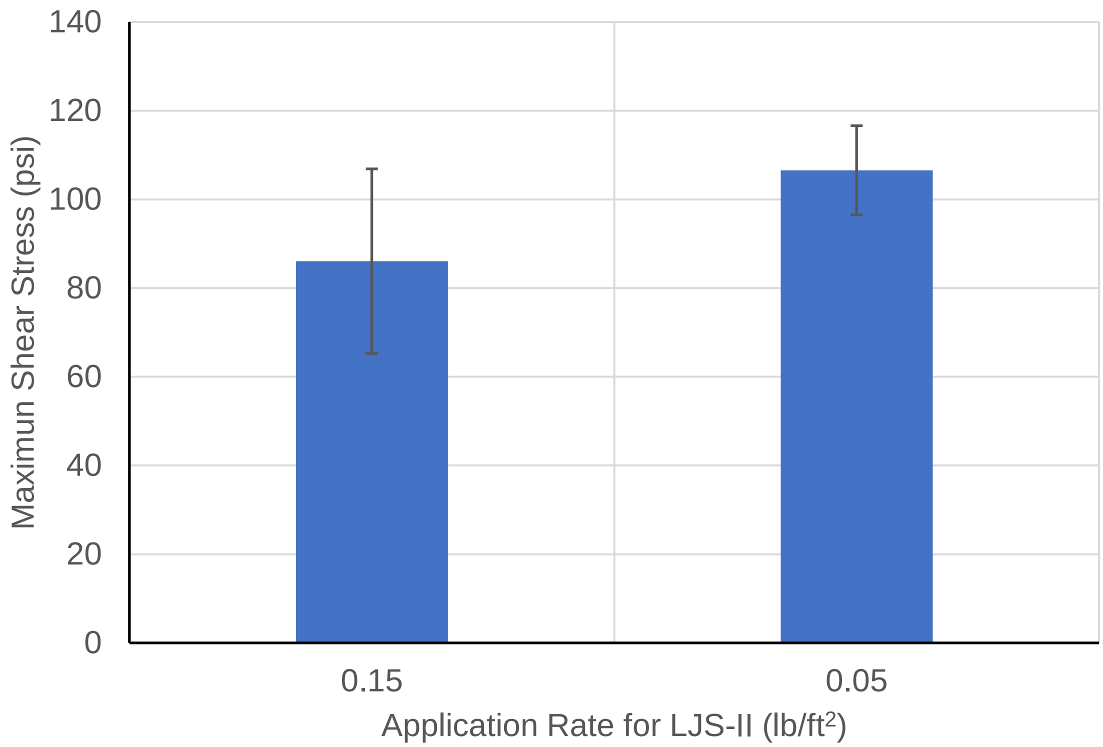


Figure 3.2. Comparison of application for the LJS-II (1 psi = 6.89 kPa).

Table 3.2. Interface shear strength results for the specimens prepared with two application rates for the LJS-II.

	Interlaken Shear Test Device (ISTD)		
Name of the Product and Application Rate	Shear Strength (psi)	Standard Deviation (psi)	COV
LJS-II (0.15 lb/ft^2)	86.1	20.8	24.2
LJS-II (0.05 lb/ft^2)	106.6	10.1	9.4

3.3 DILATION CONTROL DURING THE SHEAR TESTING

Dilation is defined as the magnitude of horizontal movement of the underlying concrete layer while the AC is sheared in the vertical direction. Dilation is primarily affected by the texture of the interface. The magnitude of dilation can be critical during shear and because it can govern the normal stress build up. The ISTD system can control normal stress while allowing for dilation. Therefore, normal force can be kept constant during the test. Normal stress was set to a low value of 10 psi for the experiments. The value was set low to simply maintain contact between the specimen and the fixture in the horizontal direction. Typical dilation progression is shown in Figure 3.3. Since the concrete surface was relatively smooth, the recorded dilations were small ranging from 0.02 to 0.03 in (0.508 to 0.762 mm) as shown in Figure 3.4.

