Texas A&M Transportation Institute

Implementing the Next Generation of Ultra-Thin Slurry Overlays: Technical Report

Technical Report 5-6615-01-R1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

in cooperation with the
Federal Highway Administration and the
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16. Abstract

In Research Project 0-6615, Use of Fine Graded Asphalt Mixes, a preliminary evaluation was made of the newly developed ultra-thin slurry seal (UTSS). The slurry is a combination of fine aggregates and emulsion that is rapidly sprayed onto the pavement surface. Some issues were raised about durability of the product, but the Texas Department of Transportation (TxDOT) wanted to evaluate its potential for both shoulder and main lane applications. Areas of interest included clearly demarcating and sealing shoulders, prolonging the life of raveling pavements, and blacking out existing markings in reconstruction projects.

In this study, the researchers evaluated existing projects constructed in three TxDOT districts, namely Beaumont, San Antonio, and Fort Worth. In these evaluations, the researchers found that UTSS introduced an unacceptable drop in skid resistance on high-speed roadways. Lab studies were then conducted, and a new formulation was introduced with substantially higher aggregate content. In the lab, skid measurements were made with the dynamic friction tester on treated slabs undergoing polishing with the Texas A&M Transportation Institute's three-wheel polisher. A significant improvement in skid was noted over the preliminary design.

The modified design was pilot tested on a highway in the Bryan District. Unfortunately, it was found that the initial improvements in skid did not last more than 2 months. The slurries were also found to not be effective in stopping reflection cracks.

For now, TxDOT should continue using this product for shoulder demarcation and sealing and not for main lane applications. However, the manufacturers have changed the methods used to place the product—replacing the spray application with a spreader box—which will provide opportunities to redesign this product to address the critical skid issues in the future.

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IMPLEMENTING THE NEXT GENERATION OF ULTRA-THIN SLURRY OVERLAYS: TECHNICAL REPORT

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The researcher in charge of this project was Tom Scullion.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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This project was conducted in cooperation with TxDOT and FHWA. The authors thank Wade Odell (Research and Technology Implementation Division) and Mike Arellano (Austin District) for their guidance throughout this project. The authors also extend thanks to all other members of the project team for their participation and feedback.

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LIST OF ACRONYMS

ARC	Asphalt Roller Compactor
BB	Black Beauty
CTM	Circular Texture Meter
CTM	Circular Track Meter
DFT	Dynamic Friction Tester
HMA	Hot-Mix Asphalt
IFI	International Friction Index
LWA	Lightweight Aggregate
MPD	Mean Profile Depth
PFC	Permeable Friction Course
SN	Skid Number
TTI	Texas A&M Transportation Institute
TxDOT	Texas Department of Transportation
UTSS	Ultra-Thin Slurry Seal

CHAPTER 1. BACKGROUND

INTRODUCTION

In Research Project 0-6615, Use of Fine Graded Asphalt Mixes, the Texas Department of Transportation (TxDOT) evaluated a new generation of slurries to be implemented in test sections around Texas. The slurry, which is called the ultra-thin slurry seal (UTSS), is a relatively new technology for restoring the surfaces of old hot-mix asphalt (HMA) pavements. It is a mixture of asphalt emulsion, small size (<No. 8) aggregates, recycled materials, polymers, and catalysts designed to improve the micro-texture and thus frictional characteristics of the HMA pavement surface. Industry has continued to develop this product, so this implementation project was initiated to determine if UTSS is appropriate for applications on high-speed highways in Texas.

UTSS is a cross between a slurry and a fog seal and is currently applied with a spray system, as shown in Figure 1. The initial cost estimated was less than $2 per square yard, which is cheaper than traditional seal coats and substantially cheaper than HMA overlays.

Figure 1. Application of UTSS.

Normally, two applications of the slurry are made, and the material is left to cure for 1 to 2 hours before traffic is allowed on the treatment. However, UTSSs have substantially fewer aggregates than traditional seals and micro-surfaces, as shown in Figure 2.

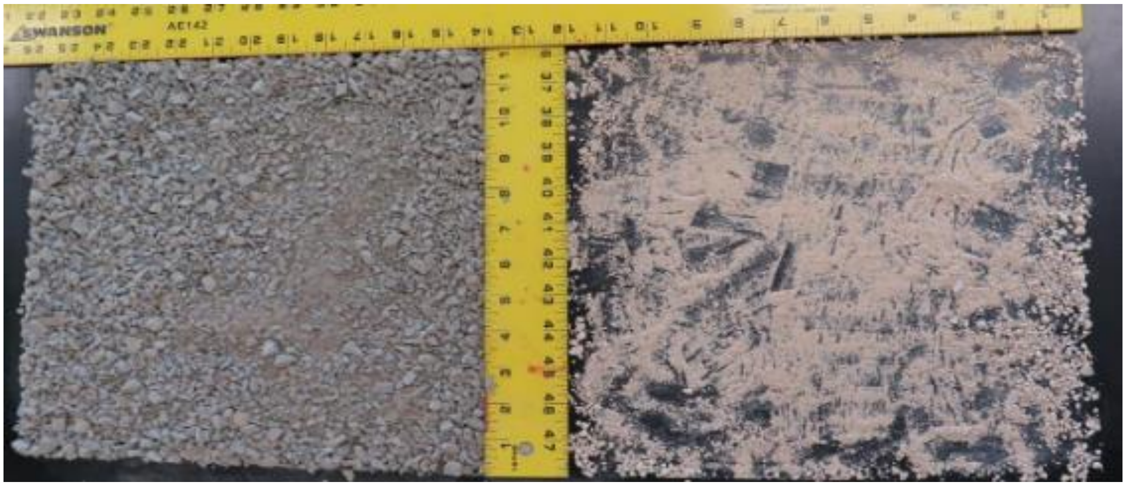


Figure 2. Micro-Surface (left) versus UTSS (right) Aggregate Rates.

Initial Evaluation of UTSS at TTI

The initial development and performance evaluation of the UTSS mixtures was performed on a dense asphaltic pavement located at the Texas A&M Transportation Institute (TTI) RELLIS outdoor facility (previously known as the Riverside Campus) in Bryan, Texas (Wilson, 2013) (see Figure 3). For the initial project, four different mixture designs with different aggregate shapes and percentages were produced by INVIA Pavement Technology for evaluation. The mixtures were A (angular aggregates, 11 percent), B (round aggregates, 11 percent), C (angular aggregates, 18 percent), and D (round aggregates, 18 percent). Figure 4 shows the friction of the sealed pavement based on the skid trailer test and dynamic friction test, respectively. According to the results, the mixture with a high percentage of angular aggregates appeared to be the best (Wilson, 2013).

Figure 3. Application of UTSS (TTI Riverside Facility).

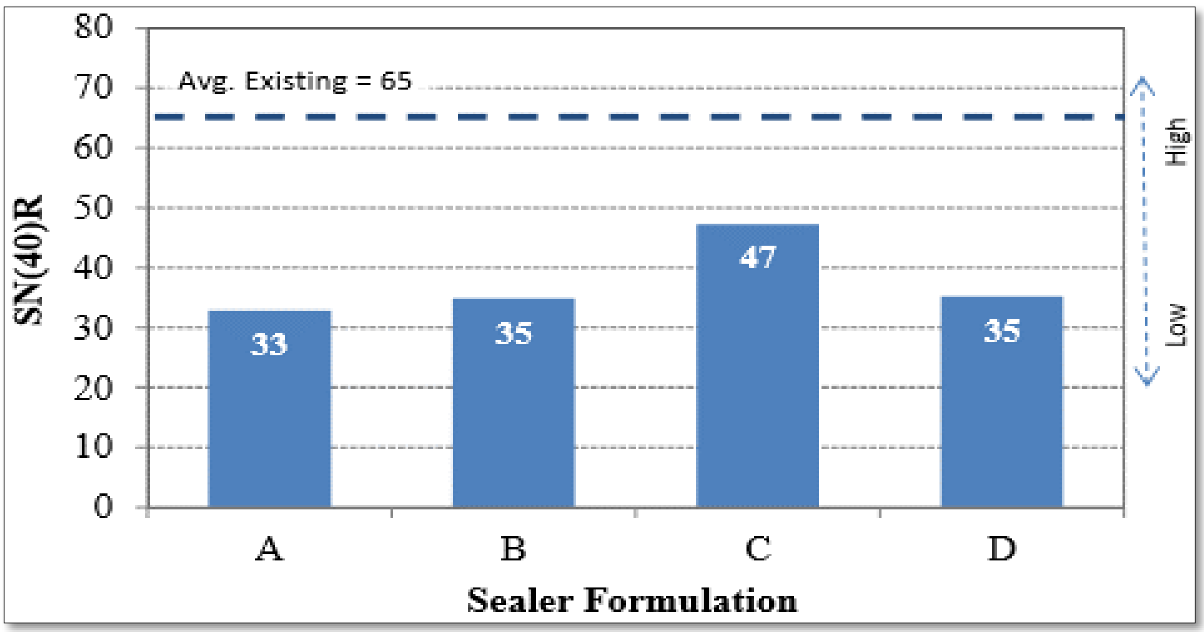


Figure 4. Skid Trailer Results (Wilson, 2013).

The one area of concern in Figure 4 is that the initial skid resistance of the pavement was 65, but after application of UTSS, the skid values reduced to mostly in the mid-30s, with formulation C performing a little better in the tests. Wilson (2013) stated, “Skid values on all sealer sections decreased after each subsequent pass of the skid trailer suggesting that the formulation may have some durability issues.”

TxDOT Interest in UTSS

TxDOT has continuing interest in the following focused applications of this product:

- Shoulder applications to seal the shoulder and improve visibility.
- Main lane applications to reduce raveling of, for example, an aged permeable friction course (PFC).
- Main lane safety applications to remove existing striping in work zones.
- Applications to clog PFCs that are reaching the end of their service life so they can be overlaid with HMA without fear of traffic moisture, rather than being milled off.

Projects were constructed in the Beaumont, San Antonio, and Fort Worth Districts. These projects were evaluated as part of this study. The Austin District, which is the main sponsor of this implementation project, also intended to use the UTSS material on pilot projects geared toward evaluating its potential as a sealant and to black out existing paint markings in reconstruction projects.

PROJECT OBJECTIVES

The main goal of this implementation project was to validate the performance of UTSS and determine its suitability for full implementation on high-speed roadways in Texas. Furthermore, the research team developed a recommendation to improve the existing design protocol (TxDOT uses a tentative protocol, Special Specification 3028). In order to achieve the main goal of the project, the research team developed the following sub-goals:

- Develop lab test procedures to evaluate the sealing potential of UTSS.
- Develop lab test procedures to measure the impact of UTSS on skid resistance.
- Validate skid numbers measured in the lab and in the field.
- Verify and refine the test specification for UTSS.

RESEARCH METHODOLOGY AND WORK PLAN

To achieve the objectives of the project, researchers performed the following:

- Reviewed the current specification.
- Performed field monitoring of existing projects, primarily with regard to both skid resistance and durability.

- Conducted lab and field evaluations to develop UTSS materials with improved skid resistance. This testing included:
    - Mixture designs: varied aggregate types and percentages.
    - Specimen preparation: gyratory compacted cylinders and slabs.
    - Field preparation: laid 3 ft by 3 ft sections on wheel paths of a highway pavement.
    - Lab and field tests: wet-track, three-wheel polisher (Figure 5), dynamic friction tester (DFT) (Figure 6), circular texture meter (CTM), and water flow tests.

Because of the concern for skid resistance and durability, the research team made extensive use of the three-wheel wet polisher (Figure 5) and the ASTM E 1911 DFT (Figure 6). The intent of this testing was to apply UTSS to the surface of a fabricated HMA slab, and then to measure the initial skid resistance and how it degraded under up to 100,000 applications of the polishing wheel.

Figure 5. Three-Wheel Polisher (Wet).

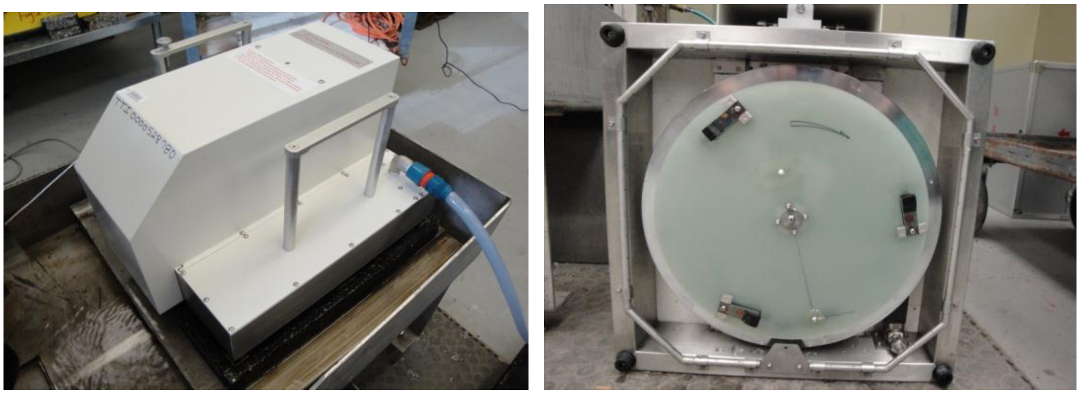


Figure 6. DFT Used in Both Lab and Field Tests.

REPORT CONTENTS AND ORGANIZATION

This report consists of seven chapters, including this chapter that provides the background, project objectives, methodology, and scope of work. The rest of the chapters are organized as follows:

- Chapter 2: Review of Current Ultra-Thin Slurry Seal Specification.
- Chapter 3: Ultra-Thin Slurry Seal Evaluation in Selected Districts.
- Chapter 4: Design and Evaluation of Improved Ultra-Thin Slurry Seal Mixtures.
- Chapter 5: Field Evaluation of Lab-Designed Ultra-Thin Slurry Seal Mixtures.
- Chapter 6: Conclusions and Recommendations.

