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Evaluation of Tack Coat Materials on Longitudinal Joints in Louisiana

by

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16. Abstract

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ABSTRACT

The primary objective of this research was to evaluate the influence of tack coat material type on the resulting longitudinal joint density and permeability. A secondary objective was to ascertain the relation between the interlayer bond shear strength and the quality of the longitudinal joint as measured by density and permeability. This research evaluated the unconfined edge area including the longitudinal joint, in regards to density and permeability, using an un-modified emulsion (SS-1) and a polymer-modified emulsion (trackless tack coat) as the tack coat material types. The research determined the influence of these tack coats in regard to density and permeability transversely from the centerline of the cold mat to the centerline of the hot mat.

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IMPLEMENTATION STATEMENT

The experience obtained from this research study has led to the development of revisions to the current specifications for required tack coat type based on field performance data as measured by density, permeability, and bond shear strength. The revised specification will provide for a well-constructed and bonded mat reducing the effect of the unconfined edge density on the longitudinal joint, which will in turn minimize the effects of cracking, raveling, and other pavement distresses at this pavement interface. Minimizing the effects of these pavement distresses should provide for a longer life expectancy of the completed roadway structure.

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INTRODUCTION

Background and Significance of Research

One of the advantages of asphalt pavements is that they can minimize traffic disruptions by being paved and opened to traffic quickly. Often, asphalt paving is performed while traffic is maintained in an adjacent lane. The disadvantage of this construction technique is that it leads to the formation of longitudinal joints. A longitudinal joint is a construction feature that is present when two or more lanes are constructed adjacent to each other. They are formed when a previous placed mat is allowed to cool (cold lane), and at some other period of time the adjacent lane is paved (hot lane) *[1]*. The disadvantage of longitudinal joints are the distresses they create (such as separation, cracking, and raveling) that cause a rather sound pavement structure to deteriorate sooner than expected.

Longitudinal joints can deteriorate quickly because the density of the joint area has been found to be 2-3% lower than the adjacent paving lanes *[1, 2]*. Low density leads to low tensile strength, which can cause the interface of the adjoining pavements to develop longitudinal cracks that usually run parallel to the centerline of the roadway. Longitudinal cracks allow water and air to infiltrate into the pavement structure. The infiltration of air and moisture accelerates aging of the hot mix materials and can result in cracking, stripping, and raveling at the interface of the adjoined pavement lanes. In addition, the intrusion of water penetrating through the hot mix asphalt (HMA) layers can cause interlayer bonding issues. Poor bonding between paving layers has been found to aggravate and accelerate these pavement distresses *[2, 3, 4, 5]*. To prevent pavement distresses due to poor bonding the current specifications for Louisiana require that the longitudinal joint be tacked where adjacent paving strips are to be placed with an approved tack coat material *[6]*.

Multiple longitudinal joint construction techniques have been studied and are currently used in multiple states, including Louisiana. Construction techniques such as echelon paving, proper rolling techniques, edge restraining devices, infrared joint heaters, cutting wheels, joint adhesives, and joint seals have been researched and implemented over the past 30 years. The overall objective of these various methods is to increase the pavement density at the joint, therefore improving durability and service life *[7]*. Research of the various construction techniques by the National Center for Asphalt Technologies (NCAT) determined that a maximum density difference of 2% at longitudinal joints would significantly improve quality of HMA joints *[1, 3, 4]*.

For most of the construction techniques mentioned above, previous documentation has established recommended procedures and is not investigated further in this project. This research project primarily focuses on tack coat materials and their influence on density, permeability, and shear strength at longitudinal joints.

Background of Tack Coat Material

Asphalt tack coat is a light application of asphalt, usually asphalt diluted with water, used to ensure strong bonding between the surface being paved and the overlying course *[5]*. Bonding is critical to transfer radial tensile and shear stresses into the entire pavement, forming a monolithic system that withstands the traffic and environmental loads. Insufficient bond or excessive tack decreases pavement bearing capacity and may cause slippage, leading to accelerated fatigue cracking and total pavement failure *[8]*. Tack coat application rates depend on several factors such as existing pavement conditions, surface type, temperature, and dilution rates. Figure 1 shows a typical tack coat application.

Figure 1
Typical application of tack coat

The three common types of tack coat used are hot paving asphalt cement, cutback asphalt, and emulsified asphalt. Cutbacks, asphalt cement combined with petroleum solvents, are not typically used for tack coat applications today due to environmental concerns. The most widely used tack coat material is emulsified asphalt, also referred to as asphalt emulsions. Asphalt emulsion is a nonflammable liquid substance that is produced by combining asphalt and water with an emulsifying agent such as soap, dust, or certain colloidal clays. The most common types of emulsions used for tack coats include slow-setting grades of emulsion such as SS-1, SS-1h, CSS-1, and CSS-1h, the rapid-setting grades of emulsion such as RS-1, RS-2, CRS-1, CRS-2, CRS-2P (polymer-modified), and CRS-2L (latex-modified), and lastly NTSS-1HM also known as trackless tack. Survey responses from 42 state DOTs and the District of Columbia found that almost all the state DOTs use slow-setting emulsions for tack coats. The most frequently used emulsions are SS-1, SS-1h, CSS-1, and CSS-1h *[9]*. Likewise, Louisiana primarily uses slow-setting emulsions.

In 2002, Mohammad et al. evaluated the influence of tack coat materials and application rates on the resulting interface bond strength *[10]*. Two types of performance graded asphalt cements, PG 64-22, PG 76-22M, and four emulsions, CRS-2P, SS-1, CSS-1, and SS-1h, were evaluated. Statistical analysis indicates that the polymer-modified CRS-2P emulsion provided significantly higher shear strength and is the best performer of the materials tested. The research also found the optimum residual application rate for the CRS-2P to be 0.09 L/m^2 (0.02 gal/yd^2).

Results from Mohammad et al. were followed by the development of NCHRP Project 9-40, which evaluated the influence of tack coat materials, application rates, and equipment type and calibration procedures on the resulting interface bond strength *[8, 10]*. Similar tack materials with the inclusion of trackless tack were tested. Researchers used an Interlayer Shear Strength Tester to evaluate the interface shear strength of emulsified tack coats under a wide range of testing conditions commonly encountered in field applications. To simulate these test conditions, cores were extracted from a full-scale test site at the center's Pavement Research Facility. The test site was designed and constructed using conventional tack coat application and paving equipment over an existing asphalt pavement surface. Results showed that the trackless tack coat produced the highest shear strength at the three application rates, while SS-1 and CRS-1 resulted in the medium and lowest strengths, respectively.

Tack Coat on Longitudinal Joints

Tack coats are added to longitudinal joints with the aim of improving the bond between cold and hot lanes, preventing longitudinal cracking, and preventing water intrusion into the joint *[11]*. The following paragraphs discuss research studies and transportation agency specifications concerning tack coat applications on longitudinal joints.

According to the *Hot-Mix Asphalt Paving Handbook 2000* and the *Best Practices for Constructing and Specifying HMA Longitudinal Joints*, all vertical surfaces should be tacked, including transverse and longitudinal joints *[12, 13]*. For longitudinal joints, it was recommended that if the free edge of the longitudinal joint was not cut back to a vertical surface, and if the mix along the joint was clean, then a tack coat would not normally be needed. A tack coat added to the face of an unconfined edge of the cold lane ensures a better bond (adhesion) and seal of abutting HMA lanes. The tack coat usually consists of asphalt cement, emulsion, or hot poured, rubberized asphalt sealer *[12, 13]*.

Research studies have found tack coat applications to have positive effects on longitudinal joints. The NCAT field research has demonstrated that the use of hot poured, rubberized asphalt sealer as a tack coat, about 1/8 in. or 3 mm thick, on the face of the first paved lane produced the most durable longitudinal joints, outperforming all other longitudinal joint construction techniques. Therefore, it appears that thick tack coats may be more effective than generally used thin coats of asphalt cement or emulsion *[1, 3, 4]*. Similar results were observed in Tennessee projects which showed that polymer emulsion tack coats appeared to increase the indirect tensile (IDT) strength of longitudinal joints *[11]*.

Tack coat application on longitudinal joints is standard practice in some countries, for example, United Kingdom, Japan, and South Africa. However, opinions vary in the United States. Some engineers believe application of thin tack coating material such as asphalt cement and emulsion in case of semi-hot joint is unnecessary since it may not contribute in improving the durability of the longitudinal joint *[4]*. However, 13 department of transportation (DOT) agencies reported that vertical surfaces, such as longitudinal joints, construction joints, curbs, gutters, etc. should be tacked *[5]*. DOT agencies in California, Colorado, Georgia, Kansas, Maryland, Minnesota, Missouri, Nebraska, Nevada, New Mexico, North Dakota, Oklahoma, South Dakota, Rhode Island, Texas, Utah, Virginia and Wyoming have tack coat specifications for longitudinal joints *[5, 14, 15, 16]*. Likewise, Louisiana currently requires that the interlayer between hot mix lifts and the longitudinal joint be tacked where adjacent paving strips are to be placed with an approved tack coat material *[6]*.