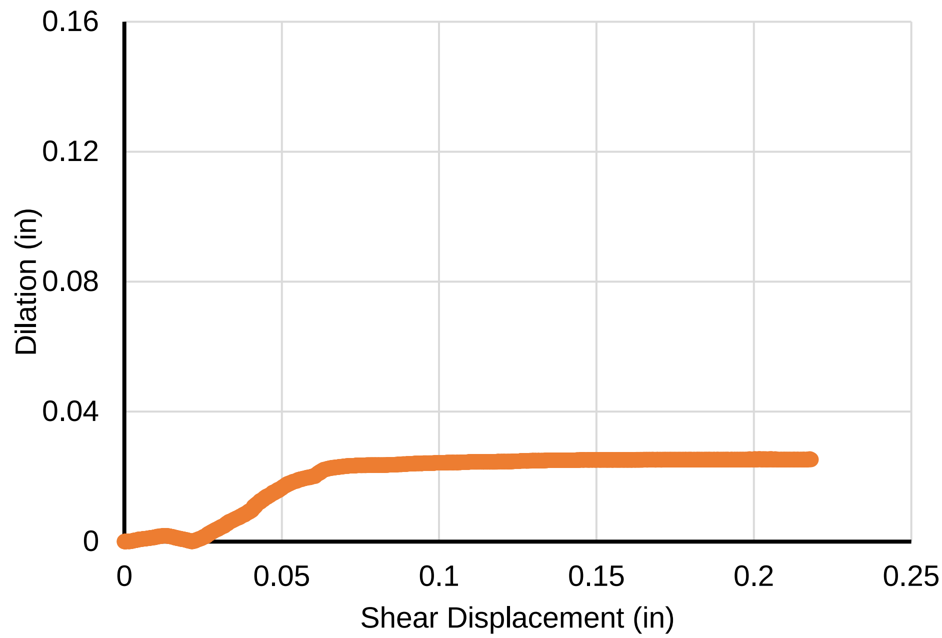


Figure 3.3. Typical dilation progression measured in the ISTD apparatus (1 in = 25.4 mm).