SUMMARY

The first chapter of this report summarized the background and the rationale for this implementation project. The chapter also described the research tasks, research methodology, and report structure. The initial work from the parent project (6615) did not validate the large-scale and long-term performance or durability of UTSS. This shortfall was one of the major reasons for launching the implementation project described in this report.

CHAPTER 2. REVIEW OF CURRENT ULTRA—THIN SLURRY SEAL SPECIFICATION

The current protocol that is used for the design of UTSS mixtures is Special Specification 3028—Frictional Asphaltic Surface Preservation Treatment (see the Appendix). This use is based largely on recommendations from the developers of UTSS. The protocol covers the different aspects discussed in this chapter.

MATERIAL QUALITY

Important parameters prescribed in this protocol include aggregate quality properties such as water absorption, micro-Deval, and gradation (Table 1). The required properties of asphalt emulsion can be found in the Appendix. The TTI lab received the ready-mixed UTSS base, which could not be directly quantified by the asphalt performance criteria provided in the protocol. That task was the responsibility of the producer (Ingevity Inc.).

Table 1. Aggregate Specification. (TXDOT SS 3028)

Physical Properties[1]			
Property	**Test Procedure**	**Min.**	**Max.**
Water Absorption, %	T 84	-	4
Micro-Deval, %	D 7428[2]	-	20
Gradation[3]			
Sieve	Standard	Master Grading Band Limits Percent Passing	Target Tolerance
No. 8	C 136	100	
No. 16	C 136	85-100	
No. 30	C 136	75-100	± 5
No. 60	C 136	10-40	± 5
No. 100	C 136	0-10	± 5
No. 200	C 117	0-5	± 1

1. Perform physical property tests on aggregates that are received before blending into sealer.
2. Micro-Deval on aggregate larger than No. 60 sieve U.S.

Note that the lightweight aggregates (LWAs) used in this research project, as described in later chapters, did not meet these requirements. The current aggregate specifications are subject to change.

MIXTURE DESIGN

In terms of mixture performance, the protocol prescribes three tests to quantify designed mixtures—wet-track abrasion, asphalt content by ignition method, and dynamic friction test—as shown in Table 2.

Table 2. Laboratory Mix Design. (TxDOT SS 3028)

Test	Test Procedure	Min	Max
Wet-Track Abrasion Loss, 3-day soak, g/m^2	D 3910[1]	--	80
Asphalt Content by Ignition Method, %	T 308	30	--
Dynamic Friction Test Number, 20 kph	E 1911[2]	0.90	--

1. Use the modified method to account for realistic application depth and fine emulsion mixture.
2. Establish base friction value using prepared laboratory compacted slab of approved mix as surface to be tested. The Dynamic Friction Test (DFT) number ratio should indicate that after application of the mastic seal, the surface retains required minimum percentage DFT number of the original pavement surface.

The wet-track abrasion and asphalt content are commonly used tests for slurries. However, the dynamic friction test requirement is very difficult (if not impossible) to implement in the design phase. It requires project-specific testing to ensure that the treatment retains 90 percent of the original skid value. These requirements will need to be revised for future versions of this specification. Including the three-wheel polisher requirement in future versions of this specification to quantify how the slurry material retains its skid resistance under repeated wheel loads will be critical.

CONSTRUCTION

Construction requirements such as weather conditions, application rates, and time before opening to traffic are all covered in this specification (see the Appendix).

SUMMARY

This chapter covered the relevant requirements stipulated in Special Specification 3028 for the design of UTSS mixtures. The limitations of the protocol were also highlighted.

CHAPTER 3. ULTRA—THIN SLURRY SEAL EVALUATION IN SELECTED DISTRICTS

This chapter presents the work performed to assist TxDOT districts with their UTSS field performance evaluation. The research team observed the performance of the original UTSS mixtures comprised of the Black Beauty (BB) aggregates (18 percent). The researchers worked with districts to identify test sections that were good candidates for application of the thin slurry mixes. The following districts and test sections were constructed and monitored by TTI:

- **Beaumont District** (construction completed first 2 weeks of July 2017):
    - Test Section 1 Liberty County.
        - FM 2518 from FM 787, south to FM 163, 424-0.056 to 428+1.470.
    - Test Section 2 Liberty County.
        - SH 105 bridge structure on Gaylor Lake Relief, 732+1.680, Structure No. 201460095101006.
    - Test Section 3 Liberty County.
        - SH 105 bridge structure on Trinity River Relief, 734+0.710, Structure No. 2014600951010057.
- **San Antonio District** (construction completed June 2017):
    - Test Section 1 Medina County.
        - IH 35, southbound main lanes, from MM 131 to MM 130.
- **Fort Worth District** (construction completed July 2018):
    - Various locations of Erath and Palo Pinto Counties, only on shoulders.

BEAUMONT DISTRICT

In Beaumont, UTSS was placed on 6 mi along FM 2518 on an existing HMA concrete surface and a bridge deck. In each case, two passes (layers) of about 0.15 gallons per square yard (gal/yd^2) were applied. A minimum of about 1 hour was needed to adequately cure the surface before allowing traffic (shaded areas sometimes required more than 1 hour to cure). The second pass was made the following day. Figure 7 and Figure 8 show the conditions of the pavement and bridge deck before and 4 months after the application of UTSS. Furthermore, the researchers determined the skid number on the sections. Table 3 and Table 4 show various skid numbers that were taken before and 4 months after the application of UTSS. After the end of 4 months, the researchers determined the skid numbers on the treated section to be about 20. A year after, the skid number dropped further, to about 15.5 on average.

Figure 7. UTSS Section on FM 2518 Beaumont.

Figure 8. UTSS Section on SH 105 Bridge Deck Beaumont.

Table 3. Skid Data from FM 2518 Beaumont Test Sections.

	Section	FM 2518, K1	FM 2518, K6
April 2018	UTSS	20.1	19.9
	Pavement at end of section	23.7	23.5
June 2019	UTSS	16.7	14.9
	Pavement at end of section (new seal)	65.1	61.4

Table 4. Skid Data from SH 105 Beaumont Test Sections.

	Section	SH 105, K1	SH 105, K6
April 2018	UTSS	24.6	24.6
	Pavement between bridges	55.6	55.4
June 2019	UTSS	23.9	23.9
	Pavement between bridges	19.6	17.8

SAN ANTONIO DISTRICT

The San Antonio District constructed a 1-mi test section in the southbound lanes of IH 35 in June of 2017. This portion of IH 35 is surfaced with an older PFC that is about at the end of its life. It is beginning to exhibit significant raveling, and the district wanted to see if UTSS could retard the raveling and extend the life of the PFC. This dilemma of what to do with old PFCs (besides removing the surface by milling) is one of the issues many districts have been facing recently.

The old PFC surface along with the beginning of the UTSS application can be seen in Figure 9. Skid measurements taken on the UTSS surface and on the existing PFC at either end of the UTSS section are shown in Figure 10. These data are somewhat concerning because the skid numbers seem to have dropped by about 10 points. Some improvements in skid were noted in the last set of measurements from April 2019, but all measurements were observed to increase, and it was concluded that this increase was attributed to either (a) the slurry wearing off; or (b) the continuation of the raveling, which was visually apparent.

Figure 9. IH 35 Existing PFC and Beginning of UTSS Application.

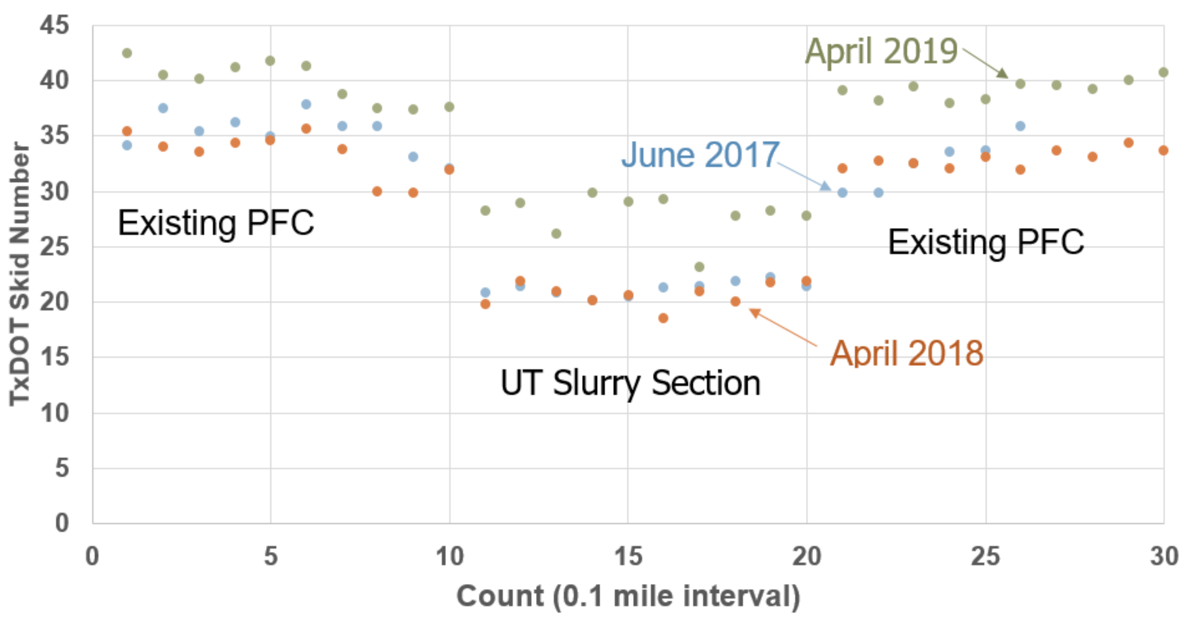


Figure 10. Skid Data on IH 35 Existing PFC and UTSS Test Section.

FORT WORTH DISTRICT

The Fort Worth District has been using UTSS mixtures on highway shoulders quite extensively for the past few years. District personnel believe UTSS serves to seal the shoulders and improve visibility by demarcating the shoulders. In July of 2018, TTI researchers worked with the district to identify sections to serve as test areas for the contract they had with Missouri Petroleum to install the surfacing on shoulder locations throughout the district. Figure 11 shows some of those installations. The researchers also sampled containers of the product to conduct laboratory tests.

Figure 11. Fort Worth Test Section on Spur 102 near Keene, Texas.

Approximately 2 weeks after placement of UTSS, the researchers conducted DFT tests and CTM measurements on the treated shoulders and the adjacent main lanes to predict the skid number (SN). These data are presented in Table 5. Since the measurements were taken soon after construction and the treated sections had no traffic due to being in the shoulder, there was very little wear on the surfaced shoulders. The predicted SNs were relatively good (compared to the main lanes). Since the shoulders are mostly used for emergency vehicles or bicycles, the SN is expected to stay about the same for a long period. Meanwhile, UTSS fulfills the purpose of blacktopping the shoulders.

Table 5. Predicted Skid Numbers for Fort Worth Test Sections.

	Avg of DFT 20	Avg MPD from CTM	Predicted SN50
IH 35 Frontage Road			
Treated Shoulder	0.38	0.84	28.8
Untreated Main Lane	0.39	1.03	31.8
Spur 102			
Treated Shoulder	0.36	0.78	26.9
Untreated Main Lane	0.22	0.68	18.9

Note: MPD = mean profile depth.

SUMMARY

This chapter outlined the work performed to assist TxDOT districts in evaluating their projects using UTSS. While UTSS demarcated the shoulder by offering a blacktop finish, it could not withstand long-term traffic (polished out within 1 year). In addition, it offered poor skid resistance at the end of its life (usually within a year). In the projects tested, the skid number was found to drop to 20 or below shortly after placing the project under traffic.

Based on the unsatisfactory performance documented on existing projects and TxDOT's desired to continue to consider this product, the researchers initiated a laboratory study to develop a slurry with improved and longer-lasting skid properties. The research efforts to generate an improved slurry are described in the next chapter of this report.

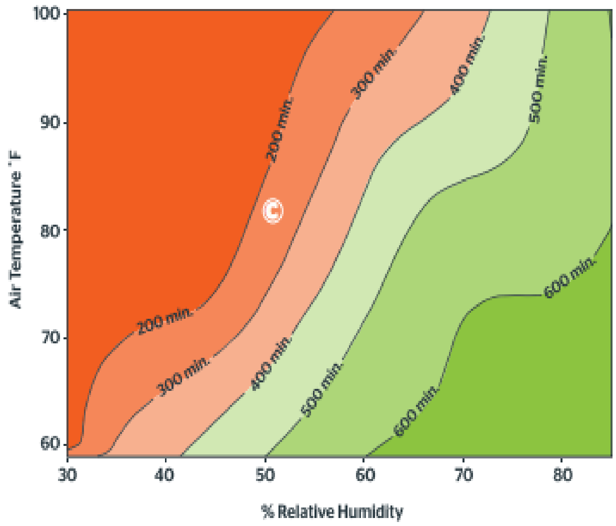
CHAPTER 4. DESIGN AND EVALUATION OF IMPROVED ULTRA-THIN SLURRY SEAL MIXTURES

The research team, through its state-of-the-art laboratory at TTI, performed laboratory tests to form a basis for evaluating the performance of the UTSS materials. This chapter covers the following:

- Preparation of samples.
- Lab testing to define how the slurry can be used to seal the surface of either an aged PFC or traditional dense-graded mix.
- Use of different aggregate types to improve the skid resistance of UTSS, which is the main issue restricting the widespread use of the product.