OBJECTIVE

The objectives of this project are the following:

1. Evaluate the influence of tack coat material type on the resulting longitudinal joint density and permeability.
2. Ascertain the relationship between the interlay bond shear strength and the quality of the longitudinal joint as measured by density and permeability.
3. Recommend revisions to the current specifications for required tack coat type based on field performance data as measured by density, permeability, and bond shear strength.

SCOPE

The project site selected was LA 3235 between Galliano and Golden Meadow in Lafourche Parish. Two types of HMA lifts were placed on top of two types of existing surfaces and were selected for testing: a binder, level 1 Superpave, laid on top of an existing milled surface; and a wearing course, level 1 Superpave, laid on top of an existing binder course. Density and permeability of the road structure transversely from centerline of the cold mat to centerline of the hot mat were cored and evaluated. Two types of emulsions were used as tack coat materials for this research. An un-modified emulsion (SS-1) and a trackless tack polymer-modified emulsion (NTSS-1HM) were tested and compared. Nine test sections were prepared, five test sections were determined for the binder on milled course, and four test sections were determined for the wearing on binder course. The lengths of each test section varied between 1100 and 4200 feet. The binder on milled test sections were on the westbound lane, whereas the wearing on binder test sections were on the eastbound lane. Each test section contained a specified tack coat and application rate, and the longitudinal joints were either tamped or un-tamped. The application rates were minimum rates of undiluted asphalt emulsion and were selected for these projects were based on HMA lift specifications *[6]*. Field cores were taken from the hot mat, cold mat, and longitudinal joints. Twenty-six cores were obtained and studied from each section.

The field cores obtained from each section were tested for in-place density, permeability, and shear strength. The in-place density was measured and recorded in accordance with test method AASHTO T-166 (DOTD 304-03). The permeability of field cores taken was measured and recorded in accordance with ASTM PS 129-01. A shearing apparatus designed by Mohammad et al. was used to produce failure at the interface of the bottom and top layers of the specimen *[10]*. The apparatus was designed to reflect the fundamental mechanisms of interface strength.

METHODOLOGY

Test Factorial and Project Specifications

The project site selected was LA 3235 between Galliano and Golden Meadow in Lafourche Parish. This section of LA 3235 is a four lane highway with a grass median. Two types of HMA lifts were placed on top of two types of existing surfaces and were selected for testing: a binder course, level 1 Superpave, laid on top of an existing milled surface, and a wearing course, level 1 Superpave, laid on top of an existing binder course. The binder course is an intermediate course between the base course and the surfacing material (wearing course). A tack coat is usually applied on top of the existing pavement to increase bonding between layers. Figure 2 shows a standard cross section of a flexible pavement.

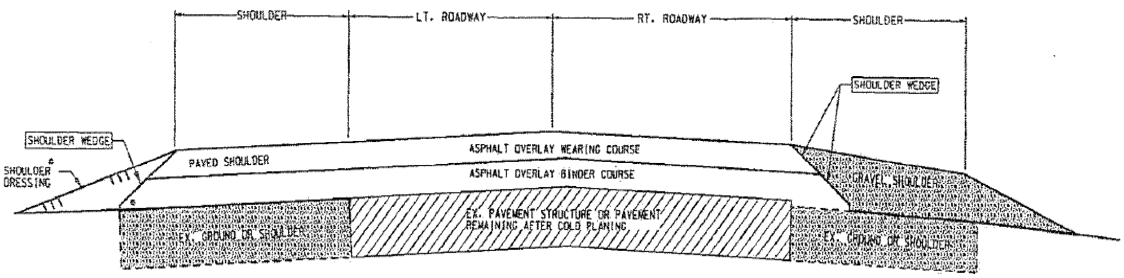

Figure 2
Standard cross section of a flexible pavement

Table 1 represents the test factorial for this research study. Two types of emulsions are used as tack coat materials: un-modified emulsion (SS-1) and a polymer-modified emulsion trackless tack (NTSS-1HM). Five test sections were established for the binder course and four sections for the wearing course. The lengths of each test section varied between 1100 and 4200 feet. The binder on milled test sections were on the westbound lane, whereas the wearing on binder test sections were on the eastbound lane.

Application rates were minimum rates of undiluted asphalt emulsion and were selected based on the type of HMA lift *[6]*. For the binder on milled section, a greater application rate was required at 0.08 gal/yd^2 because a milled surface requires additional tack. An additional test section (test section 5) was added to the binder on milled section with an application rate of 0.04 gal/yd^2. Section 5 was used primarily to compare with section 3 and the 0.08 gal/yd^2 application rate to determine which application rate performed the best. Figure 5 and 6 below show differences between the 0.04 and 0.08 gal/yd^2 application rates. The minimum rates of undiluted asphalt emulsion for the wearing on binder section was 0.03 gal/yd^2. The current specifications do not require any tamping of the longitudinal joint during construction whereas past specifications did require tamping of the longitudinal joint *[6, 17]*. Therefore, this research includes a tamped and an un-tamped cold lane interface at the longitudinal joint. As seen in Figure 3, there was a total of 26 field cores taken at each test section. Six cores were taken from the center of the hot lane and six from the cold lane. Another three cores were taken one foot from the longitudinal joint from each lane and a further eight cores were taken at the longitudinal joint. There were 130 cores taken from the binder on milled section and 104 from the wearing on binder section; a total of 234 total cores were obtained. The test sections were cored in this manner to obtain a well-defined density map of the roadway cross section. Each test sections contained three station markings, as shown in Figure 4, where eight to ten cores were taken. The field cores taken from the project site were then measured and recorded for in-place density, permeability, and bond shear strength.

Table 1
Test factorial per project lift

Test Section	Longitudinal Joint		Tack Coat Material Type		No. of Cores Acquired		Tack Coat Application Rate (gal / yd^2)	
	Not Tamped	Tamped	SS-1 (Conventional Emulsion)	NTSS-1HM (Trackless Tack)	Binder Course	Wearing Course	Binder Course	Wearing Course
1	X		X		26	26	0.08	0.03
2		X	X		26	26	0.08	0.03
3	X			X	26	26	0.08	0.03
4		X		X	26	26	0.08	0.03
5	X			X	26	-	0.04	-
Total Cores Acquired					130	104		
					234			

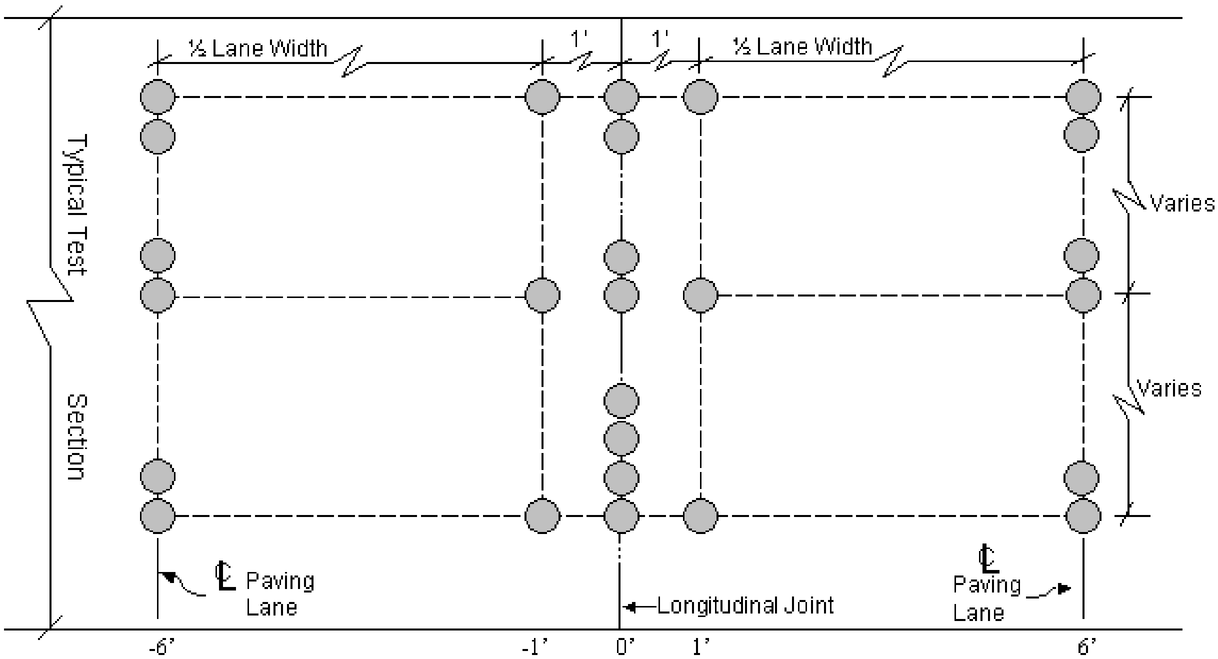

Figure 3
6-in. core locations per test section

Figure 4
Coring for STA 35+00

Figure 5
0.04 gal/yd^2 Trackless Tack

Figure 6
0.08 gal/yd^2 Trackless Tack

Density Test

Density studies by Brown showed that in-place voids should be no more than approximately 8% and should never fall below approximately 3% during the life of the pavement. It has been observed that high voids can lead to permeability of water and air resulting in water damage, oxidation, raveling, and cracking, and low voids can lead to rutting and shoving of the asphalt mixture *[18]*. Longitudinal joints have the problem of high air voids leading to air and water infiltration. NCAT recommended that the minimum acceptable compaction level be specified and that longitudinal joints should be no more than 2% lower in density than the density specified for the mat. They also contend that air void contents at the joints should not be allowed to exceed 10% *[1, 3, 4]*.