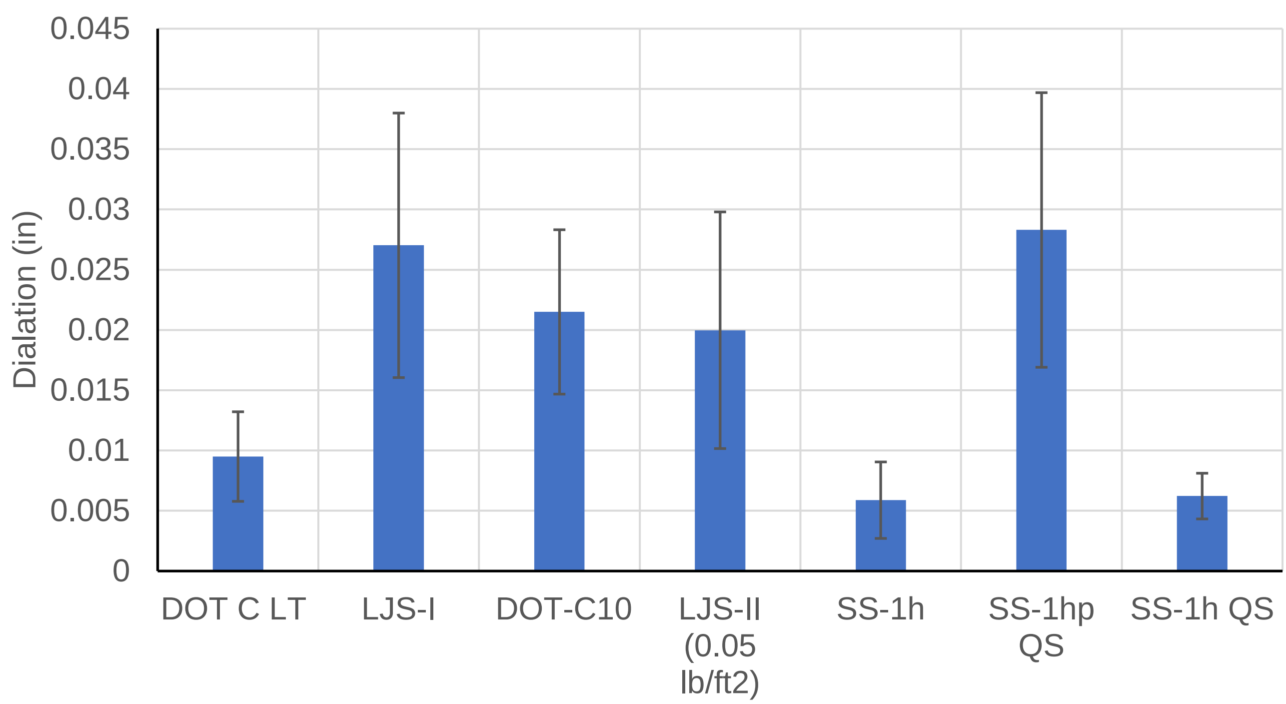
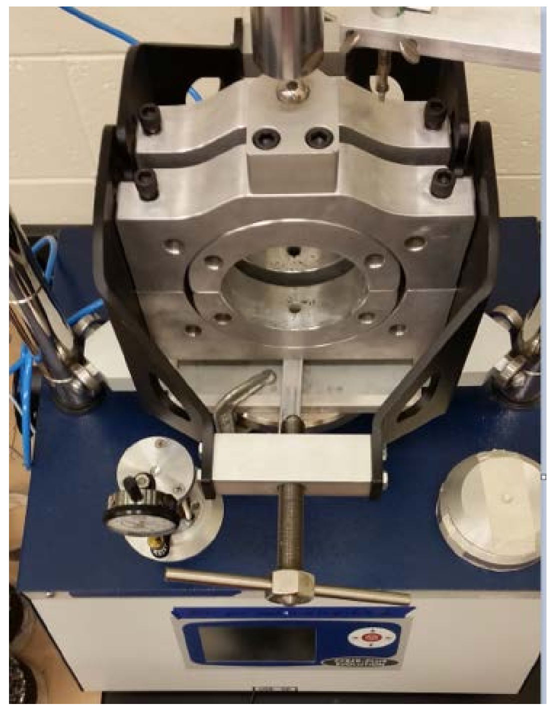


Figure 3.4. Dilation results measured in the ISTD (1 in = 25.4 mm) (0.05 indicates an application rate of 0.05 lb/ft²).

3.4 SIMPLIFIED SHEAR TESTING CONFIGURATION

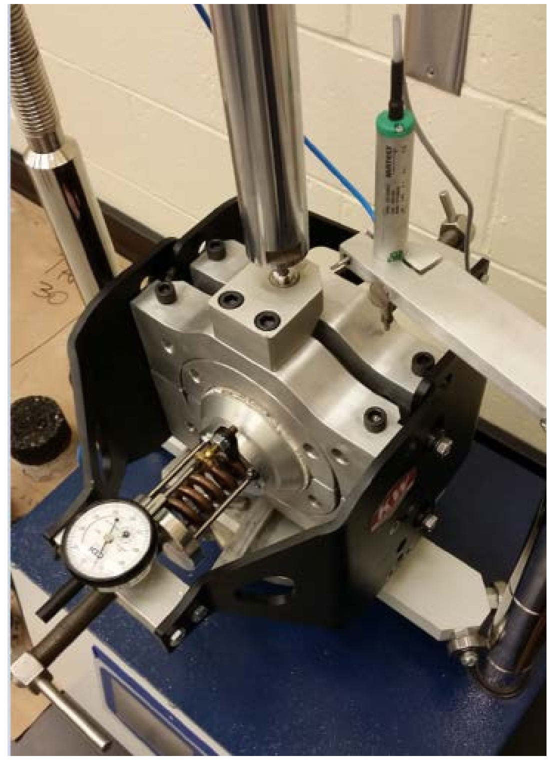
One of the goals of this study was to provide recommendations for a simplified shear testing apparatus that can be integrated with a suitable existing testing protocols at IDOT. The MS-43 shear fixture was used for this purpose. The simplified shear fixture can be integrated to the loading frames like the Auto-SCB and does not require the secondary control channel to control normal loads. Normal loads are not controlled in most of the simplified shear testing fixtures, including the MS-43 shear testing device. A spring and dial gage is provided to monitor the normal load accumulation during the test. Spring boundary in the normal direction is used to establish initial contact with the specimen and plates holding the specimens horizontally. Figure 3.5 shows the detailed design of the device. Since it is not possible to have servo-channels to add a secondary control axis like it was done in the ISTD system, the configurations like MS-43 allows easy integration to loading systems like the Instrotek Auto-SCB device.