UTSS DESIGN AND APPLICATION

The UTSS design information can be found in the UTSS applicator guide prepared by Ingevity, the producer of the UTSS mixture design. The same information is adopted in Special Specification 3028 described in Chapter 2 (TxDOT, 2014). According to Ingevity, the typical design of UTSS includes slow-setting emulsion (i.e., CSS-1H) and fine aggregates. UTSS emulsion and aggregates were provided by Ingevity. The aggregates were of two types: BBs and LWAs. The sizes of the provided aggregates were passing No. 6 (1/8 inch), No. 8, No. 16, and No. 30. The application and curing time of UTSS depend on air temperature, humidity, and wind speed, as shown in Figure 12 (Ingevity Corporation, 2018). In this research, the specimens (slabs and 6-inch molds) were kept in an environmental chamber (55°C/131°F, RH < 50 percent) to speed up the drying process. This implies that the specimen in the field could be subjected to traffic after 500 minutes, as shown in Figure 12. However, in the lab, the slab specimens were left to cure for 500 minutes (about 8 hours) after the application of the first layer. After that, the second UTSS layer was applied and left to cure for 2 more days before the slabs were subjected to polish testing.



Dry Time Correction Factors

Wind MPH	Wind Factor in Drying Time
1	100%
5	30%
10	20%
15	15%
20	10%

Pavement °F above Air Temp °F	Pavement °F Drying Factor
0° F	100%
10° F	75%
20° F	50%
30° F	25%

Chart times should be adjusted for steady wind (mph) and pavement temperature conditions.

Figure 12. UTSS Dry Time versus Air Temperature (F) and Relative Humidity.

UTSS SURFACE SEALING

The researchers measured the ability of the UTSS material to seal the pavement surface of Type D and PFC. The researchers performed a falling head permeability test on cylindrical samples and slabs. The cylindrical samples were subjected to the permeability test using the Florida test method, whereas the permeability of the slabs and field samples was assessed using the typical field HMA flow test.

Permeability Test—Florida Test Method

The test was performed in accordance with Florida Test Method FM 5-565 on 6-inch diameter by 2.5-inch thick gyratory compacted specimens (Florida Department of Transportation, 2015). In addition, the permeability test was performed on field PFC samples collected from FM 359 in the Houston District. Prior to testing, each specimen was saturated underwater overnight to eliminate any trapped air (Figure 13). Each specimen was then placed into the test apparatus enclosure and tightly sealed (using a pressured membrane) on the circumferential face to only allow the vertical flow of water added through an attached graduated cylinder (Figure 13). The graduated cylinder is supplied with two marks (upper and lower) at a spacing of 63.1 cm to hold 500 ml of water between the marks (see Figure 14). During testing, the operator records the time it takes the water to travel from the top to the bottom marks when a flow control valve under the specimen is opened. The recorded elapsed time of water flow, as well as the hydraulic head at the initial and final mark, is used to calculate the coefficient of permeability of the specimen treated with a different amount of UTSS. The coefficient of permeability, *k*, is determined using the following equation:

$$k = \frac{aL}{At} ln \left[\frac{h_1}{h_2}\right] * t_c$$

Where:

k = coefficient of permeability, cm/s;

a = inside cross-sectional area of the cylinder, cm^2;

L = average thickness of the test specimen, cm;

A = specimen average cross-sectional area, cm^2;

t = elapsed time between h_1 and h_2, s;

h_1 = initial hydraulic head, cm;

h_2 = final hydraulic head, cm; and

*t_c = 1 at 20°C water temperature.

Other values of t_c are provided in the protocol.

Figure 13. Permeability Test Using the Florida Test Method.

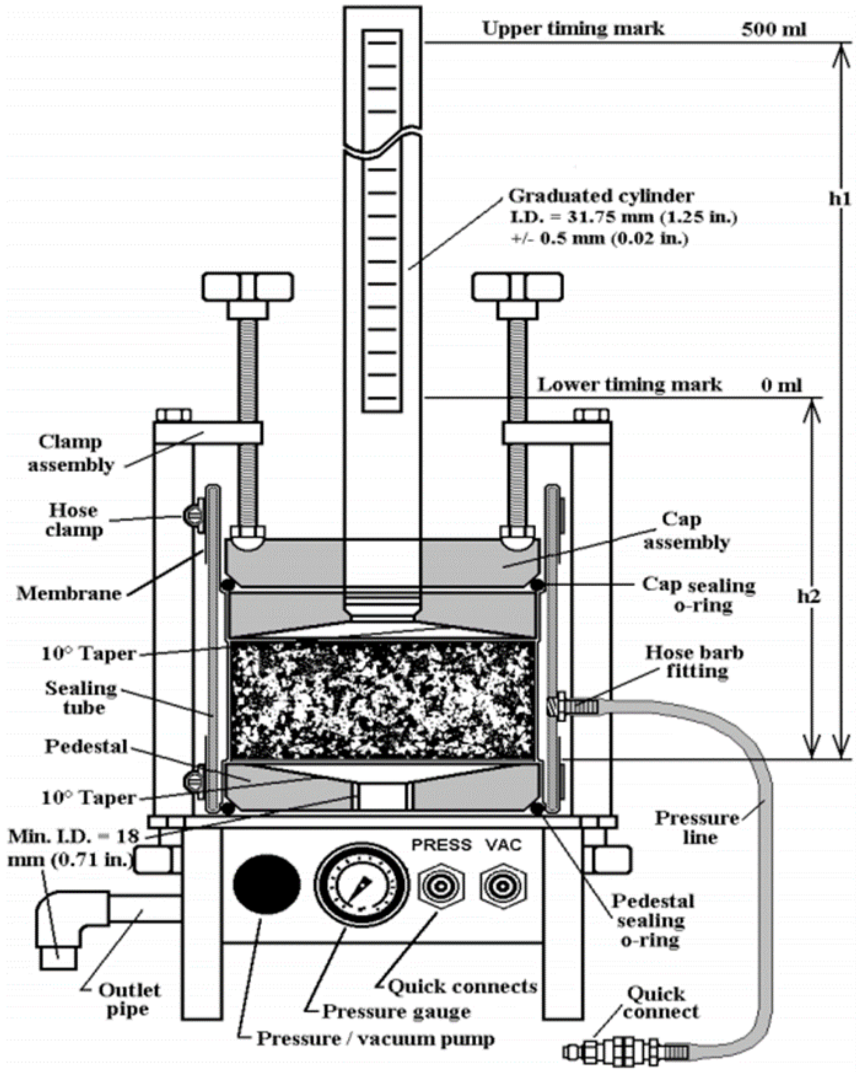


Figure 14. Diagram of Graduated Cylinder.

Permeability Test—Specimen Preparation

The lab specimens for permeability experiments were fabricated in the lab with 7±1 and 20±1 percent air void for Type D and PFC mixtures, respectively. Three specimens from each mixture were surface coated with varying amounts of UTSS (based on BB aggregates) to form an experimental matrix for assessing the amount of UTSS needed to seal the specimen surface (Figure 15, Table 6). The UTSS application started at 0.25 gal/yd^2 (about 18 g/surface), followed by an increment of 0.125 gal/yd^2 (about 9 g/surface), as shown in Table 6. During the UTSS application, duct tape was wrapped around the specimen circumference near the surface to ensure no side dripping (Figure 15). After the UTSS application, the specimens were kept in an environmentally controlled room at 60°C for about 24 hours to accelerate the curing process.

Figure 15. UTSS Treatment Application on Type D and PFC Molds.

Table 6. Different Amounts of UTSS Treatment on Type D and PFC Molds.

HMA Mixture	Surface UTSS (g)	Surface UTSS (g)	Surface UTSS (g)	Surface UTSS (g)	Surface UTSS (g)	Surface UTSS (g)	Surface UTSS (g)
Type D	0	18	27	40	—	—	—
PFC	0	18	27	36	45	54	63

On the field specimen (Figure 16), only the surface layer (PFC) was assessed. The layer was saw-cut from cores obtained from FM 359, as explained earlier. No surface treatment was applied to these specimens.

Figure 16. PFC Field Cores.

Permeability Test—Discussion of Results

The next two subsections reveal the permeability test results on the PFC and Type D molds/cores, respectively.

PFC Test Results

Table 7 and Figure 17 show the flow of water with time in the PFC molds, where the longest time to reach the zero mark was observed for specimens with a higher amount of UTSS application. Similarly, the shortest time was observed for samples with lower amounts of UTSS.

Table 7. Water Flow in PFC Molds.

PFC Control		Applied 18 g UTSS		Applied 27 g UTSS		Applied 36 g UTSS		Applied 45 g UTSS		Applied 54 g UTSS		Applied 63 g UTSS	
Time (s)	Height drop (mL)	Time (s)	Height drop (mL)	Time (s)	Height drop (mL)	Time (s)	Height drop (mL)	Time (s)	Height drop (mL)	Time (s)	Height drop (mL)	Time (s)	Height drop (mL)
4.26	500	4.44	500	4.29	500	6.78	500	8.00	500	9.12	500	19.85	500
3.48	450	3.68	450	3.48	450	5.56	450	6.50	450	7.41	450	15.44	450
2.89	400	3.06	400	2.94	400	4.37	400	5.53	400	6.09	400	12.21	400
1.91	300	2.12	300	2.19	300	2.78	300	3.59	300	4.16	300	8.55	300
1.06	200	1.27	200	1.21	200	1.82	200	2.28	200	2.62	200	5.09	200
0.44	100	0.63	100	0.52	100	0.81	100	1.13	100	1.28	100	2.43	100
0	0	0	0	0	0	0	0	0	0	0	0	0	0

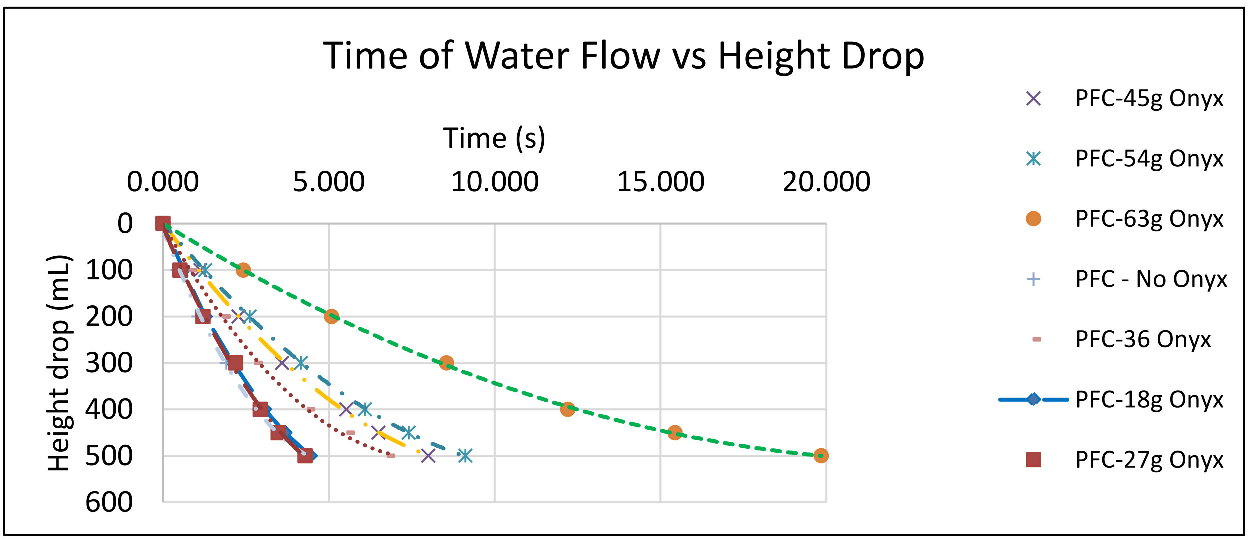


Figure 17. Rate of Water Flow through PFC Mold at Different UTSS Treatment Levels.

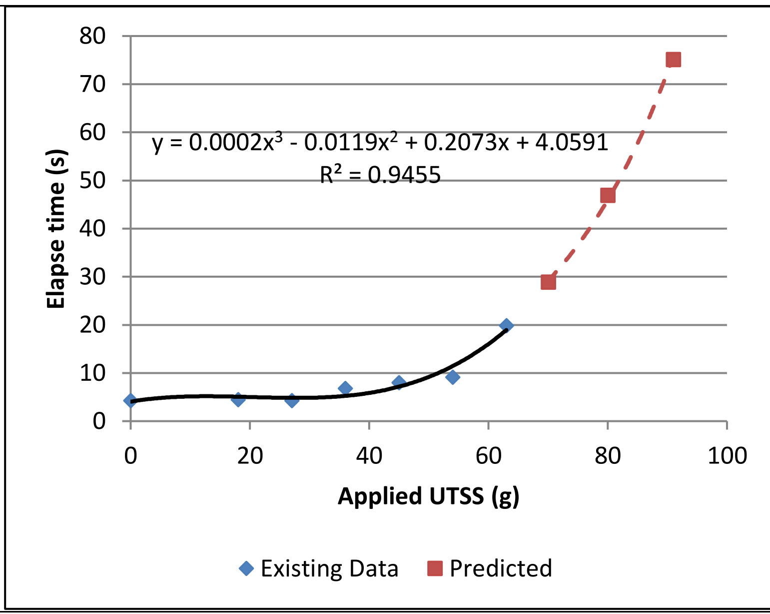
In addition, the researchers calculated the coefficient of permeability for each of the tested specimens. Table 8 shows the coefficients of permeability for PFC molds treated with different amounts of UTSS. Percentage improvement as compared to a Type D dense mixture (flow time = 74.8 seconds) is also shown. The improvement values show that the PFC molds were not completely sealed for all levels of the added surface UTSS. Therefore, the researchers used a statistical extrapolation model to predict the amount of UTSS needed to seal a new PFC mold to a level equivalent to a new dense HMA mixture (i.e., Type D), as shown in Table 9.

Table 8. Coefficient of Permeability for PFC Mixtures.