The percent of air voids was calculated by comparing a test specimen's bulk specific gravity (G_{mb}) with its theoretical maximum specific gravity (G_{mm}) and assuming the difference is due to air. G_{mm} was given in the job mix formula (JMF). Once G_{mm} is known, portable non-destructive devices can be used to measure HMA density in-place *[19]*. AASHTO T-166 (DOTD TR 304-03), "Bulk Specific Gravity of Compacted Bituminous Mixtures Using Saturated Surface-Dry Specimens," was used to determine G_{mb} of field cores obtained from each test section. This test method determines the G_{mb} of a compacted HMA samples by determining the ratio of its weight to the weight of an equal volume of water. Field cores were weighed in air dry conditions, weighed in water, and weighed at saturated surface dry (SSD) conditions. Those weights were then used to calculate bulk specific gravity and pavement density percentage. AASHTO T-209, "Theoretical Maximum Specific Gravity and Density of Hot Mix Asphalt" was used to find G_{mm} and percent air voids in the sample.

$$G_{mb} = A/(C-B) \qquad (1)$$

G_{mb} = mixture bulk specific gravity, unitless;
A = weight in air, g;
B = weight in water, g; and
C = weight of Saturated Surface Dry (SSD), g.

$$Air\ Voids\ (percent) = ((G_{mm}-G_{mb})/G_{mm})*100 \qquad (2)$$

G_{mm} = mixture maximum specific gravity, unitless

Permeability Test

High air void content usually leads to a high water permeability. Water intrusion into HMA mixtures can lead to a multitude of distresses such as raveling, stripping and cracking. Tack coat application to longitudinal joints can act as a seal from water intrusion and increase bonding strength at the joint.

The field cores were tested for permeability in accordance with ASTM PS 129-01, "Measurement of Permeability of Bituminous Paving Mixtures Using a Flexible Wall Permeameter." This test method covered procedures for determining the relative permeability of water saturated field cores of compacted bituminous paving mixtures using a flexible wall permeameter as seen in Figure 7. Water flows in a vertical direction through the test specimen and the time interval for the water head to drop from the initial reading to the final reading is recorded. Using Darcy's law, the coefficient of permeability is expressed using the following equation:

$$k = (aL/At) * \ln (h1/h2) \quad (3)$$

k = coefficient of permeability, cm/sec;
a = inside cross-sectional area of standpipe, cm^2;
L = length of sample (thickness of the asphalt mat), cm;
A = cross-sectional area of permeameter through which water can penetrate the pavement, 214 cm^2;
t = elapsed time between h1 and h2, sec;
h1 = initial head, cm;
h2 = final head, cm; and
ln = Natural Logarithm.

Figure 7
Falling head flexible wall permeameter

Shear Loading Apparatus and Bond Shear Strength Testing

Measurement of interlayer (between layers) and interface (at joints) shear strengths required the acquisition of shearing fixtures. For interlays shear strength testing, the shearing apparatus designed by Mohammad et al. was used. This device was designed to produce failure at the interface of the bottom and top layers of the specimen *[10]*. As seen in Figure 8, the interlays shearing apparatus has two parts. Each part has a 150-mm (5.9-in.) diameter and 50.8-mm (2-in.) deep indention that holds the specimens during testing. The shearing apparatus was mounted inside the Superpave Shear Tester (SST) as seen in Figure 9. A similar apparatus was designed and fabricated to measure the shear strength of mixtures at the joint interface. This apparatus was designed to reflect the fundamental mechanisms of interface shear strength.

Direct shear testing was conducted to measure shear strengths. A simple shear test was conducted with the SST to determine the shear strength of the test specimen at the interface. A shearing load was applied at a constant rate of 222.5 N/min (50 lb./min) on the specimen until failure *[10]*.

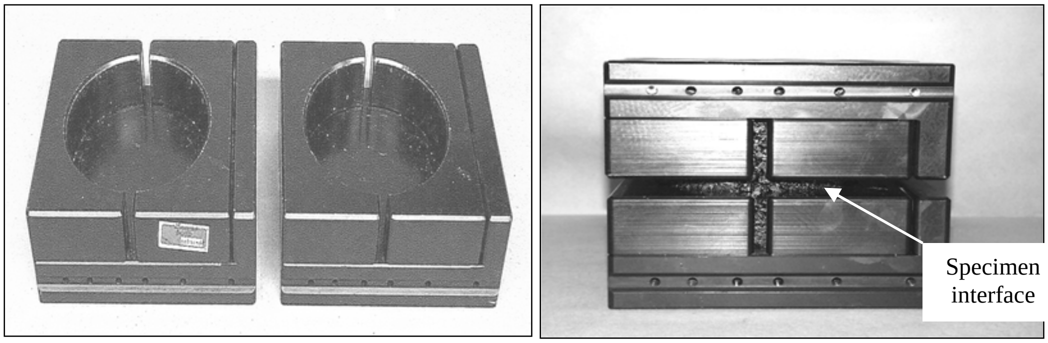

Figure 8
Interlayer shearing apparatus with a sample inside *[10]*

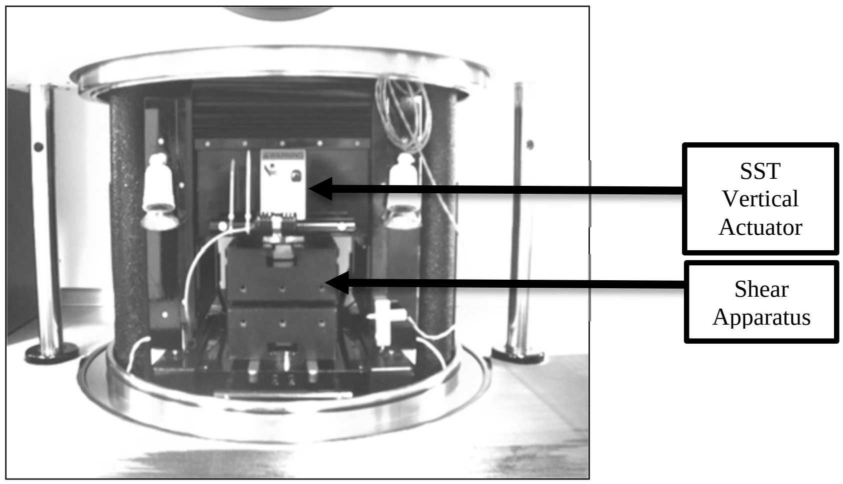

Figure 9
Interlayer shearing apparatus inside the Superpave Shear Tester *[10]*

Data Analysis

Laboratory test data was analyzed statistically to examine the influence of different asphalt tack coat materials and joint types (tamped vs. un-tamped) on the interface and on the interlayer bonding strength. Test results were grouped accordingly to test longitudinal joint type and the type of tack coat used to characterize the variation of interface and interlayer bonding. Statistical analysis of the test results were carried out using the Statistical Analysis System (SAS) software. Various procedures within the SAS software were considered. The Fisher's Least Significant Difference (LSD) with a 95% confidence interval was selected. This multiple comparison procedure ranked the mean density values and placed them in groups designated A, B, C, D, A/B, and so forth. The letter A is used to rank the group with the highest mean density followed by other letter grades in the appropriate order. A double-letter designation, such as A/B, indicates that the mean density of that group is not significantly different from either group A or B *[10]*.

DISCUSSION OF RESULTS

Density Results

Tables 4 to 16 and Figures 12 to 24 in Appendix A display the core sample density data obtained from the field tests. Like many of the previous studies completed on longitudinal joints, the results confirm longitudinal joint density was lower than mat densities. Generally, the cold lane mats had lower densities than the hot lane mats and the cold lane mats showed lower densities at the unconfined edge as compared to the confined edge of the hot lane mats. The SAS software was used for density comparisons. Statistical comparisons were used for all test sections to determine the best tack coat and tack coat application.

The 0.08 gal/yd^2 trackless tack coat yielded overall greater densities than the 0.04 gal/yd^2 trackless tack on the longitudinal joint un-tamped sections. There was very little statistical difference, however, there was a 1% increase in longitudinal density at the 0.08 gal/yd^2 application rate.