a)



b)

c)



d)

Figure 3.5. a) Front view of MS-43 placed in the Auto-SCB loading fixture, b) MS-43 view, c) Normal load applied using the spring and dial system, d) Specimen test.

Preliminary testing using this device was completed. A typical load-displacement curve obtained using the simplified shear testing device (MS-43) and ISTD is shown in Figure 3.6 for the DOT-C-LT tack coat. The responses obtained from the two machines appear to be consistent for these specimens. Although the goal is to apply shear at the interface in the vertical axis, the two systems are using different fixture arrangements to apply the shear. This may affect the results to a degree due to machine compliance. Machine compliance refer to the contribution of the fixture parts of the testing system to the measured displacements. When such custom design fixtures are used, machine compliance's contribution to measured displacement can be variable. However, the biggest difference is in the way normal loads are controlled. A spring clamping system is used in the MS-43, whereas a servo-pneumatic system with a load cell and LVDT is used in the ISTD. The ISTD system can control normal loads at a desired level input by the user to allow or prevent dilation. The normal loads are not controlled in the MS-43 system. Therefore, it is important to investigate these two configurations carefully rather than just looking at the load-displacement curve. The investigation should include monitoring of normal load accumulation as well as the shear strength.

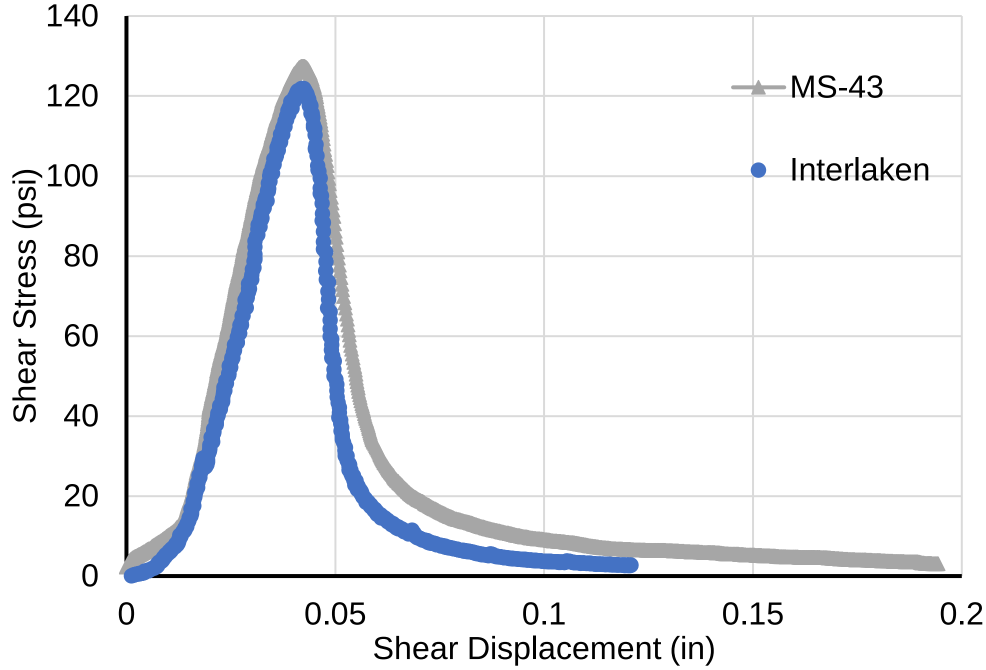


Figure 3.6. Shear Load vs Displacement Curve of two DOT-C-LT specimens tested using the MS-43 and the Interlaken Shear Test Device (ISTD) (1 psi = 6.89 kPa).