Applied UTSS on PFC Molds	**Untreated**	**18 g**	**27 g**	**36 g**	**45 g**	**54 g**	**63 g**
Constant parameters = $\frac{aL}{A} ln\left[\frac{h_1}{h_2}\right]$	0.576	0.576	0.576	0.576	0.576	0.576	0.576
Elapsed time (t)	4.26	4.44	4.29	6.78	8	9.12	19.85
K (constant/time) (cm/s)	1.353E-01	1.298E-01	1.344E-01	8.502E-02	7.205E-02	6.32E-02	2.904E-02
Percentage improved (Relative to type: untreated Type D dense HMA) (t = 74.8 s)	0%	0%	0%	3%	5%	6%	21%

Table 9. Predicted Amount of UTSS Needed to Seal a New PFC Mold.

Measured	**UTSS (g)**	**Time**
	0	4.26
	18	4.44
	27	4.29
	36	6.78
	45	8.00
Predicted	63	9.12
	70	28.86
	80	46.88
	91	75.09



Type D Test Results

Table 10 and Figure 18 show the time it took for the water to flow through the Type D dense-graded HMA specimens with different amounts of UTSS treatment. The rate of change of the water flow (mL/s) was higher for the 0 and 18 g UTSS treatments and dramatically reduced for UTSS treatments above 27 g, as shown in Figure 18.

Table 10. Water Flow in Type D Molds.

Control—Untreated HMA Mold		Applied 18 g UTSS		Applied 27 g UTSS		Applied 40 g UTSS	
Time (s)	Height drop (mL)	Time (s)	Height drop (mL)	Time (s)	Height drop (mL)	Time (s)	Height drop (mL)
74.80	500	89.56	500	231.540	500	304.950	500
56.70	450	65.81	450	174.947	450	222.377	450
45.24	400	51.14	400	138.413	400	173.037	400
29.65	300	33.75	300	89.393	300	109.467	300
17.80	200	20.39	200	53.040	200	64.020	200
8.80	100	9.74	100	24.400	100	29.933	100
0.00	0	0.00	0	0.000	0	0.000	0

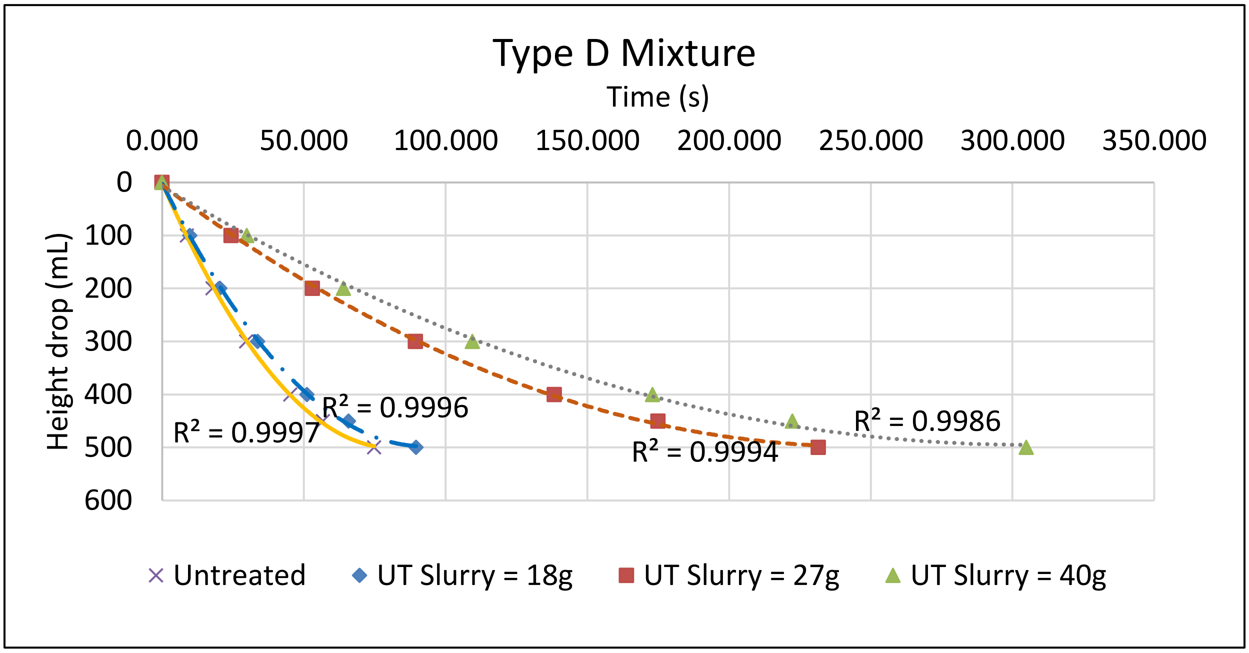


Figure 18. Rate of Water Flow through Type D Samples at Different UTSS Treatment Levels.

The Type D mixture produced a coefficient of permeability that was smaller than the one deduced for PFC mixtures. A relatively long time was observed for the 500 mL of water to flow through the Type D mixtures. The coefficients of permeability for the Type D molds treated with UTSS are shown in Table 11.

Table 11. Coefficient of Permeability for Type D Mixtures.

Applied UTSS on type D gyratory compacted molds	Control Untreated	18 g	27 g	40 g
Constant parameters = $\frac{aL}{A} ln \left[\frac{h_1}{h_2}\right]$	0.576	0.576	0.576	0.576
Elapsed time (t)	74.79	89.56	231.54	304.95
K (constant/time) (cm/s)	7.707E-03	6.436E-03	2.490E-03	1.890E-03
Percentage improved (relative to untreated type D dense HMA) (t = 74.8 s)	0%	20%	210%	308%

Field Core Test Results

Figure 19 shows lab permeability flow time for the FM 359 field cores of PFC. Four field core specimens were tested, two from the shoulders (denoted with S) and the other two from the wheel path (denoted with W). This work was abandoned because it was found that even though these were PFCs, the voids had sealed up with very little water flow. There was no need to apply UTSS to this highway because it could be sealed as is rather than by milling off the existing PFC.

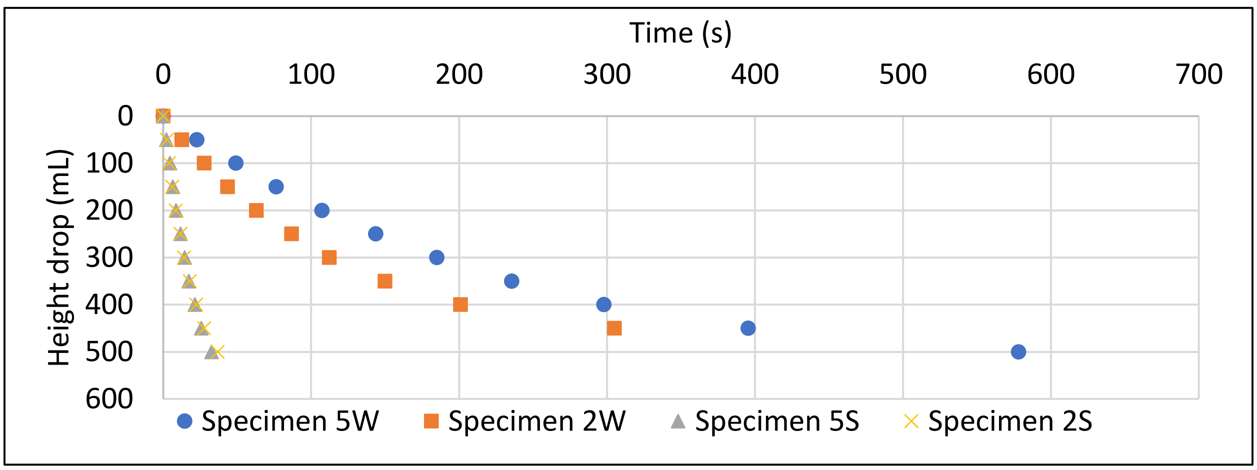


Figure 19. Permeability Flow Time for the FM 359 Field Cores.

In summary, using non-treated specimens as a benchmark, the researchers determined that the permeability properties of the lab-prepared un-trafficked HMA mixtures improved with the use of the UTSS surface treatment. However, the rate of improvement differed significantly between the dense Type D and PFC mixture specimens. The rate of water flow was high for PFC (design air void = 20±2 percent) and relatively low for Type D (design air void = 7±1 percent), as expected. It was also noted that most of the initial UTSS treatment (<27 g = 0.4 gal/yd^2) on PFC disappeared into the large voids, so there were no significant changes in permeability. Similarly, the permeability resistance improved significantly for Type D mixtures compared to PFC. In addition, the researchers noted that about 90 g (1.3 gal/yd^2) were needed to seal the surface of a new PFC mold to the same level as a non-treated Type D dense HMA mixture.

Regarding the PFC field cores, the experiment showed that cores from the wheel path were practically sealed. For specimens of about 2.5 inches, the water flow time approached 600 seconds. This finding emphasizes the point that field testing should be conducted on existing PFCs to see if they are still performing as designed. If they have closed, as was found to be the case on FM 359, then there is no need to remove the existing PFC because it can be sealed, and a new surface applied.

Flow Test—Field Permeameter

The water flow test on HMA slabs and field specimens was performed using a field permeameter in accordance with Tex-246-F (TxDOT, 2009). The test is designed to evaluate the permeability of PFC pavements. The basic equipment includes a simple open cylinder with a clear pipette attached to it to clearly show the drop of water as the water channels through the surface of the HMA. The recorded measurement from this test is the time it takes for water to travel from the top to the bottom mark on the pipette (10 inches apart), as shown in Figure 20.

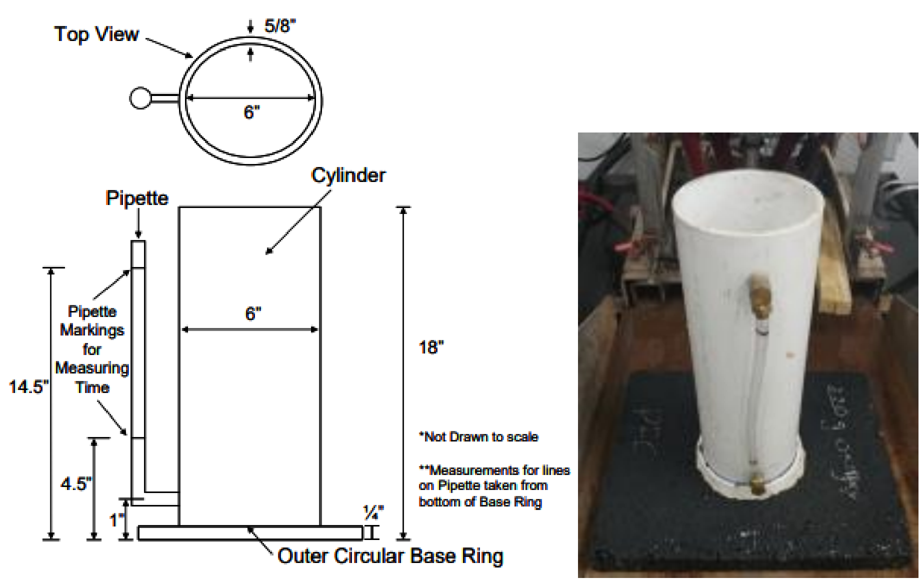


Figure 20. Field Permeameter.

Flow Test—PFC Slabs

A state-of-the-art asphalt roller compactor (ARC) was used to compact PFC slabs (19.75 inch by 15 inch by 2 inch.), which were later treated with UTSS to evaluate the effect of UTSS on sealing the PFC slabs. The UTSS treatment was applied using a special brush, as shown in Figure 21. A similar procedure was followed when preparing Type D slabs for UTSS surface friction assessment.

Figure 21. Slab Compaction and Application of UTSS Treatment.

Flow Test—Discussion of Results

Table 12 shows the time it took for water to penetrate the 2-inch PFC slabs treated on the surface with a different application of UTSS materials. The researchers observed increased flow time with increased UTSS treatment. Furthermore, at a constant application rate, the research team did not observe the difference in time flow for slabs treated with 15 percent and 18 percent aggregate UTSS mixtures. The data in Table 12 also show that at a double shot application rate (2 x 0.125gal/yd^2), the PFC slabs became water resistant to levels above the Type D slab.

Table 12. Laboratory Flow Test and Results on UTSS Treated Slabs.

UTSS Surface Finish	Control Without UTSS	BB 18% Aggregates	LWA 15% Aggregates	LWA 18% Aggregates
Pictorial View of the PFC Slabs				
Application Rate	N/A	single shot ≈ 0.125gal/yd^2	double shots ≈ 0.25gal/yd^2	double shots ≈ 0.25gal/yd^2
Curing	N/A	72hrs @60^{o}C	72hrs @60^{o}C	72hrs @60^{o}C
Time of Water Flow	19.88 sec	1min, 13.72 sec	4min, 24.30 sec	4min, 14.73 sec

Flow Test—Existing PFC Pavements on US 359

The permeability test was also performed on existing PFC pavements. Three locations (shoulder [S], inner wheel [WP], and outer wheel [W]) on US 359 were tested, and cores were extracted and taken to the lab for CT scanning to estimate existing air voids.

Table 13 shows the flow time for the three locations tested in the field. In all, it took a long time for the water to percolate into the PFC pavement (>>20 seconds) at the three locations tested, which means the trafficked PFC no longer drained water.

Table 13. Field Flow Test.

Section	Old PFC Pavement Surface		Time of Water Flow
1		Shoulder (S)	**13 min and 56.79 sec**
2		Outer wheel (W)	**11 min and 48.56 sec**
3		Inner wheel (WP)	**77 min and 17.50 sec**

CT Scan on PFC Field Cores—Rationalizing Existing Water Flow

Table 14 shows CT scan results of the estimated air void for the cores extracted from US 359. The results indicate that the estimated air void was higher at the top half-inch of the PFC and reduced toward the center, where the air void detected was below 10 percent (the typical air void of a new PFC pavement is about 20 percent). The reduction was more prominent on the inner lane (3W) than the outer lane (1W) and shoulders (3S). A similar trend was noted during the field flow test. Note that there is a spike in the middle of the air-void plot, which represents the joint between the pavement bottom dense layer and the surface PFC. At that point, there was no effect on water flow initiating from the surface.