Density comparison between the SS-1 and trackless tack revealed no statistical differences for untamped sections, and minor statistical differences for tamped sections. Similar transverse densities were observed. In some cases, the statistical analysis comparison of the density profile of the trackless tack and SS-1 indicate more uniformity across the mat with the trackless tack.

Standard deviation and coefficient of variation for the binder/milled surface is double on the center of the mats than what it is for the wearing course, but are fairly close in value at the longitudinal joint. Density standard deviation for all cores was approximately 1.8-1.9% which closely matched previous statistical evaluations. Metcalf et al.'s statistical evaluation of quality assurance for HMA was 1.8% for 1960, 1.7% for 1971-77, 1.8% for 1975-77, and 1.9% for 1985-97 *[20]*.

Permeability Test Results

The cores studied for the permeability test were all obtained from the wearing course. The permeability results shown on Table 2 show a clear relationship between density and permeability. For HMA, a lower permeability is more successful because water will have a harder time infiltrating the pavement. Denser cores were observed to have lower coefficients of permeability (COP) than the less dense cores. The average center lane density was approximately 3% denser than the longitudinal joint cores resulting in the center lane being more impermeable to water intrusion. Figure 10 illustrates the coefficient of permeability (COP) results for the center lane and longitudinal joint.

For the center lane cores, trackless tack tamped showed the best results with an average COP value of 3.9 ft./day as shown in Figure 10. Trackless tack, both tamped and un-tamped, received more consistent values than the conventional emulsions (SS-1). The conventional emulsions, both tamped and un-tamped, produced higher coefficient of variation (COV) producing skewed averages. Comparing trackless tack tamped with trackless tack un-tamped, displayed a significant improvement of permeability performance when the trackless tack is tamped.

For the longitudinal joint cores, the conventional un-tamped emulsion (SS-1U) had the lowest average COP followed by the trackless tack tamped. From Table 2, it can be observed that the average density was higher for the SS-1 Un-tamped resulting in lower COP values. As previously stated from the density results, trackless tack did not produce higher densities than the conventional emulsion.

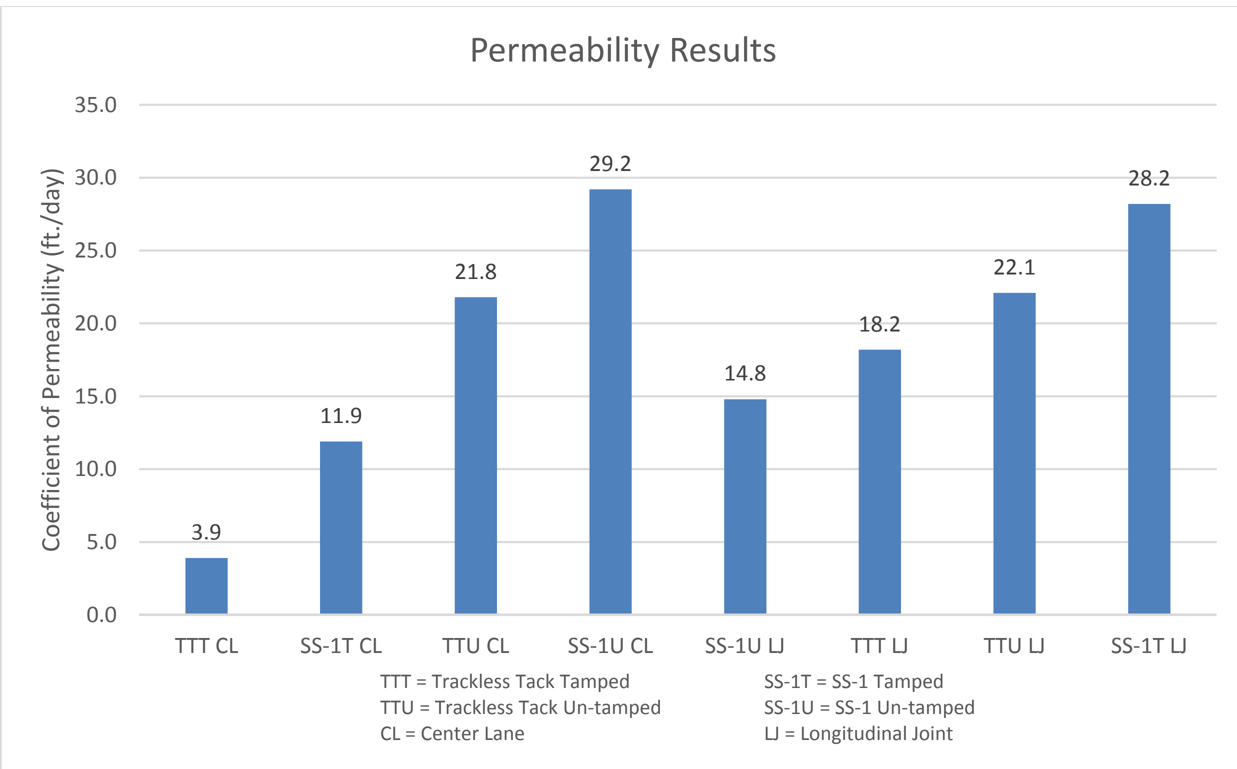

Figure 10

Permeability results for center lane and longitudinal joints on wearing course lift

Table 2

Permeability results for center lane and longitudinal joint on wearing course lift

Center Lane				Longitudinal Joint			
CORE	**K FT/DAY**	**DENSITY**	**Type**	**CORE**	**K FT/DAY**	**DENSITY**	**Type**
A 176	2.1	93.0	TTT	C 231	10.9	89.7	SS-1U
A 184	2.2	92.9	SS-1T	C 178	15.5	89.3	TTT
A 220	4.7	92.3	SS-1U	C 145	17.7	89.4	TTU
A 167	5.7	92.0	TTT	C 213	18.6	89.6	SS-1U
A 132	21.5	91.7	TTU	C 186	20.9	89.3	SS-1T
A 201	21.6	91.7	SS-1T	C 161	20.9	89.1	TTT
A 150	22.1	91.8	TTU	C 137	26.5	88.6	TTU
A 210	53.8	91.4	SS-1U	C 196	35.5	89.1	SS-1T
Average	**16.7**	**92.1**		**Average**	**20.8**	**89.3**	

CORE	**K FT/DAY**	**DENSITY**	**Type**	**CORE**	**K FT/DAY**	**DENSITY**	**Type**
A 176	2.1	93.0	TTT	C 178	15.5	89.3	TTT
A 167	5.7	92.0	TTT	C 161	20.9	89.1	TTT
Average	**3.9**	**92.5**		**Average**	**18.2**	**89.2**	

A 132	21.5	91.7	TTU	C 145	17.7	89.4	TTU
A 150	22.1	91.8	TTU	C 137	26.5	88.6	TTU
Average	**21.8**	**91.8**		**Average**	**22.1**	**89.0**	

A 184	2.2	92.9	SS-1T	C 196	35.5	89.1	SS-1T
A 201	21.6	91.7	SS-1T	C 186	20.9	89.3	SS-1T
Average	**11.9**	**92.3**		**Average**	**28.2**	**89.2**	

A 220	4.7	92.3	SS-1U	C 231	10.9	89.7	SS-1U
A 210	53.8	91.4	SS-1U	C 213	18.6	89.6	SS-1U
Average	**29.2**	**91.9**		**Average**	**14.8**	**89.7**	

Shear Test Results

Many core samples were either not tested or untestable resulting in many values being discarded as seen in Table 3. However, the binder course hot lane core samples were all successfully collected and are shown in Figure 11. Shear strength values were analyzed cautiously due to high coefficient of variation (COV) values.

Although COV values were high, the average shear strength results, colored red below, show trackless tack tamped had the highest average shear strength followed by the SS-1 un-tamped, Figure 11. This correlates with Mohammad et al. data, showing trackless tack produced higher shear strength than the conventional tack coat *[8]*. The application rate of 0.08 gal/yd^2 had a higher average shear strength than the 0.04 gal/yd^2 which coincides with previous NCAT studies *[1, 3, 4]*. SS-1 tamped had the lowest average shear strength. Overall the data collected in this shear test coincides with previous tack coat study trends and was used in the conclusion.