The dilation measurement for the two specimens tested in the ISTD and MS-43 is shown in Figure 3.7. The measurements from MS-43 were taken manually. According to the results, both specimens reach a similar magnitude of dilation at the end of the test. The normal load was kept at a relatively constant normal stress rate (around 10-15 psi). However, normal stress reached 30-35 psi in the MS-43 device. This is expected due to spring reaction to the dilation occurring during the test.

According to the preliminary testing completed using the MS-43, it was concluded that this system is easy to use and has potential to be used as part of existing loading devices. A careful investigation of this device in comparison to the existing shear device ISTD is needed to make sure the simplified configuration can produce comparable results. The investigation should primarily focus on reproducibility of the results with AC-PCC as well as AC-AC composite specimens. Normal load accumulation will need to be carefully examined to check if this has a statistically significant effect on shear strength.

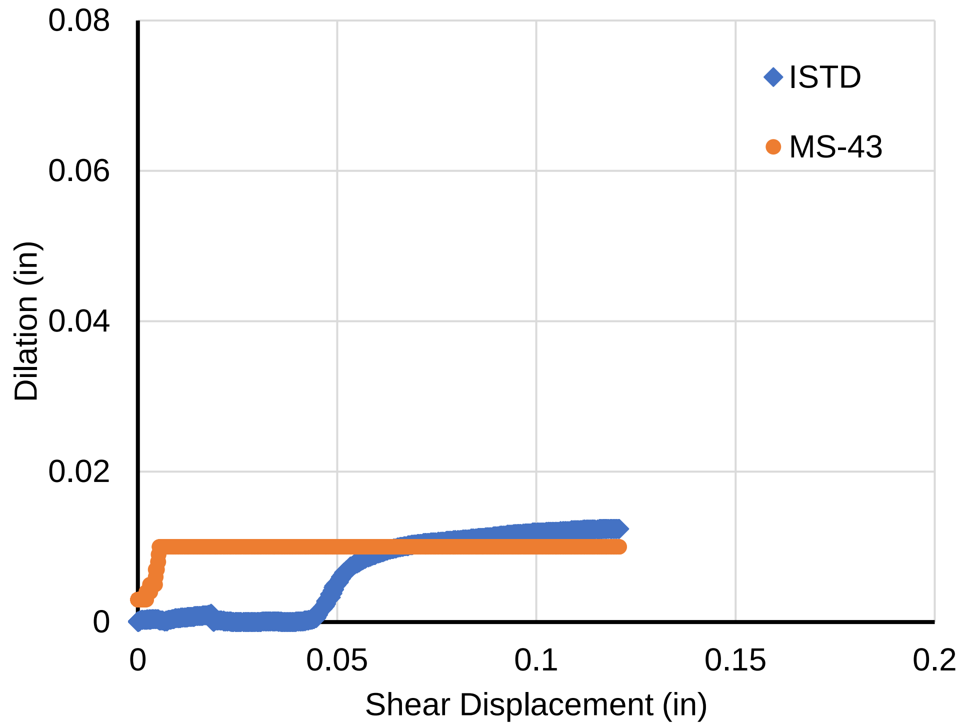


Figure 3.7. Dilation of two DOT-C-LT specimens tested using the MS-43 and the Interlaken Shear Test Device (ISTD) (1 in = 25.4 mm).