Table 14. CT Scan and Air-Void Plot for Field HMA Cores.

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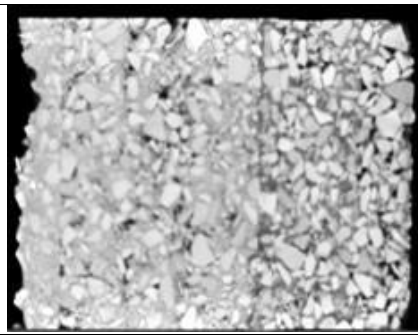
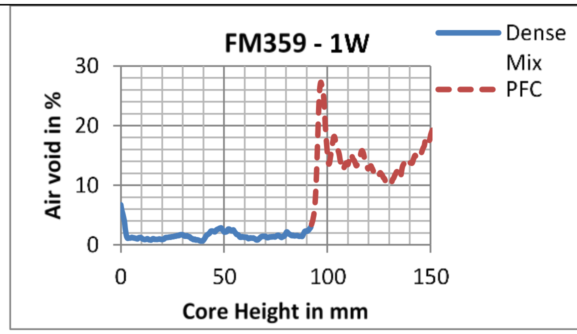
<tr><td>1W</td><td></td><td>
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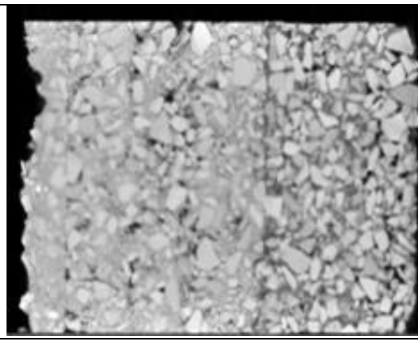
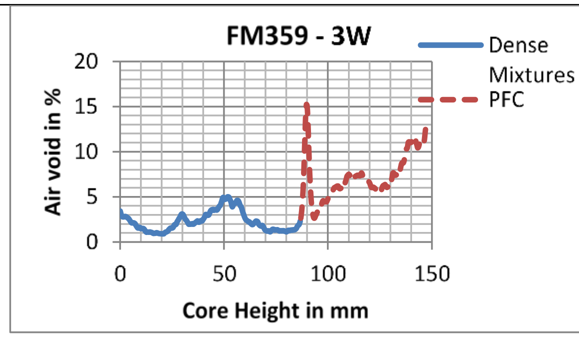
<tr><td>3W</td><td></td><td>
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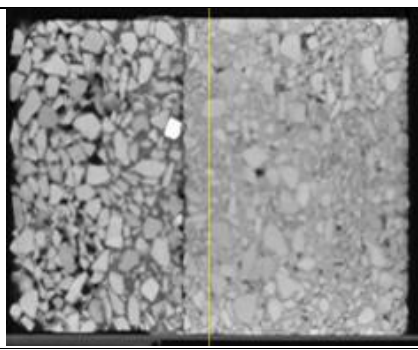
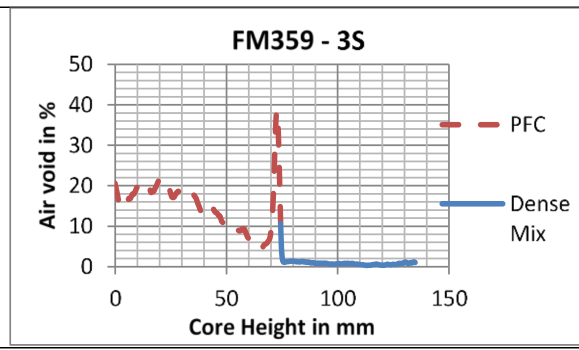
<tr><td>3S</td><td></td><td>
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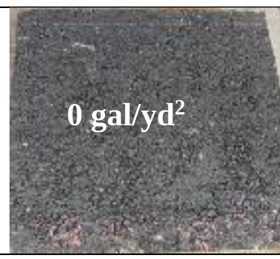
UTSS FRICTION EVALUATION

A major challenge of this project was to assess the impact of UTSS treatment on long-term frictional properties of pavement surfaces. As described earlier, the initial skid readings from IH 35 in San Antonio were not encouraging. To complete the assessment, the researchers performed DFT and CTM tests on laboratory-compacted slabs trafficked with the wet three-wheel polisher to estimate skid resistance after different numbers of wheel passes. In addition, the team used the wet-track abrasion test to assess surface wearing indicators such as poor adhesion between asphalt and aggregates. In the initial tests described below, the original UTSS formulation with the BB aggregates was used. However, as shown in Figure 2, the amount of rock used in UTSS is very low, and as will be described later, additional tests were performed where the original aggregates were replaced with lightweight aggregates.

Polishing, DFT, and CTM Tests on the Field-Collected UTSS Mixture

Before assessing skid for different UTSS mixtures, the research team performed a pilot test on two specimens (Table 15) to establish the relationship between skid values and number of wheels passes of the polisher. One sample was untreated and the other had 0.25 gal/yd^2 of UTSS. The base mix was a Type D Superpave mix from the Knife River plant in College Station. The UTSS used for the pilot study was the original BB UTSS from the field.

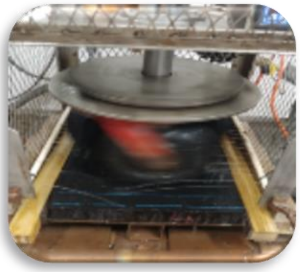
Table 15. Original UTSS Treated and Untreated Type D Slab Samples.

Surface Treatment	Untreated (D5)	UTSS Treated (D4)
BB UTSS		

A wheel polisher, as shown in Figure 22, was used to polish the slabs, and the DFT and circular track meter (CTM) were deployed to estimate the micro- and macro-texture of the surfaces of the slabs, respectively. Together, the DFT and CTM were used to estimate the skid resistance of the slabs after each of the following wheel passes: 0, 5,000, 10,000, 20,000, and 50,000 passes. A general procedure for measuring and estimating surface skid resistance is shown in Table 16.

Figure 22. Wheel Polisher, CTM, and DFT.

Table 16. Procedure for Estimating Skid Resistance.

Step	Procedure	Description
1	Surface polishing 	• Performed on both treated and untreated slabs. • Performed at different wheel passes to simulate field surface wearing due to traffic. • Performed under wet conditions.
2	Surface drying 	• After wet polishing, the surface was dried to enable the laser-based CTM test to be performed. • Specimens were let dry at room temperature with a fan blowing for more than 12 hours.
3	Surface profile measuring by CTM (see Figure 10)	• MPD of the surface measured for all specimens after 0, 5,000, 10,000, 20,000, and 50,000-wheel passes. • Performed on a dry slab surface.
4	Surface friction measuring by DFT (see Figure 10)	• Measured under wet condition after 0, 5,000, 10,000, 20,000, and 50,000 wheel passes. • Test start speed was set at 80 km/hr. • Coefficient of friction (μ) was recorded at 20, 30, 40, and 60 km/hr.
5	Skid resistance SN50	• Estimated SN50 using statistical models with μ and MPD as the variable inputs.

Results and Discussion on the Field-Collected UTSS Mixture Friction

Table 17 shows pictures of the treated and untreated slabs that were polished with a different number of wheel passes. The pictures clearly show the loss of UTSS treatment for every wheel pass evaluated. The corresponding friction (DFT) and mean profile depth (CTM) are discussed next.

Table 17. Polished Slab Surfaces at Different Levels of Wheel Passes.

Wheel Passes	0	5,000	10,000	20,000	50,000
UTSS Treated Slab (D4)					
Untreated Slab (D5)					

During the DFT test, friction measurements were made at different speeds. Figure 23 shows the variation of the DFT coefficient of friction with increased polishing at different testing speeds. The friction resistance of the UTSS treated slab started low and stayed about the minimum value for all the wheel passes evaluated. On the other hand, friction on the untreated slab started high at zero passes and then reduced to a minimum and coincided with the treated slab friction after 10,000-wheel passes. In general, UTSS seems to reduce the origin friction of HMA (see the value at zero-wheel passes). (One limitation of the three-wheel polisher is that the number of wheels passes in the field that 10,000 passes represents is unknown; the polishing action is realistic but not correlated to actual field performance.) The characteristic rise in skid value at 5,000 passes at the higher speed levels is related to wearing the asphalt coating off the surface rock; after 5,000 passes, the skid value drops, indicating that the rocks are polishing.

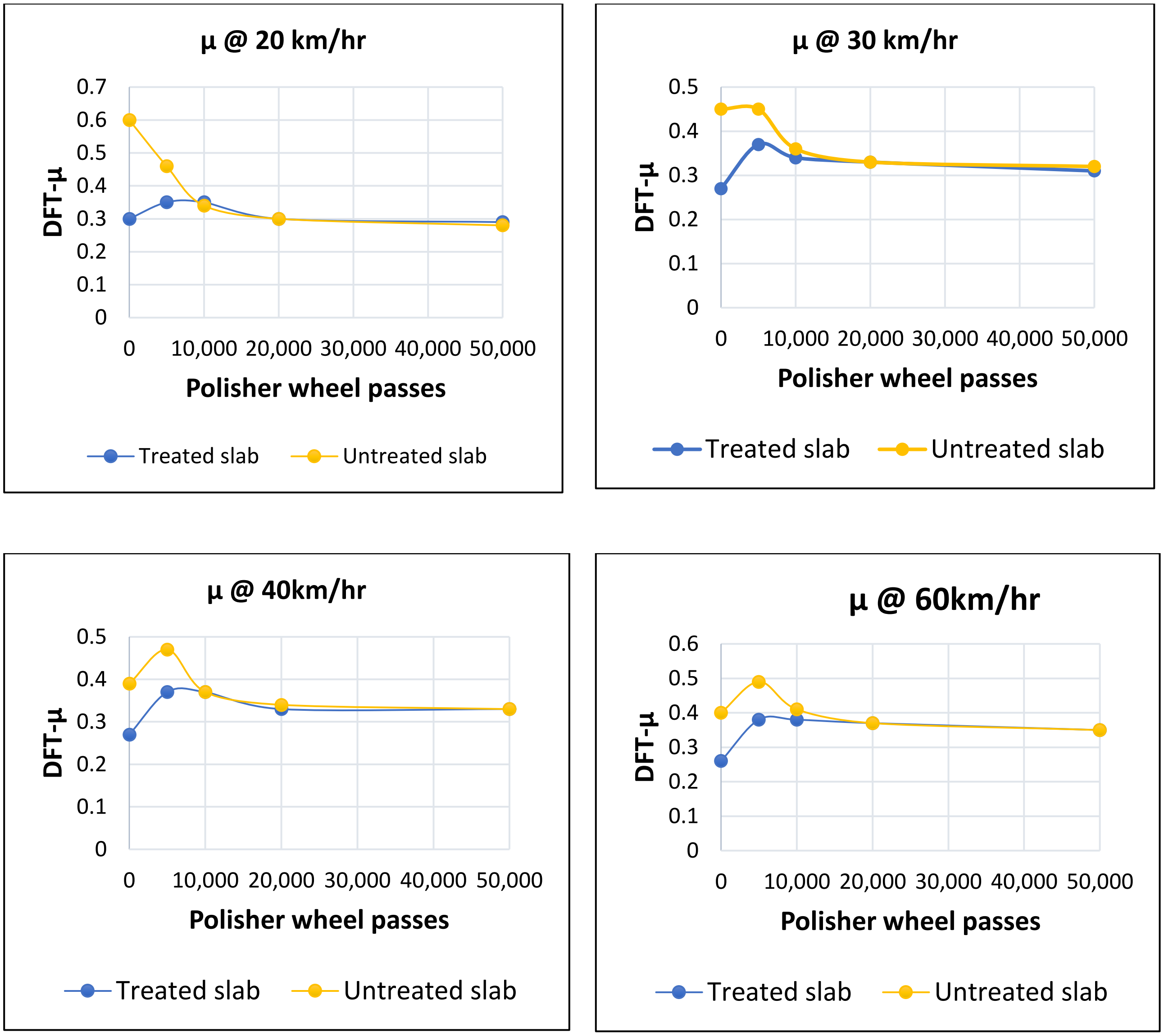


Figure 23. DFT versus Wheel Passes at 20, 30, 40, and 60 km/hr DFT Test Speeds.

Furthermore, for all wheel passes, the researchers observed that the slab MPD (as measured with the CTM of the UTSS treated slabs was lower than for the untreated slabs (Figure 24).