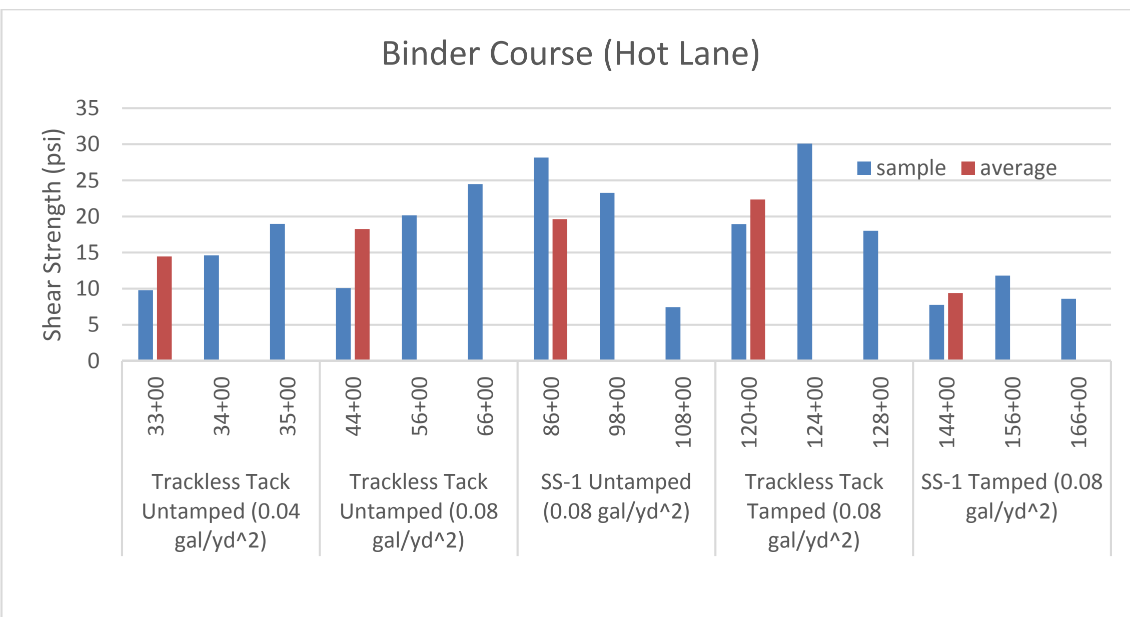

Figure 11
Shear strength results

Table 3
Shear strength results

BINDER COURSE	Station	Cold Mat				Interface				Hot Mat			
Type		Shear Strength (psi)	Avg.	Std.	CV%	Shear Strength (psi)	Avg.	Std.	CV%	Shear Strength (psi)	Avg.	Std.	CV%
Trackless Tack Untamped (0.04 gal/yd^2)	33+00	20.82				untestable				9.8			
	34+00	18.21	20.20	1.76	8.71	untestable				14.62	14.46	4.59	31.71
	35+00	21.56				untestable				18.97			
Trackless Tack Untamped (0.08 gal/yd^2)	44+00	untestable				untestable				10.08			
	56+00	untestable				untestable				20.16	18.24	7.39	40.53
	66+00	untestable				untestable				24.49			
SS-1 Untamped (0.08 gal/yd^2)	86+00	9.64				untestable				28.15			
	98+00	untestable	9.63	0.01	0.15	untestable				23.26	19.62	10.83	55.18
	108+00	9.62				untestable				7.44			
Trackless Tack Tamped (0.08 gal/yd^2)	120+00	untestable				untestable				18.95			
	124+00	12.18				untestable				30.08	22.34	6.72	30.06
	128+00	untestable				untestable				18			
SS-1 Tamped (0.08 gal/yd^2)	144+00	10.65				untestable				7.74			
	156+00	untestable	8.02	3.72	46.38	untestable				11.8	9.38	2.14	22.81
	166+00	5.39				14.94				8.6			

WEARING COURSE	Station	Cold Mat				Interface				Hot Mat			
Type		Shear Strength (psi)	Avg.	Std.	CV%	Shear Strength (psi)	Avg.	Std.	CV%	Shear Strength (psi)	Avg.	Std.	CV%
Trackless Tack Untamped (0.03 gal/yd^2)	36+00	untestable				untestable				13.03			
	40+00	untestable				untestable				15.22	13.61	1.41	10.35
	44+00	12.43				untestable				12.59			
SS-1 Untamped (0.03 gal/yd^2)	52+00	9.63				untestable				untestable			
	58+00	untestable				untestable				8.66			
	62+00	untestable				untestable				untestable			
Trackless Tack Tamped (0.03 gal/yd^2)	89+00	untestable				untestable				untestable			
	92+00	16.72	17.46	1.05	5.99	untestable				untestable			
	96+00	18.2				untestable				14.21			
SS-1 Tamped (0.03 gal/yd^2)	104+00	11.83				untestable				12.31			
	108+00	16.99				untestable				20.52			
	112+00	untestable				untestable				untestable			

CONCLUSIONS

Based upon the observations obtained from the field and lab test of this study, it can be concluded that trackless polymer-modified tack coat is capable of delivering improved performances on longitudinal joint densities and provide increased shear strength. The following findings and conclusions are shown based on the outcome of this study:

- Longitudinal joint density was lower than mat densities.
- The unconfined edge of the cold mat had lower density than the confined edge of the hot mat.
- The 0.08 gal/yd^2 trackless tack coat yielded overall greater densities than the 0.04 gal/yd^2 trackless tack on the longitudinal joint un-tamped sections. The density test showed a 1% increase in longitudinal density at the 0.08 gal/yd^2 application rate.
- Density comparison of SS-1 and trackless tack revealed no statistical differences for untamped sections, and minor statistical differences for tamped sections.
- The statistical analysis comparison of the density profile of the trackless tack and SS-1 indicates more uniformity across the mat with the trackless tack.
- Density standard deviation for all cores was approximately 1.8-1.9% which closely matched previous statistical evaluations.
- Denser cores produced lower coefficients of permeability. Trackless tack tamped produced the lowest coefficient of permeability (COP) for the center lane and SS-1 un-tamped produced the lowest COP for the longitudinal joint. Both COPs were the lowest because the cores were the densest.
- Trackless tack tamped consistently produced a lower COP than trackless tack un-tamped for both the center lane and longitudinal joint.
- Although the COV (coefficient of variation) was high, shear strength data coincided with previous studies showing trackless tack tamped produced the highest average shear strength.
- The 0.08 gal/yd^2 trackless tack coat yielded a greater average shear strength than the 0.04 gal/yd^2 trackless tack on the longitudinal joint un-tamped sections.

RECOMMENDATIONS

Based on the outcome of this study, the authors recommend the use of Trackless Polymer-Modified tack coat. Since this was a limited study, further research should be recommended to evaluate the performance of trackless tack on more projects.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

AASHTO	American Association of State Highway and Transportation Officials
ASTM	American Society for Testing and Materials
cm	centimeter(s)
DOT	Department of Transportation
DOTD	Department of Transportation and Development
FHWA	Federal Highway Administration
ft.	foot (feet)
G_{mb}	Bulk Specific Gravity of Mixture
G_{mm}	Theoretical Maximum Specific Gravity of Mixture
gal/yd^2	gallons per square yard
HMA	Hot Mix Asphalt
IDT	Indirect Tensile Strength
in.	inch(es)
L/m^2	liters per square meter
LTRC	Louisiana Transportation Research Center
lb.	pound(s)
lb./min	pounds per minute
mm	millimeter(s)

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APPENDIX A

Table 4

Avg. density for all sections @ 0.08 gal/yd^2 on binder course/milled surface

Location	***% Avg. Density***	***Stdev.***	***%C.V.***
-6	**91.8**	**2.26**	**2.46**
-1	**91.1**	**1.94**	**2.13**
0	**87.2**	**1.26**	**1.44**
1	**92.1**	**1.30**	**1.41**
6	**92.0**	**2.10**	**2.28**

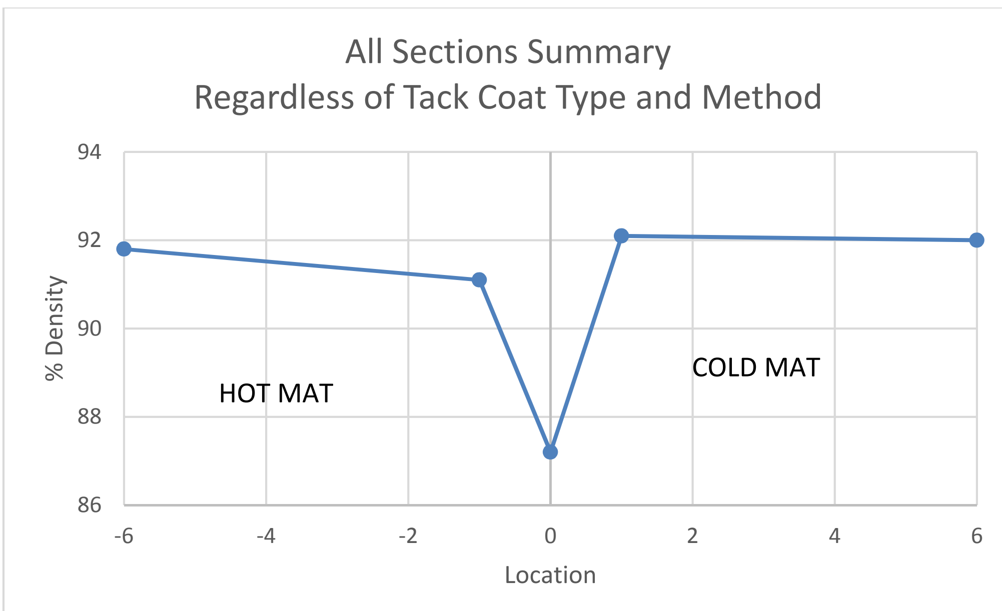

Figure 12

All sections summary

Table 5

Avg. density comparison for Trackless Tack (untamped) @ 0.08 vs. @ 0.04 gal/yd^2 on binder course/milled Surface