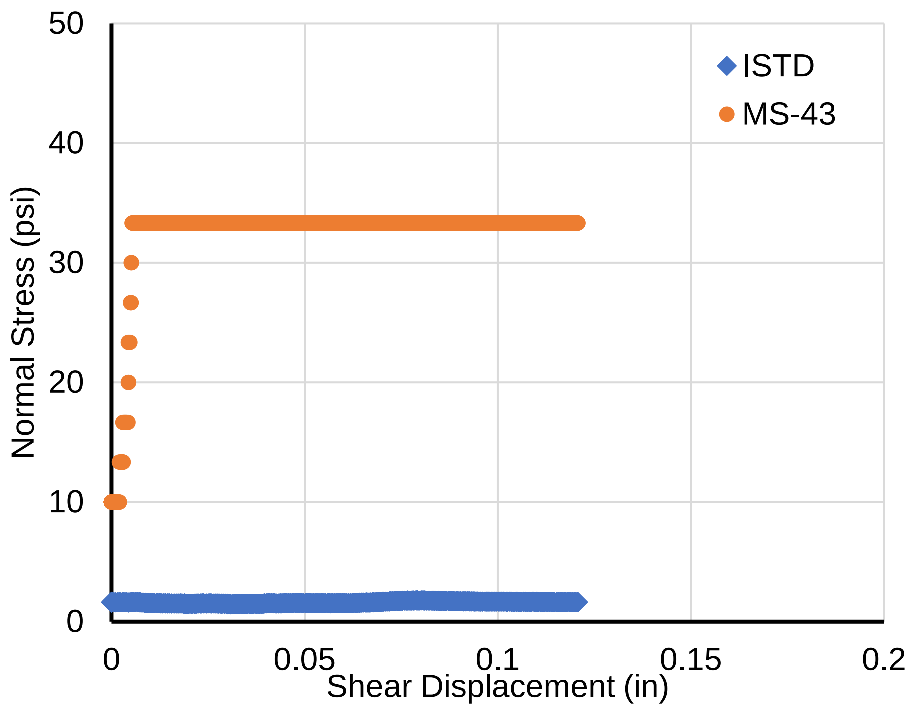


Figure 3.8. Normal stress of two DOT-C-LT specimens tested using the MS-43 and the Interlaken Shear Test Device (ISTD) (1 psi = 6.89 kPa).

CHAPTER 4: SUMMARY OF FINDINGS AND CONCLUSIONS

Shear strength of seven tack coat materials were evaluated using the interface shear testing device developed as part of an earlier ICT study. The materials included three commonly used emulsion type tack coats and four hot-applied products. Asphalt concrete to Portland cement PCC specimens were prepared for shear testing. One type of asphalt mixture was used on top of the PCC cores obtained from a slab. Tack coats were applied at a base application rate of 0.05 lb/ft^2 (0.244 kg/m^2). The application rate was increased to 0.15 lb/ft^2 (0.732 kg/m^2) for one of the hot-applied products. A minimum of six replicates were used for each tack coat.

A summary of findings is provided as follows:

- Emulsion type products resulted in shear strengths between 38 and 73 psi with the SS-1hp (QS) product having the highest strength in this range. The results for emulsion products were consistent with the previous ICT studies.
- Hot-applied products had significantly higher shear strengths than the emulsion type products ranging from 98 to 189 psi. The product called DOT-C-10 provided the highest shear strength with an average peak stress of 189 psi.
- The shear strength of the LJS-II product was reduced by approximately 20 psi when applied at a higher application rate of 0.15 lb/ft^2 (0.732 kg/m^2).
- All of the specimens were prepared after heating the concrete cores with tack coat applied. This is believed to result in better mobilization of tack coat material and providing improved adhesion properties. Heating of the specimens should also better simulate the amount of heat transfer during the placement of overlays in the field.

A simplified shear testing device, MS-43, was acquired and some preliminary testing was completed. The device is easy to use and has some promising applications. The following recommendations are made for future use of the simplified shear testing device:

- The simplified shear testing device can be integrated to screw-driven type of loading frames. Rate of loading is relatively slow compared to regular testing done for asphalt concrete. The rates can be adjusted in the new Auto-SCB device in which the simplified shear testing device can be used with.
- A load cell with a higher capacity (20 kN) should be used with the shear testing as the maximum shear loads may exceed the existing 10 kN capacity.
- The simplified device allows for dilation of the specimen in the horizontal direction. This is the case with most of the simplified shear testing devices. However, depending on the stiffness of spring attached to the device, normal pressure builds up. According to our preliminary investigation, this pressure can be significant and should be monitored to determine if it has any effect on the results. A spring with lower stiffness is recommended to minimize normal pressure build up. The type of spring and its stiffness can be

determined based on a comprehensive testing of the simplified machine side by side with the ISTD as explained next.