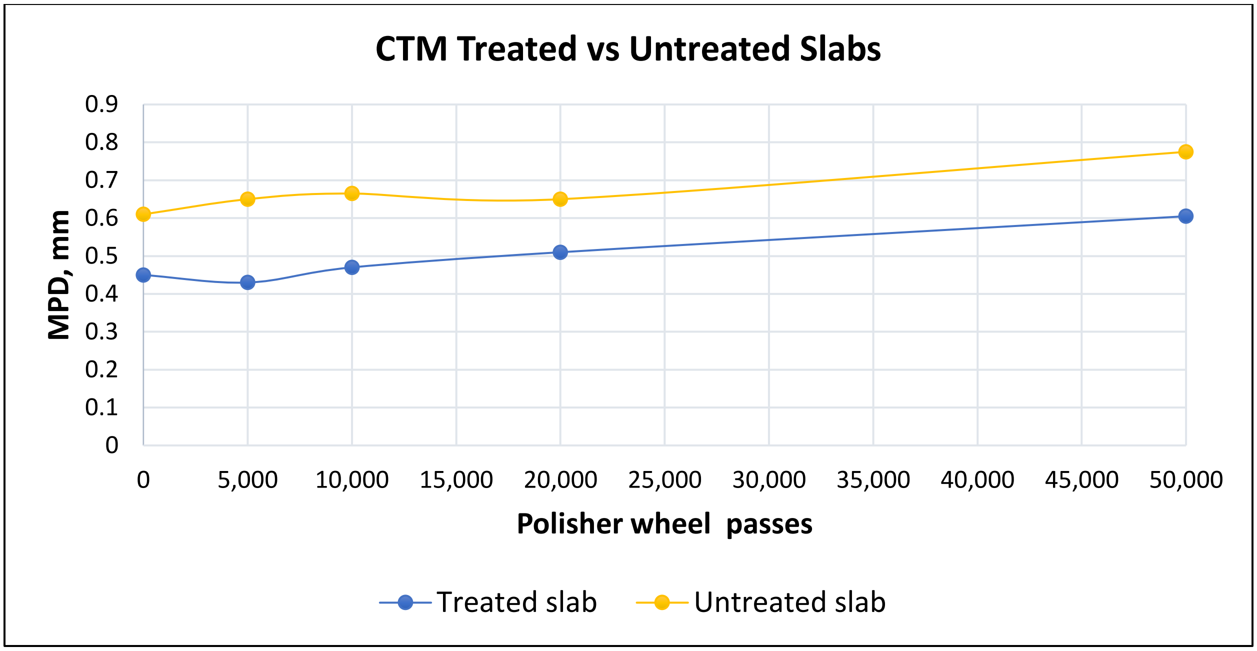


Figure 24. CTM MPD versus Wheel Passes.

With reference to the prevailing Special Specification 3028, the DFT coefficient of friction ratio (0.3/0.6 = 0.5) of the BB UTSS dropped below the minimum recommended value (0.9) (

Table 13). However, this criterion does not include the effect of the CTM-MPD. The computed coefficient of friction and MPD were incorporated into statistical models developed by Wambold et al. (1995) and Chowdhury et al. (2017) to predict the International Friction Index (IFI) and skid number (SN50). Equations 1 through 3 represent the statistical models used to predict the IFI and SN of the UTSS treated and untreated slab surfaces (Table 18).

$$IFI = 0.081 + 0.732 \times DFT_{20} \times e^{\frac{-40}{Sp}} \quad (1)$$

$$Sp = 14.2 + 89.7MPD \quad (2)$$

$$SN(50) = 4.81 + 140.3 \times (IFI - 0.045) \times e^{\frac{-20}{Sp}} \quad (3)$$

Table 18. Predicted Skid Numbers of UTSS Surface—Treated and Untreated Slabs.

	UTSS Treated Slab					**Untreated Slab**				
Polish wheel passes	**μ@ 20 km/hr**	**MPD**	**Sp**	**IFI**	**Predicted SN50**	**μ@ 20 km/hr**	**MPD**	**Sp**	**IFI**	**Predicted SN50**
0	0.3	0.45	54.57	0.19	18.6	0.6	0.61	68.92	0.33	34.4
5,000	0.35	0.43	52.77	0.20	19.8	0.46	0.65	72.51	0.27	29.3
10,000	0.35	0.47	56.36	0.21	20.8	0.34	0.67	73.85	0.23	24.2
20,000	0.3	0.51	59.95	0.19	19.8	0.3	0.65	72.51	0.21	22.1
50,000	0.29	0.61	68.47	0.20	21.0	0.28	0.78	83.72	0.21	22.8

Figure 25 shows the predicted SN versus the polish wheel passes for both treated and untreated slabs. In Figure 25, the predicted SNs (at 50 km/hr) of the treated slab hovered around 20 for wheel pass levels evaluated, whereas the SNs of the untreated slab varied from 34 (zero-wheel passes) to 22 (after 50,000-wheel passes). In general, UTSS at its current design (with BB aggregates) reduced the skid number of the HMA slabs and would not be acceptable based on the 90 percent retained friction in Special Specification 3028.

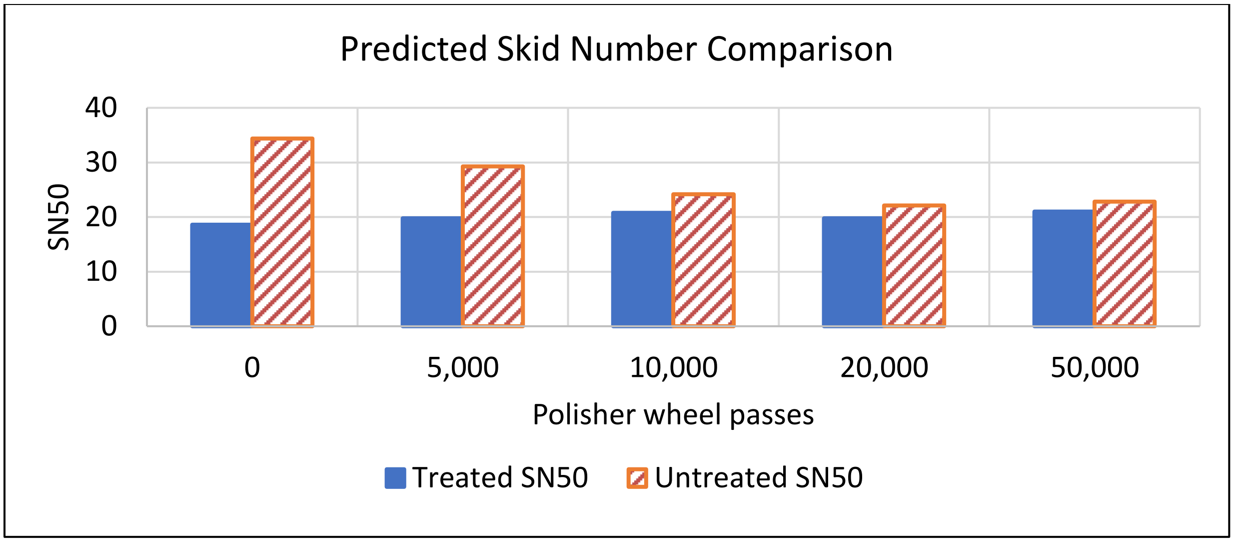


Figure 25. BB UTSS — Treated Slab versus Untreated Slab Skid Numbers.

Laboratory—Designed Mixtures of UTSS

Since the BB-based UTSS showed relatively poor skid results, the LWA-based UTSS was introduced. LWA is known to have excellent skid properties, and because of its nature on a weight basis, it will allow more volume of rock into the UTSS formulation. The ability of the contractor to change from the BB aggregate to the lightweight aggregate was confirmed before TTI proceeded with this evaluation. In this evaluation, the research team used different LWA sizes to design different UTSS mixtures. The mixtures were compared in terms of friction performance. Figure 26 shows the comparison of different UTSS mixtures based on different aggregate types and sizes. The LWA No. 6-0 (0.25 gal/yd^2/18 percent rock) UTSS showed the best performance. Similarly, the BB No. 30-09 (0.25/18 percent) UTSS mixtures were the poorest. Note that the first letters on the mixture ID represent the aggregate type, followed by aggregate size, application rate, and aggregate percentage in the total mixture.

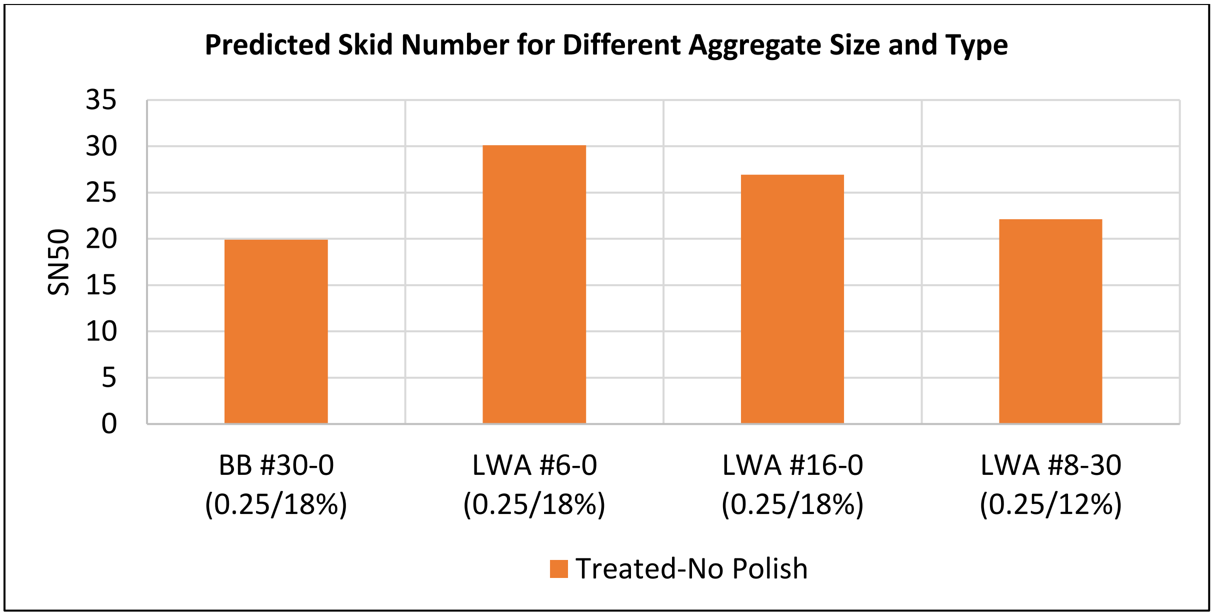


Figure 26. Skid Number Comparison for Different UTSS Mixtures before Slab Polishing.

After the initial comparison, a full lab skid evaluation was performed on the UTSS mixture comprised of LWA No. 6-0 aggregates at two shot rates and two different aggregate dosages. In addition, based on the initial polishing and skid test results, the researchers decided to focus the new tests on between 1,000 and 20,000 passes of the polisher. Measurements were made on the newly surfaced slabs after 1,000, 5,000, and 20,000-wheel passes. Four slabs with different UTSS treatment combinations and one untreated slab were used in the test program. The slabs were Type D1 (0.2/18 percent), Type D2 (0.2/15 percent), Type D3 (0.25/18 percent), Type D4 (0.25/15 percent), and Type D5 (control). Figure 27 shows the general skid test results. However, to identify the best slab treatment, normalization of the data was needed because the slabs' initial surface conditions slightly differed. The normalized data are shown in Figure 28, whereby Type D4 (0.25/15 percent) performed slightly better than the other treated slabs since it offered a steady and slower rate of skid loss. Nevertheless, it was outperformed by Type D5, the new untreated slab.

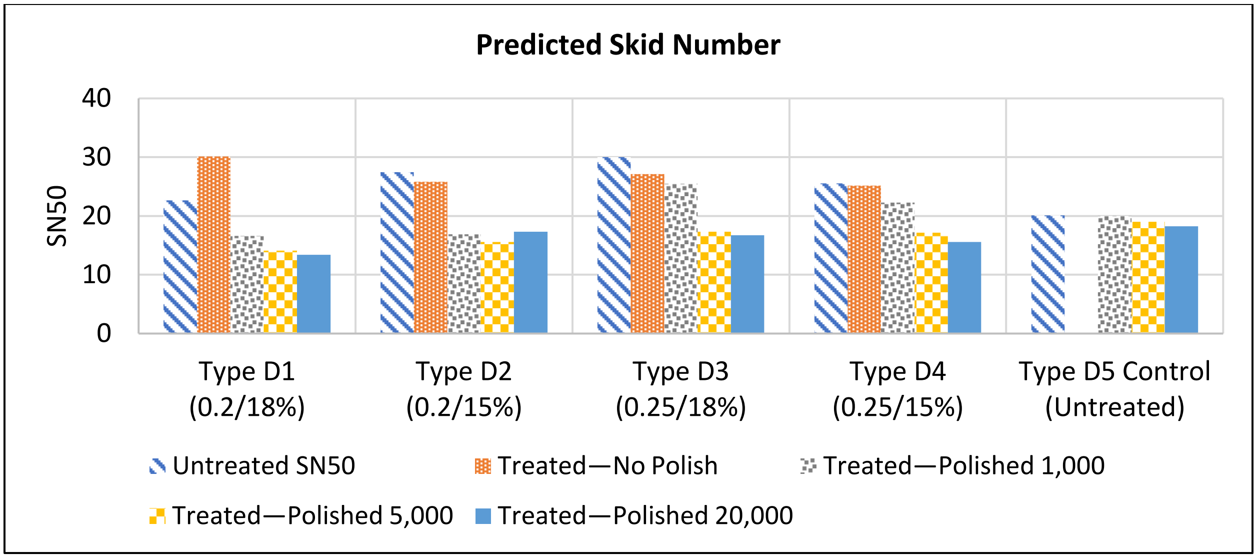


Figure 27. LWA UTSS Treated Slab Skid Numbers.