TTU 0.08 vs. TTU 0.04			SAS Comparison	
Location	***Trackless Tack 0.08***	***Trackless Tack 0.04***	***TT 0.08***	***TT 0.04***
-6	**92.1**	**90.4**	**A**	**A**
-1	**91.5**	**91.5**	**A**	**A**
0	**86.8**	**85.8**	**A**	**B**
1	**92.8**	**92.4**	**A**	**A**
6	**92.8**	**91.3**	**A**	**A**

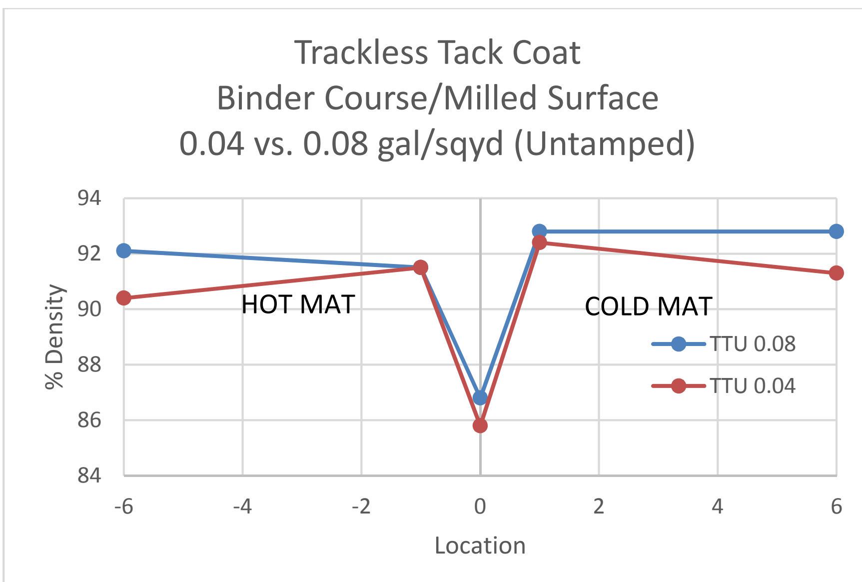

Figure 13

TTU 0.04 vs. TTU 0.08

Table 6
Avg. density comparison for Trackless Tack (untamped) vs. SS-1 (untamped) @ 0.08 gal/yd² on binder course/milled surface

TTU 0.08 vs. SS-1U 0.08			SAS Comparison	
Location	***Trackless Tack***	***SS-1***	***TT***	***SS-1***
-6	**92.1**	**91.7**	**A**	**A**
-1	**91.5**	**90.9**	**A**	**A**
0	**86.8**	**87.3**	**A**	**A**
1	**92.8**	**92.7**	**A**	**A**
6	**92.8**	**93.5**	**A**	**A**

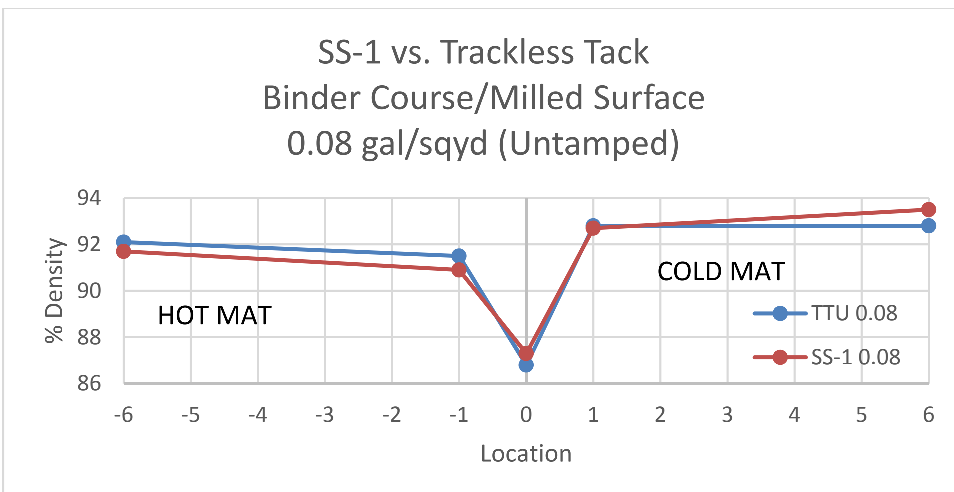

Figure 14
SS-1U 0.08 vs. TTU 0.08

Table 7
Avg. density comparison for Trackless Tack (tamped) vs. SS-1 (tamped) @ 0.08 gal/yd^2 on binder course/milled surface

TTT 0.08 vs. SS-1T 0.08			SAS Comparison	
Location	***Trackless Tack***	***SS-1***	***TT***	***SS-1***
-6	**90.1**	**93.1**	**B**	**A**
-1	**89.3**	**91.7**	**A**	**A**
0	**89.3**	**87.2**	**A**	**B**
1	**91.6**	**92**	**A**	**A**
6	**90.1**	**92.8**	**A**	**A**

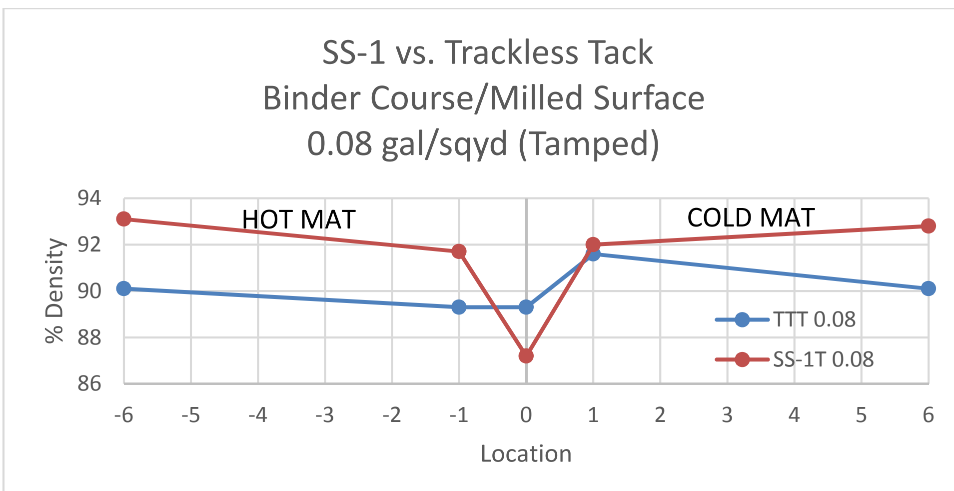

Figure 15
TTT 0.08 vs. SS-1T 0.08

Table 8

Avg. density comparison for Trackless Tack (untamped) vs. SS-1 (tamped) @ 0.08 gal/yd^2 on binder course/milled surface

TTU 0.08 vs. SS-1T 0.08			SAS Comparison	
Location	***Trackless Tack***	***SS-1***	***TT***	***SS-1***
-6	**92.1**	**93.1**	**A**	**A**
-1	**91.5**	**91.7**	**A**	**A**
0	**86.8**	**87.2**	**A**	**A**
1	**92.8**	**92.0**	**A**	**A**
6	**92.8**	**92.8**	**A**	**A**

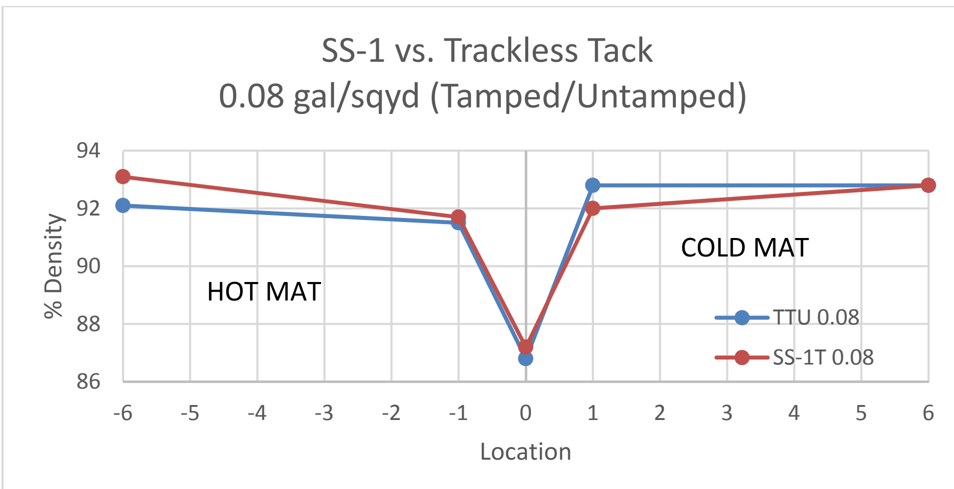

Figure 16

TTU 0.08 vs. SS-1T 0.08

Table 9
Avg. density for Trackless Tack (untamped) @ 0.08 gal/yd² on binder course/milled surface