- Comprehensive testing is required with the simplified shear testing device as compared to the ISTD after the modification. The testing plan should include comparison of both machines for HMA-HMA and HMA-PCC specimens with selected tack coats applied at various rates. Both of the machines can be used for all of the specimens. In addition to shear strength, normal stresses and dilation should be recorded. The testing of the simplified shear testing device should be done with the original spring and alternative low stiffness spring. The outcome of the testing will allow evaluating the effect of spring stiffness and direct comparison of both of the machines.

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APPENDIX A: MATERIAL PROPERTIES

A.1 PCC AGGREGATE GRADATIONS

COARSE AGGREGATE 1, CM16, KANKAKEE

Sieve/Test	Average	Unit
1/2" (12.5mm)	100.0	%
3/8" (9.5mm)	96.2	%
1/4" (6.3mm)	64.1	%
#4 (4.75mm)	39.8	%
#8 (2.36mm)	7.6	%
#16 (1.18mm)	3.0	%
#200 (75um)	1.77	%
Pan	0.00	%

Figure A.1: CM16 aggregate gradation expressed in terms of percentage of aggregate passing through the specified sieve. Provided by Prairie Materials.

COARSE AGGREGATE 2, CM11, KANKAKEE

Sieve/Test	Average	Unit
1 1/2" (37.5mm)	100.0	%
1" (25mm)	100.0	%
3/4" (19mm)	85.7	%
5/8" (16mm)	68.4	%
1/2" (12.5mm)	44.8	%
3/8" (9.5mm)	24.6	%
1/4" (6.3mm)	10.9	%
#4 (4.75mm)	6.9	%
#8 (2.36mm)	2.7	%
#16 (1.18mm)	2.0	%
#200 (75um)	1.56	%
Pan	0.00	%

Figure A.2: CM11 aggregate gradation expressed in terms of percentage of aggregate passing through the specified sieve. Provided by Prairie Materials.

FINE AGGREGATE, FA, MID-AMERICA, MAHOMET

Table A.1: Fine Aggregate Gradation (Provided by Prairie Materials)

Sieve	% Passing
3/8 (9.5 mm)	100
#4 (4.75 mm)	96.1
#8 (2.36 mm)	89.5
#16 (1.18 mm)	79.1
#30 (0.6 mm)	63.9
#40 (0.425 mm)	48.2
#50 (0.3 mm)	25.4
#100 (0.15 mm)	2.5
#200 (0.075 mm)	1.3
Pan	0

APPENDIX B: SHEAR TEST RESULTS AND VOLUMETRICS

Table B.1: Summary of Results for First Round of Specimens with 7% AV Target

					Average			Standard Deviation		
Name	**Specimen**	**Air Voids**	**Gyrations**	**Maximum Shear Stress (psi)**	**Air Voids**	**Gyrations**	**Maximum Shear Stress (psi)**	**Air Voids**	**Gyrations**	**Maximum Shear Stress (psi)**
DOT-C LT	S1	5.5	67	130.0	6.6	81	153.96	0.6	15	21.0
	S2	7.1	65	30.4						
	S3	7.9	135	146.6						
	S4	5.4	124	162.4						
	S5	8.1	145	26.12						
	S6	5.5	66	169.5						
LJS-I	S53	6.2	150	99.5	6.5	116	80.27	0.2	5	3.3
	S54	6.2	131	83.6						
	S57	6.7	114	80.1						
	S58	6.7	111	75.8						
	S59	6.9	106	81.6						
DOT-C10	S65	6.2	128	141.9	7.3	105	126.89	0.5	10	23.8
	S67	9.3	159	117.79						
	S68	6.8	85	91.9						
	S69	7.3	105	116.6						
	S70	7.9	82	131.0						
	S71	6.5	127	153.0						
LJS-II (0.05 lb/ft^2)	S41	7.1	74	80.3	7.6	75	87.07	0.6	3	18.4
	S42	6.8	75	92.9						
	S43	6.8	75	72.8						
	S44	10.0	71	77.9						
	S45	7.8	86	121.9						
	S50	6.9	69	76.6						
SS-1h	S17	7.0	63	122.6	6.5	93	120.17	0.2	10	17.7
	S18	6.7	89	126.5						
	S19	5.9	135	148.2						
	S20	6.4	124	134.5						
	S21	6.5	85	127.6						
	S22	6.6	103	89.5						
SS-1h QS	S29	6.7	81	123.4	6.7	94	120.45	0.5	7	9.0
	S30	7.0	114	134.6						
	S31	6.6	85	111.8						
	S32	5.1	82	117.7						