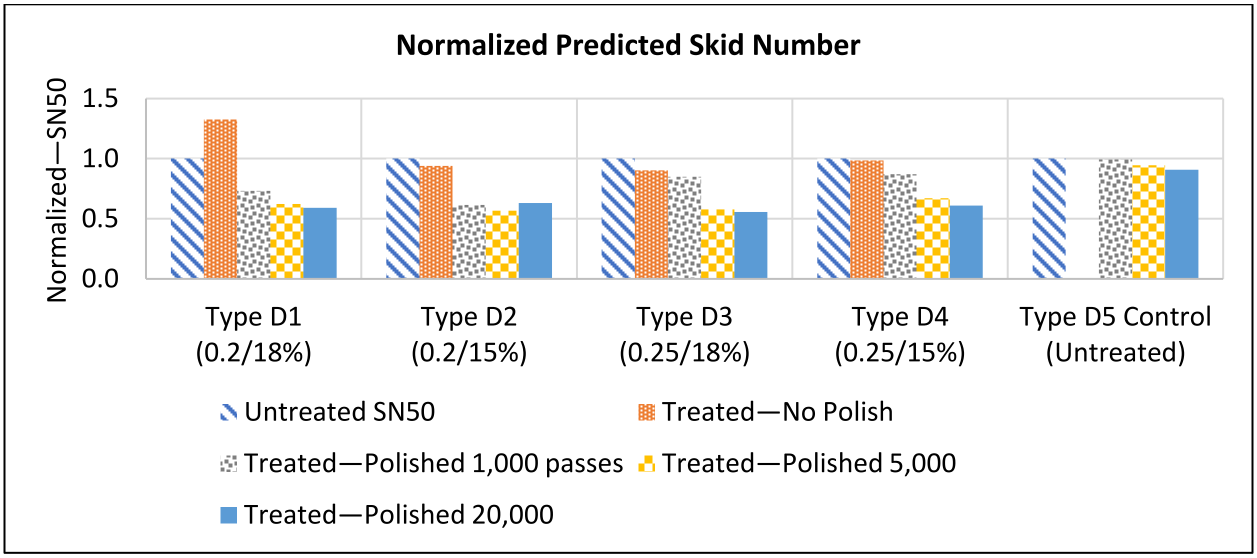


Figure 28. Normalized LWA UTSS Treated Slab Skid Numbers.

WET—TRACK ABRASION

Another indicator of the performance of UTSS is its abrasion resistance under the wet-track abrasion test. The test is typically performed on mastic asphalt to determine adherence (aggregate and binder) and the minimum binder required for the mastic mix. In this study, the test was performed in accordance with the ASTM 3910 protocol (ASTM, 2015).

Wet—Track Abrasion Test

A procedure for the wet-track abrasion test included pouring of the UTSS mixture into the circular opening of a template resting on the roofing felt, followed by oven curing in the oven at 60°C for 24 hours. After curing, the disk-shaped specimen was removed from the mold, and its dry weight was measured. The specimen was soaked in water at 25°C for 1 hour, and after that, it was mechanically abraded underwater with a rubber hose for 5 minutes and 15 seconds. The abraded specimen was placed under running water to remove loose particles, dried at 60°C, and weighed again to determine the wear value. The wear value was reported in grams per square meter (or square foot) based on the formula and correction factors according to ASTM 3910 protocol (Table 19). A pictorial of the wet-track abrasion test procedure is shown in Figure 29. A few of the wet-track abrasion tested samples are shown in Figure 30.

Table 19. Wear Value Formula and Correction Factors.

Model	Running Time	Conversion Constant - g/ft.^{2}	Conversion Constant - g/m^2	C-100 Correction Factor
C-100	5 min. ± 2 sec.	3.06	32.9	1.00
A-120	6 min., 45 sec. ± 2 sec.	2.78	29.9	1.17
N-50	5 min., 15 sec. ± 2 sec.	3.48	37.5	0.78
Modified N-50	5 min., 15 sec. ± 2 sec.	3.06	32.9	0.78

CALCULATION

Calculate the loss of material abraded in g/ft^2 or g/m^2 (wear value):

$$\textit{wear value} = (A - B) \bullet C \bullet D$$

Where:

A = Initial dry specimen weight
B = Abraded dry specimen weight
C = Conversion constant from Table 1
D = C-100 correction factor from Table 1.

					
1	Specimen Preparation Template	2	Curing Oven	3	Weight Measuring Scale
					
5	5Soaking	6	Wet Track Abrasion	7	Washing; then back to step 2 and 3

Figure 29. Wet-Track Abrasion Test Sequence.

Figure 30. Wet-Track Abrasion UTSS Tested Disks.

Issues with Wet—Track Abrasion Test

Two major problems with the test were observed during the preparation of the disk specimens.

- *The template*: The current template mold for casting the specimen is too deep and does not reflect the size of the aggregates in the UTSS mixtures, which are apparently too small (less than No. 8 sieve). Because of this mismatch, most aggregates tended to sink, and the final surface of the specimen became too smooth, with unrealistic wear value (low wear value). To solve the problem, the research team manufactured a 2-mm thin template to replace the regular template.

- *Squeegeeing*: The current protocol requires the spreading and leveling of the mixture during molding to be done with a squeegee. However, the squeegee caused bleeding (when the large template was used) or pulled aggregates on one side when applied on thinner specimens. To solve the problem, the research team used a special hairbrush to uniformly spread the mixture on the felt disk.

Results and Discussion of the Wet—Track Abrasion Test

Table 20 shows the wear values of the BB and LWA mixtures. The results varied considerably, perhaps due to difficulties in squeegeeing the UTSS mixture in thin specimens on open spaces without a guide frame (or template). Moreover, bleeding due to squeegeeing could have been a problem. In a later stage, the researchers used a brush to spread the mixtures on the roofing felt disks (this is not in the protocol). This process was mostly done on the LWA mixtures and reduced the variations and produced wear values close to 80, the maximum limit advised in Special Specification 3028. The limit is intended to tell if there is enough binder/adhesion in the mixture.

Table 20. Wet—Track Abrasion Test Results.

ID	Initial Weight (g)	Weight After Test (g)	Weight Loss (g)	Wet-Track Value (g/m²)	Description
BB 18%	60.3	57.2	3.1	90.7	WTV>80 (less binder)
BB 18%	74.3	72.6	1.7	49.7	WTV<80 (ok)
BB 18%	82.1	79.7	2.4	70.2	WTV<80 (ok)
LWA 8-30/12%	140.3	136.9	3.4	99.5	WTV>80 (less binder)
LWA 8-30/18%	114.3	98.7	15.6	456.3	WTV>>80 (may be excessive aggregates/less binder)
BB 18%	83.9	78.7	5.2	152.1	WTV>80 (less binder)
BB 18%	129.2	126.2	3.0	87.8	About right
LWA 8-30/12%	140.3	136.9	3.4	99.5	WTV>80 (less binder)
LWA 16-0/18%	132.8	130.5	2.3	67.3	WTV<80 (ok)
LWA16-0/18%	75.1	72.5	2.6	76.1	WTV<80 (ok)
LWA 8-30/18%	90.8	89.4	1.4	41.0	WTV<<80 (bleeding or excessive binder)
LWA 16-0/18%	82.1	79.7	2.4	70.2	WTV<80 (ok)
LWA 16-0/18%	124.2	122.0	2.2	64.4	WTV<80 (ok)

SUMMARY

In general, the selected lab frictional (DFT, CTM, and wet-track abrasion) and permeability test methods (Florida method and water flow method) showed the performance level of the evaluated UTSS mixtures. The research team found that the UTSS produced with LWA aggregates performed better than the one produced with BB aggregates. However, additional tests in the field are essential to fully validate the mixtures and methods.

CHAPTER 5. FIELD EVALUATION OF LAB—DESIGNED ULTRA—THIN SLURRY SEAL MIXTURES

Based on the laboratory work, the research team prepared different ultra-thin mixtures for assessing friction in the field. The prepared mixtures are shown in Table 21. The designed mixtures were placed on two Texas state highways (SH 36 in Gustine and SH 21 in Bryan). On SH 36, which was a new overlay, two small patches (3 ft x 3 ft) were surfaced with the material, whereas on SH 21 (an old existing highway), five patches were placed. The patches were placed in the wheel paths and were big enough to permit friction measurements with the DFT device. In addition to assessing the materials' skid performance, the research team performed the water flow test on the existing surface. The flow time in each of the tested locations on the two highways was above 10 minutes, which implied that the pavement surfaces were practically impermeable.

Table 21. Ultra-Thin Trial Mixture Matrix for Field Evaluations.

Item #	UTSS Mixture Type	Application Layers	Location
1	15% No 6 LWA at 0.325 gal/yd^2	3 @ 0.125 gal/yd^2	SH 36 Gustine, Tx
2	15% No 6 LWA at 0.25 gal/yd^2	2 @ 0.125 gal/yd^2	SH 36 Gustine, Tx
1	15% No 6 LWA at 0.20 gal/yd^2	2 @ 0.1 gal/yd^2	SH 21 Bryan, Tx
2	15% No 6 LWA at 0.25 gal/yd^2	2 @ 0.125 gal/yd^2	SH 21 Bryan, Tx
3	18% No 16 LWA at 0.25 gal/yd^2	2 @ 0.125 gal/yd^2	SH 21 Bryan, Tx
4	18% BB aggregate at 0.25 gal/yd^2	2 @ 0.125 gal/yd^2	SH 21 Bryan, Tx
5	24% BB aggregate at 0.25 gal/yd^2	2 @ 0.125 gal/yd^2	SH 21 Bryan, Tx

In the field, the UTSS mixtures were applied on square sections of 3 ft by 3 ft. The mixtures were applied manually and spread very fast before they dried up due to prevailing weather conditions (high temperature and wind) (Figure 31). Each patch was divided into four equal quadrants to assist with achieving an equal application rate and minimize temperature effects. An approximately 1-hour buffer (30 minutes for temperatures above 100°F) was instituted between layer applications. Similarly, 2 hours of curing elapsed before conducting the skid (DFT and CTM) tests.

Figure 31. Application of UTSS on SH 21.

SH 36 (GUSTINE, TEXAS)

On SH 36, two patches were surfaced with two different application rates of the mixture LWA 6-0/15 percent to assess the effect of two different application rates of the mixture. The application emulsion rates were 0.375 gal/yd^2 and 0.25 gal/yd^2. Figure 32 shows the treated section on SH 36.

Figure 32. UTSS Treated Sections on SH 36.

Prior to testing the friction of the treated sections, two randomly selected untreated sections were tested (DFT and CTM) for comparison purposes. Figure 33 shows the predicted SN for the treated and untreated sections on SH 36. The randomly selected untreated section recorded DFT/CTM-based SN50 of about 23.5, whereas the UTSS treated sections showed improved SN50 of about 27. The improvement was mainly due to the doubling of the surface macro-texture (the MPD measured by the CTM) (Table 22). In addition, there were no SN differences between the two- and three-shot UTSS applications.

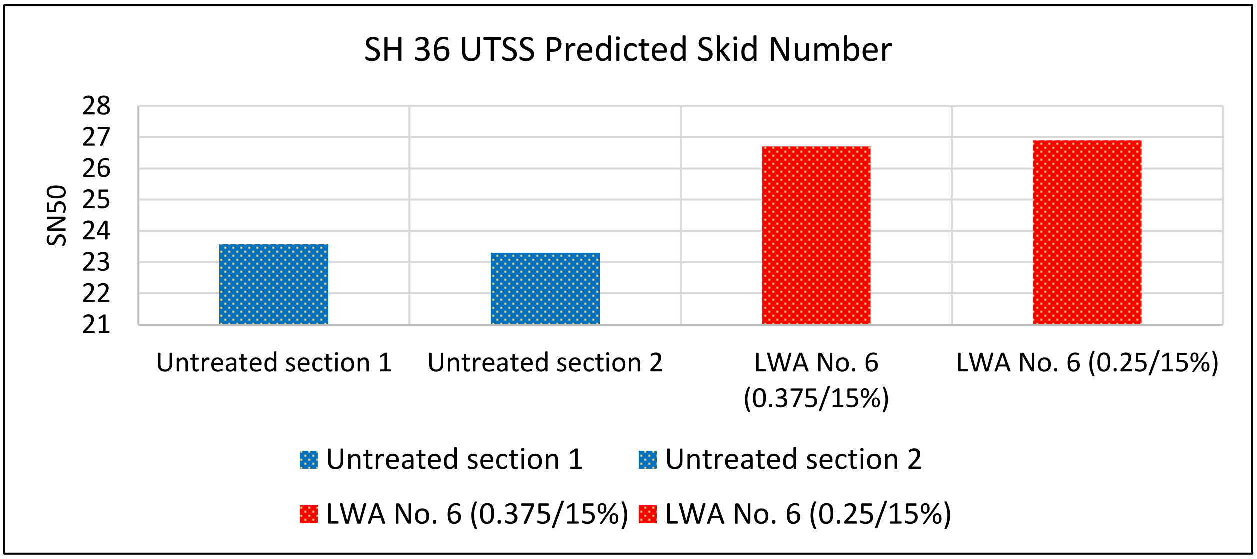


Figure 33. Predicted SN for UTSS Treated and Untreated Sections on SH 36.

Table 22. Micro-and Macro-Texture Values Used to Predict Skid Number on SH 36 Test Sections.

Section and UTSS Type	μ @ 20 km/hr	MPD	Sp	IFI	Predicted SN50
SH 36 EB—No treatment 1	0.38	0.55	63.09	0.23	23.6
SH 36 EB—No treatment 2	0.36	0.57	65.33	0.22	23.3
SH 36 EB—0.375 shot of LWA	0.29	1.12	114.66	0.23	26.7
SH 36 EB—0.25 shot of LWA	0.3	1.07	110.18	0.23	26.9

SH 21 (BRYAN, TEXAS)

On SH 21, five patches of UTSS mixtures were built with different mixture designs, as shown earlier in Table 21. The patches were assessed for skid resistance and crack sealing of the existing aged dense HMA pavement immediately after the application of the slurry and 2 months later (Figure 34).

Figure 34. Before and After Traffic Passes of UTSS Surface Evaluation on SH 21.

Figure 35 shows the predicted SN (based on CTM and DFT) of the tested patches just before and after 2 months of traffic. The resulting skids include SNs of untreated adjacent control sections (behind [1] and in front of [2] the treated patches) for comparison. The results indicate that the initial (just after construction) SN on the LWA treated sections hovered around 28. Similar SNs were observed on sections treated with BB mixtures of the same aggregate percentage. BB treated surfaces with an extra 6 percent aggregates produced initial SNs of about 31. After 2 months of traffic passes, no matter what the initial SN was, all values on treated sections dropped to about 20, whereas the SN on untreated sections remained the same, at around 26. In addition, after 2 months of traffic, the research team observed wide open cracks, which implied that UTSS could not seal the existing pavement surface cracks (Figure 36).