TTU 0.08				SAS Analysis
Location	***% Avg. Density***	***Stdev.***	***%C.V.***	
-6	**92.1**	**1.46**	**1.59**	**A**
-1	**91.5**	**0.64**	**0.70**	**A**
0	**86.8**	**0.32**	**0.37**	**B**
1	**92.8**	**0.87**	**0.93**	**A**
6	**92.8**	**1.38**	**1.49**	**A**

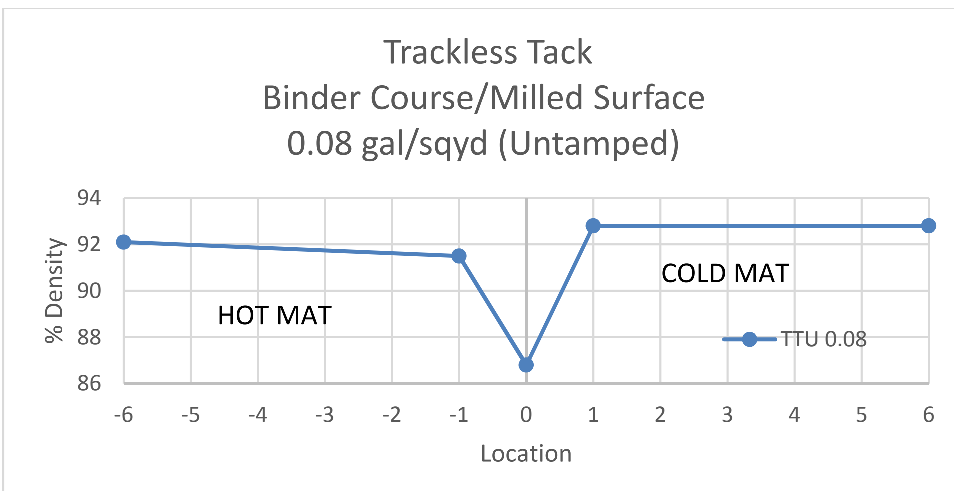

Figure 17
TTU 0.08

Table 10
Avg. density for SS-1 (untamped) @ 0.08 gal/yd^2

SS-1U 0.08					SAS Analysis
Location	***% Avg. Density***	***Stdev.***	***%C.V.***		
-6	**91.7**	**0.42**	**0.45**		**B/C**
-1	**90.9**	**1.49**	**1.64**		**C**
0	**87.3**	**0.56**	**0.65**		**D**
1	**92.7**	**0.63**	**0.68**		**B/A**
6	**93.5**	**1.15**	**1.23**		**A**

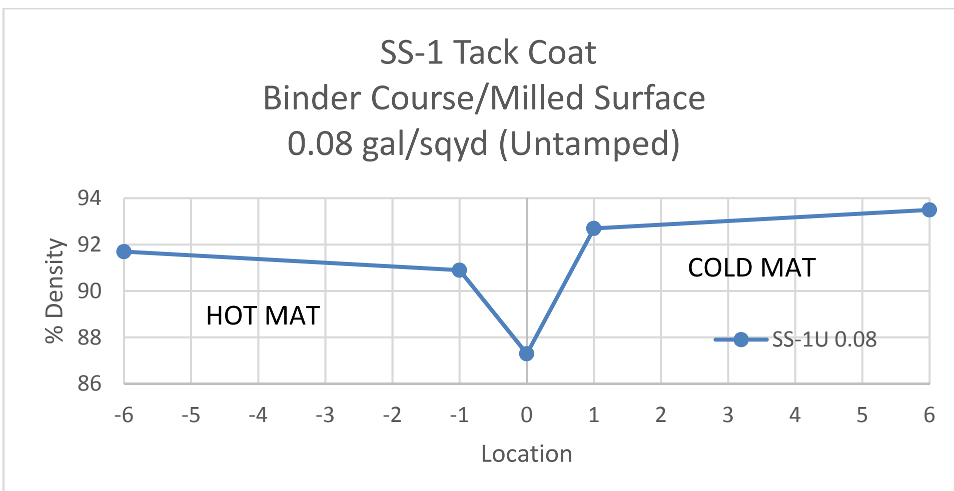

Figure 18
SS-1U 0.08

Table 11
All sections summary @ 0.03 gal/yd^2 on wearing course

Location	*% Avg. Density*	*Stdev.*	*%C.V.*
-6	**92.0**	**1.03**	**1.12**
-1	**91.9**	**1.33**	**1.45**
0	**89.6**	**0.94**	**1.04**
1	**93.8**	**1.16**	**1.24**
6	**93.9**	**0.83**	**0.89**

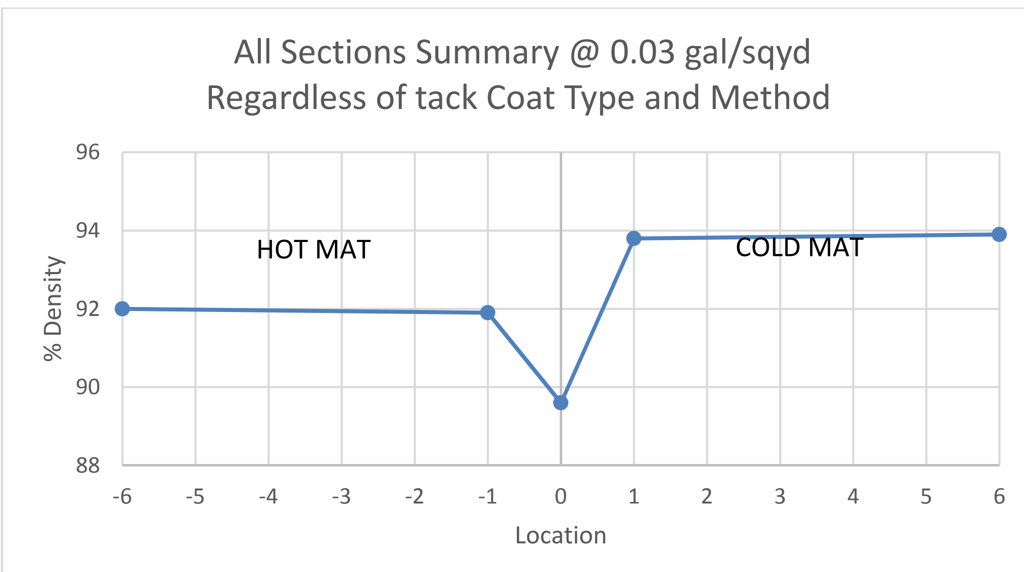

Figure 19
All sections summary @ 0.03

Table 12
Avg. density comparison for Trackless Tack (untamped) vs. SS-1 (untamped) @ 0.03 gal/yd^2 on wearing course

TTU 0.03 vs. SS-1U 0.03			SAS Comparison	
Location	***Trackless Tack***	***SS-1***	***TT***	***SS-1***
-6	**91.7**	**91.5**	**A**	**A**
-1	**91.9**	**91.1**	**A**	**A**
0	**89.6**	**90.0**	**A**	**A**
1	**93.0**	**93.9**	**A**	**A**
6	**93.5**	**94.0**	**A**	**A**

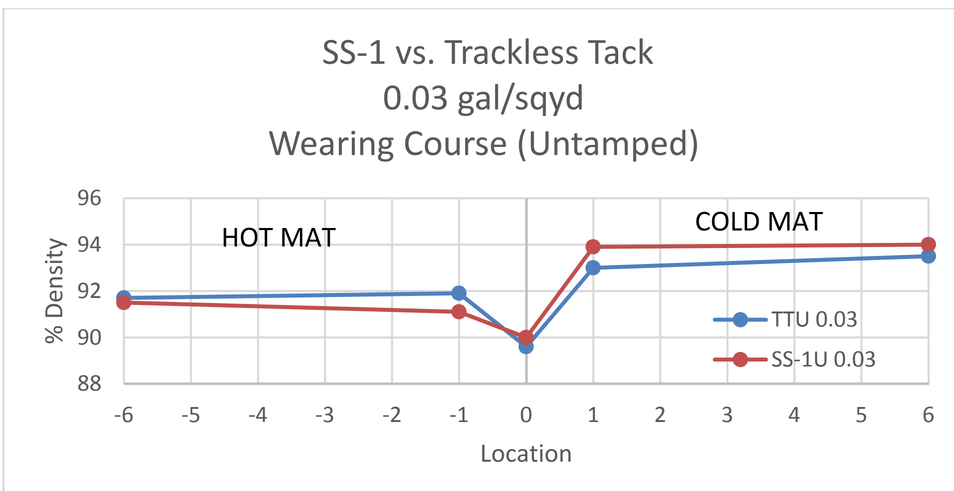

Figure 20
SS-1U 0.03 vs. TTU 0.03

Table 13
Avg. density comparison for Trackless Tack (tamped) vs. SS-1 (tamped) @ 0.03 gal/yd^2 on wearing course