	S33*	8.4	147	153.7						
	S34	6.5	108	114.8						
SS-1hp QS	S13	3.7	200	218.0	7.8	73.7	117.52	1.1	26.1	18.6
	S14	9.2	50	108.3						
	S15	7.6	61	100.8						
	S16	6.5	110	143.4						

Table B.2: Summary of Results for First Round of Specimens with 10% AV Target (* Indicates values that were not considered in the average because the result was off from ± three times standard deviation)

					Average			Standard Deviation		
Name	**Specimen**	**Air Voids**	**Gyrations**	**Maximum Shear Stress (psi)**	**Air Voids**	**Gyrations**	**Maximum Shear Stress (psi)**	**Air Voids**	**Gyrations**	**Maximum Shear Stress (psi)**
DOT-C LT	S107	9.4	29	139.2	9.7	30.8	133.87	0.2	1.9	5.26
	S108*	10.0	30	72.8						
	S109	9.8	30	127.2						
	S110	9.8	30	130.2						
	S111*	9.7	29	152.4						
	S112	10.0	34	138.8						
LJS-I	S95	9.8	34	124.5	10.0	33.8	97.73	0.7	1.6	20.73
	S97	11.0	35	109.6						
	S98	10.2	35	85.9						
	S100	9.1	31	70.9						
DOT-C10	S119	11.0	33	200.4	10.3	33.2	188.96	0.8	1.3	23.76
	S120	10.1	31	173.4						
	S121*	10.0	31	49.4						
	S122	10.5	33	209.0						
	S123	11.0	34	150.0						
	S124	8.8	35	212.0						
LJS-II (0.15 lb/ft^2)	S77	10.5	30	61.4	11.1	29.4	86.07	1.2	0.8	18.62
	S78	11.0	28	73.3						
	S80	10.1	29	94.9						
	S81	10.4	30	115.7						
	S82	13.4	30	85.1						

					Average			Standard Deviation		
Name	**Specimen**	**Air Voids**	**Gyrations**	**Maximum Shear Stress (psi)**	**Air Voids**	**Gyrations**	**Maximum Shear Stress (psi)**	**Air Voids**	**Gyrations**	**Maximum Shear Stress (psi)**
LJS-II (0.05 lb/ft^2)	S83	9.8	30	91.8	9.8	29.6	106.57	0.5	1.0	8.99
	S84	9.7	31	101.9						
	S85	9.0	30	117.2						
	S86	9.8	29	113.6						
	S88	10.5	28	108.3						
SS-1h	S143	10.0	30	32.1	9.6	30.0	38.18	0.3	0.6	10.68
	S145	9.3	30	49.3						
	S146	9.1	31	34.3						
	S147	9.6	29	23.6						
	S148	9.7	30	51.7						
SS-1hp QS	S131	10.3	31	48.4	9.3	30.8	73.15	0.8	0.7	19.46
	S132	9.6	32	88.1						
	S133	9.8	30	92.8						
	S134	7.9	31	50.6						
	S135	8.8	30	85.9						
SS-1h QS	S155	10.4	30	59.0	9.7	30.6	61.69	0.4	1.4	8.11
	S156	9.6	31	51.4						
	S157	9.9	33	63.4						
	S158	9.2	30	58.6						
	S159	9.5	29	76.0						

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