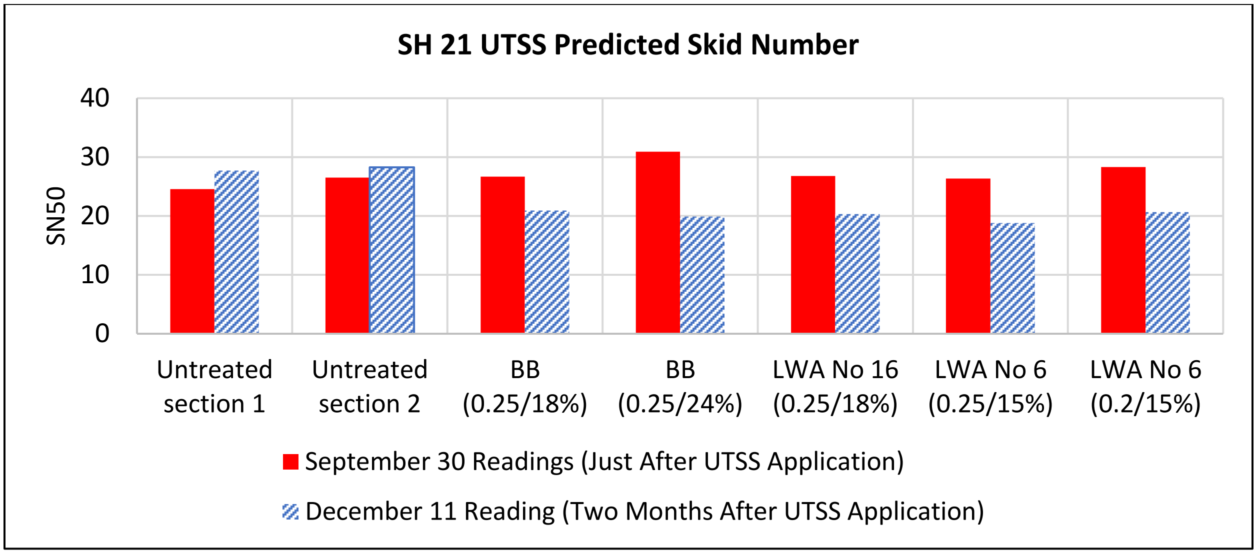


Figure 35. Predicted SN for Treated and Untreated Sections on SH 21.

Figure 36. Crack Sealing Failure on SH 21.

FUTURE MIXTURE DESIGN

Improved construction techniques developed by the industry may provide potential for improving mixture designs. Future construction will move away from use of the spraying bars, which have limited nozzle sizes, and introduce a new system that uses chutes, an open side hopper, and a spreader box to place UTSS on the pavement surfaces. The new system will enable the use of larger and higher-dosage aggregates in the mixtures. Figure 37 and Figure 38 show the current and future construction equipment, respectively.

Figure 37. Current UTSS Application Equipment.

Figure 38. New Generation UTSS Application Equipment (Dec 2019 demo).

SUMMARY

This chapter presented the evaluation of UTSS mixtures in the field. The results of the evaluation indicated that some of the UTSS mixtures could increase the friction of the pavements before traffic passed (just after application). However, after a few months of traffic, the skid number (SN50) dropped to about 20 for all mixtures. Overall, the mixtures did not perform well in the field. Future mixtures with relatively large aggregates could do better. For now, the aggregate size is limited by the current mixture application equipment. More work is needed to determine if a coarser aggregate gradation can be economically developed.

CHAPTER 6. CONCLUSIONS AND RECOMMENDATIONS

Based on the study findings, the research team developed the conclusions and recommendations presented in this chapter. These conclusions and recommendations are solely based on the work reported herein, with limitations thereof.

LABORATORY TESTS

The conclusions and recommendations based on laboratory tests are as follows:

- The DFT and CTM can discriminate friction performance of UTSS mixtures at different wheel polisher passes.
- The permeability performance of the UTSS mixtures can be assessed with the field permeameter (slabs/pavements) or the Florida test method (cores/lab molds).
- The UTSS treated surfaces could only sustain wheel polisher passes up to about 1,000 to 5,000 before the friction dropped way below the original surface friction.
- The LWA-based mixtures performed better than the original BB-based mixtures.
- Significant variation exists in the Wet Track Abrasion test, and thus more tests are needed to justify the usage of this test to quantify the UTSS mixtures.
- The current UTSS applicator has small nozzle sizes and therefore limits the allowable aggregate sizes and quantities in the mixtures. Improvements to the slurry applicators may provide a way to improve the UTSS mixtures.

FIELD EVALUATIONS

The conclusions and recommendations based on field evaluations are as follows:

- Independent of the original skid number, the skid number after treatment always dropped to a value of around 20 after a few months of traffic passes depending on the:
    - Aggregate types and quantity in the mixture.
    - Level of traffic.
    - Condition of the existing surface.
- UTSS was not effective at sealing cracks.
- UTSS in its current form can be not used for high traffic volume roads.

- UTSS improved the blacktop surface of the pavement and thus can be used to demarcate shoulders.

STATE OF THE SPECIFICATION AND IMPROVEMENT

The conclusions and recommendations related to the state of the specification and improvement are as follows:

- The specification should be modified to include the effect of macro-texture measured by the CTM. The effect would be more pronounced for relatively larger aggregates.
- The wet-track abrasion test needs improvements.
- The molding template is too thick relative to UTSS aggregate sizes. Aggregates (especially dense ones) could sink in and lead to unrealistic wear values. The research team improvised thinner disk specimens.
- The limit criterion of 80 g/m^2 is not realistic for small aggregates (i.e., <No. 8).
- Specifications need to be revised to include a DFT/polisher requirement. For example, "50,000 passes of the polisher with less than a 10% loss in skid."

SUMMARY

Overall, the research team determined that UTSS in its current form should not be used to surface the main lanes of high-speed TxDOT highways. However, UTSS can be used to demarcate shoulders. Future specifications should include a requirement to retain skid resistance for a to-be-determined number of passes with the three-wheel polisher. Once developed, a new type of UTSS applicator that allows for relatively larger sizes or increased amounts of aggregates should be used to demonstrate the improved retained skid resistance of the next generation of slurries.

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APPENDIX. SPECIAL SPECIFICATION 3028—FRICTIONAL ASPHALTIC SURFACE PRESERVATION TREATMENT

Special Specification 3028

Frictional Asphaltic Surface Preservation Treatment

1. DESCRIPTION

Apply a surface preservation treatment consisting of one or more applications of a single layer of asphaltic and aggregate material.

2. MATERIALS

Furnish materials in accordance with the following:

2.1. **Asphalt.** Furnish an emulsified asphalt in accordance with Table 1. Provide water in accordance with Article 204.2., "Materials."

Table 1. Emulsified Asphalt

Property	Test Procedure	Min	Max
Viscosity	T 59	20	100
Particle Charge Test	T 59	Positive	
Sieve, %	T 59	0	0.1
Residue by Distillation, percent	T 59	60	-
Penetration at 77°F, 100 g, 5 sec.	T 49	40	150

Use a quantity of emulsified asphalt in the mixture, expressed as a percentage of total weight, the percentage shown on the plans, or as directed.

2.2 **Aggregate**. Furnish aggregate meeting Item 302, "Aggregates for Surface Treatments," of the grade shown in Table 2.

Table 2. Aggregates

Physical Properties[1]				
Property		Test Procedure	Min.	Max.
Water Absorption, %		T 84	-	4
Micro-Deval, %		D 7428[2]	-	20
Gradation[3]				
Sieve	Standard	Master Grading Band Limits Percent Passing	Target Tolerance	
No. 8	C 136	100		
No. 16	C 136	85-100		
No. 30	C 136	75-100	± 5	
No. 60	C 136	10-40	± 5	
No. 100	C 136	0-10	± 5	
No. 200	C 117	0-5	± 1	

1. Perform physical property tests on aggregates that are received before blending into sealer.
2. Micro-Deval on aggregate larger than No. 60 sieve U.S.

2.3 **Additives.** Add clay, polymers, water, and other additives as required. Use a minimum of 4% polymer by weight. Furnish water free of industrial wastes and other objectionable matter.
or:
Other Additives. Use approved additives as recommended by the Frictional Asphaltic Surface Preservation Treatment manufacturer when necessary to adjust mix time in the field.

Table 4. Production or Field Sample

Test	Test Procedure	Min	Max
Solids Content by Evaporation, %	T 59[1]	48	--
Asphalt Content by Ignition Method, %	T 308[3]	30	--
Rotational Viscosity, 20 rpm, RV spindle, 25°C, cP	D 2196[2]	800	4000
Temperature for storage and application, °F	--	60	130

1. Dry specimens to a state where measurements taken 20 minutes apart do not change.
2. Test samples within 7 days.
3. Reduce sample size to achieve asphalt quantity. It is very important that this test be performed on a completely dry sample.

3. MIX DESIGN

3.1 Furnish a laboratory mix design meeting the requirements shown in Table 3:

Table 3. Laboratory Mix Design

Test	Test Procedure	Min	Max
Wet-Track Abrasion Loss, 3 day soak, g/m^2	D 3910[1]	--	80
Asphalt Content by Ignition Method, %	T 308	30	--
Dynamic Friction Test Number, 20 kph	E 1911[2]	0.90	--

1. Use the modified method to account for realistic application depth and fine emulsion mixture.
2. Establish base friction value using prepared laboratory compacted slab of approved mix as surface to be tested. The Dynamic Friction Test (DFT) number ratio should indicate that after application of the

mastic seal, the surface retains required minimum percentage DFT number of the original pavement surface.

3.2 Furnish a production or field sample meeting the requirements shown in Table 4:

4. EQUIPMENT

4.1 **Mixing Plant.** Provide a stationary pugmill, weigh-batch, or continuous mixing plant as approved. Equip plants with digital proportioning and metering devices that produce a uniform mixture of asphalt, aggregate and additives in the specified proportions.

4.2 **Distributor.** Provide applicable equipment in accordance with Article 316.3., "Equipment." Furnish the necessary facilities and equipment for determining the temperature of the mixture, regulating the application rate, and securing uniformity at the junction of 2 distributor loads. Furnish a distributor capable of keeping the Frictional Asphaltic Surface Preservation Treatment in uniform suspension and adequately mixing the asphalt, aggregate and additives.

4.3 **Asphalt Storage and Handling Equipment.** When using storage tanks, furnish a thermometer in each tank to continuously indicate the asphalt temperature. Keep equipment clean and free of leaks. Keep asphalt material free of contamination. Furnish storage tanks capable of keeping the Frictional Asphaltic Surface Preservation Treatment in uniform suspension and adequately mixing the asphalt, aggregate and additives.

5. CONSTRUCTION

5.1 **Adverse Weather Conditions**. Do not place mixture when, in the Engineer's opinion, general weather conditions are unsuitable. Meet the requirements for air and surface temperature shown below.

5.1.1 **Standard Temperature Limitations**. Apply mixture when air temperature is above 50°F and rising. Do not apply mixture when air temperature is 60°F and falling. In all cases, do not apply mixture when surface temperature is below 60°F.

5.1.2. **Cool Weather Night Air Temperature**. The Engineer reserves the right to review the **National Oceanic and Atmospheric Administration** (**NOAA**) weather forecast and determine if the nightly air temperature is suitable for mixture placement.

5.1.3. **Cold Weather Application**. When mixture application is allowed outside of the above temperature restrictions, the Engineer will approve the mixture and the air and surface temperatures for application. Apply mixture at air and surface temperatures as directed.

5.2. **Surface Preparation**. Remove existing raised pavement markers. Repair any damage incurred by removal as directed. Remove dirt, dust, or other harmful material before applying. When shown on the plans, remove vegetation and blade pavement edges.

5.3. **Application.** Apply the mixture when the air temperature is at or above 60°F, or above 50°F and rising. Measure the air temperature in the shade away from artificial heat. The Engineer will determine when weather conditions are suitable for application.

Distribute material at the following rates or as directed:

- First application: 1.0 to 1.5 lbs per SY.
- Second application: 1.0 to 1.5 lbs per SY.
- Total application after the second application: 2.5 lbs per SY minimum.

5.4. **Edges**. Adjust the shot width so operations do not encroach on traffic or interfere with the traffic control plan, as directed. Use paper or other approved material at the beginning and end of each shot to construct a straight traverse joint. Unless otherwise approved, match longitudinal joints with the lane lines. The Engineer may require a string line if necessary, to keep the edge straight. Use sufficient pressure to flare the nozzles fully.

5.5. **Workmanship**. Immediately take corrective action if treatment material is exhibiting evidence of poor workmanship, delayed opening to traffic, or surface irregularities, including streaks, uncoated, and blotchy areas. The Engineer may allow placement to continue for no more than one day of production while taking appropriate action. Suspend application if the problem still exists after one day until the problem is corrected to the satisfaction of the Engineer.

5.6. **Opening to Traffic.** Open the treated surface to traffic when directed. Furnish and uniformly distribute clean, fine sand on the surface to blot the excess when an excessive quantity of mixture is applied. Maintain ingress and egress as directed by applying sand to freshly treated areas.

6. MEASUREMENT

Frictional Asphaltic Surface Preservation Treatment will be measured by the ton or by the square yard of the composite Frictional Asphaltic Surface Preservation Treatment mixture, which includes asphalt emulsion, aggregate, and additives. At the completion of the project, any unused Frictional Asphaltic Surface Preservation Treatment will be weighed back and deducted from the accepted Frictional Asphaltic Surface Preservation Treatment quantity delivered.

7. PAYMENT

The work performed and materials furnished in accordance with this Item and measured as provided under "Measurement" will be paid for at the unit bid price per ton or square yard for "Frictional Asphaltic Surface Preservation Treatment." This price is full compensation for preparing the existing surface (including removing existing raised pavement markers); furnishing, hauling, preparing, and placing materials; and equipment, labor, tools, and incidentals.