TTT 0.03 vs. SS-1T 0.03			**SAS Comparison**	
Location	***Trackless Tack***	***SS-1***	***TT***	***SS-1***
-6	**93.2**	**91.7**	**A**	**A**
-1	**93.3**	**91.2**	**A**	**A**
0	**89.6**	**89.6**	**A**	**A**
1	**93.3**	**94.3**	**A**	**A**
6	**93.5**	**94.4**	**A**	**A**

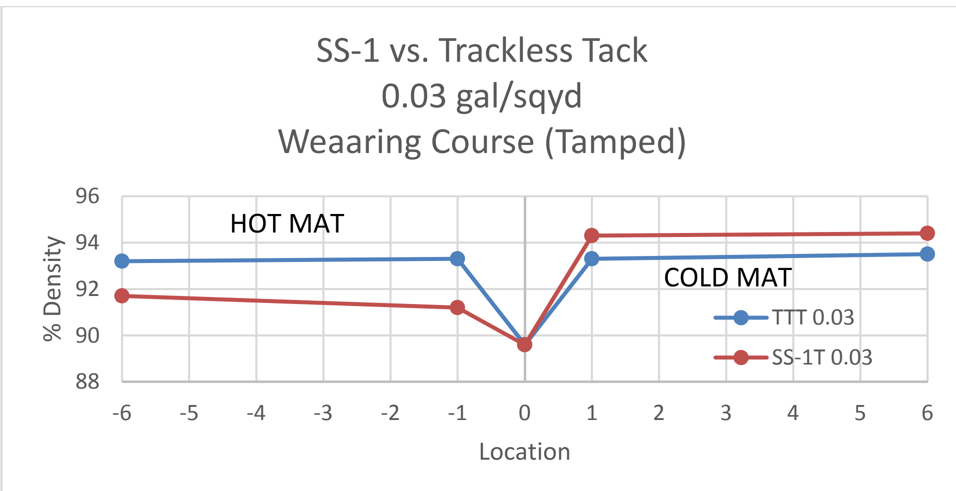

Figure 21
SS-1T 0.03 vs. TTT 0.03

Table 14
Avg. density comparison for Trackless Tack (untamped) vs. SS-1 (tamped) @ 0.03 gal/yd^2 on wearing course

TTU 0.03 vs. SS-1T			SAS Comparison	
Location	***Trackless Tack***	***SS-1***	***TT***	***SS-1***
-6	**91.7**	**91.7**	**A**	**A**
-1	**91.9**	**91.2**	**A**	**A**
0	**89.6**	**89.6**	**A**	**A**
1	**93.0**	**94.3**	**A**	**A**
6	**93.5**	**94.4**	**A**	**A**

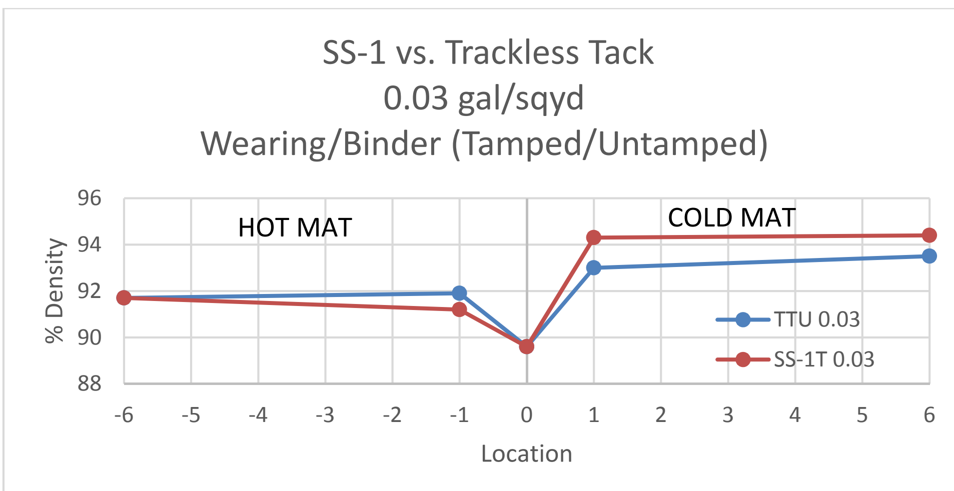

Figure 22
TTU 0.03 vs. SS-1T 0.03

Table 15
Avg. density for Trackless Tack (untamped) @ 0.03 gal/yd^2 on wearing course

TTU 0.03				SAS Comparison
Location	***%Avg. Density***	***Stdev.***	***%C.V.***	
-6	**91.7**	**0.11**	**0.12**	**B**
-1	**91.9**	**1.22**	**1.33**	**B/A**
0	**89.6**	**1.34**	**1.50**	**C**
1	**93.0**	**1.05**	**1.13**	**B/A**
6	**93.5**	**0.51**	**0.55**	**A**

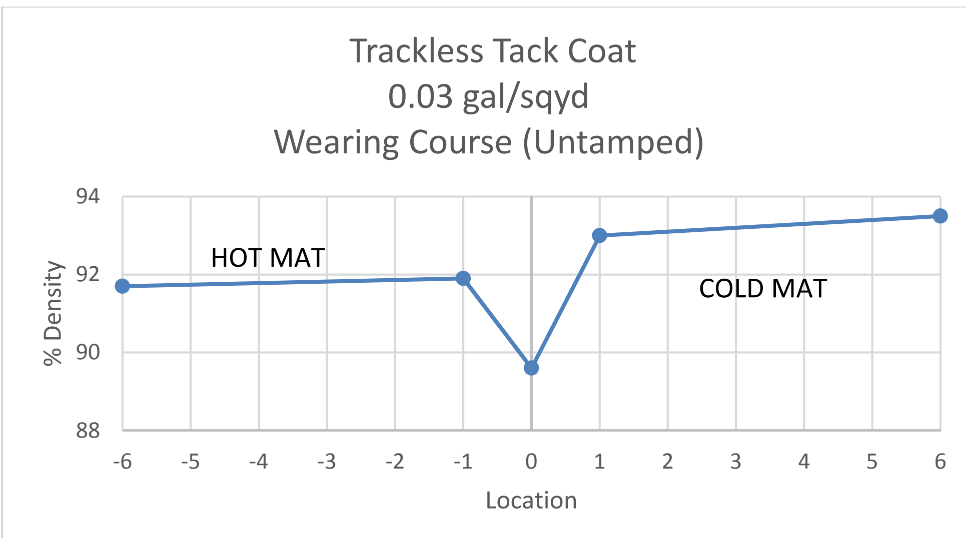

Figure 23
TTU 0.03

Table 16
Avg. density for SS-1 (untamped) @ 0.03 gal/yd² on wearing course

SS-1U 0.03				
Location	***%Avg. Density***	***Stdev.***	***%C.V.***	**SAS Comparison**
-6	**91.5**	**0.85**	**0.93**	**B**
-1	**91.1**	**0.33**	**0.36**	**B**
0	**90.0**	**1.01**	**1.12**	**B**
1	**93.9**	**1.02**	**1.09**	**A**
6	**94.0**	**0.80**	**0.85**	**A**

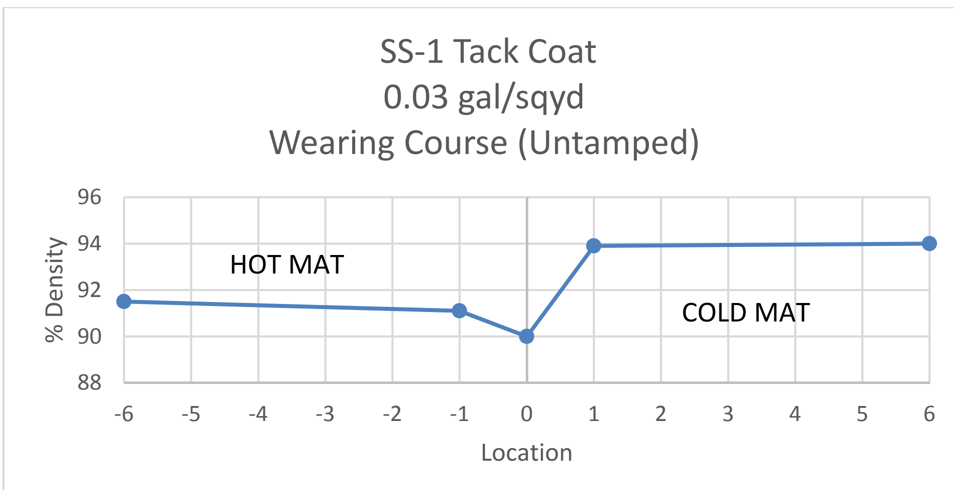

Figure 24
SS-1U 0.03

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