TTI: 5-6744-01-R1

Implementation of the HMA Shear Test for Routine Mix-Design and Screening: Technical Report

Implementation Report 5-6744-01-R1

Cooperative Research Program

TEXAS A&M TRANSPORTATION INSTITUTE
COLLEGE STATION, TEXAS

in cooperation with the
Federal Highway Administration and the
Texas Department of Transportation
http://tti.tamu.edu/documents/5-6744-01-R1.pdf

Technical Report Documentation Page

1. Report No. FHWA/TX-18/5-6744-01-R1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle IMPLEMENTATION OF THE HMA SHEAR TEST FOR ROUTINE MIX-DESIGN AND SCREENING: TECHNICAL REPORT		5. Report Date Published: February 2019 6. Performing Organization Code
7. Author(s) Lubinda F. Walubita, Tito Nyamuhokya, Sang Ick Lee, and Adrianus Prakoso		8. Performing Organization Report No. Report 5-6744-01-R1
9. Performing Organization Name and Address Texas A&M Transportation Institute College Station, Texas 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 5-6744-01
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office 125 E 11th Street Austin, Texas 78701-2483		13. Type of Report and Period Covered Technical Report: July 2015–August 2018 14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

Project Title: Implementation of the HMA Shear Test for Routine Mix-Design and Screening

URL: http://tti.tamu.edu/documents/5-6744-01-R1.pdf

16. Abstract

Rutting and permanent deformation (PD) continues to be a flexible pavement failure mode of concern, particularly under heavy traffic loading, high-temperature environments, and severe shear stress conditions such as highway intersections and urban stop-go sections, or where lower asphalt-binder performance grades (PG) have been used. With the record summer temperatures in recent years, several surface rutting and shear failures have occurred with hot mix asphalt (HMA) mixes that had passed the Hamburg wheel tracking test (HWTT) criterion. In an effort to mitigate these surface rutting and shear failure distresses, Texas Department of Transportation (TxDOT) project 0-6744 *New HMA Shear Resistant and Rutting Texas for Texas Mixes* proposed several key modifications to the HWTT protocol to improve its ability to simulate field rutting conditions under extreme shear environments, including testing the HMA mixes at elevated temperatures (i.e., 60°C). Additionally, a new supplementary HMA shear test, the simple punching shear test (SPST), was developed that showed good potential to be considered as a supplement or surrogate to the HWTT for shear strength evaluation and screening of HMA mixes.

This implementation project verified and refined the modified HWTT protocol and the proposed SPST test for screening HMA mixtures susceptible to rutting, permanent deformation, and shear failure. Specifically, the study involved performing the SPST and the traditional HWTT tests on HMA at both the standard (50°C) and elevated test temperatures (i.e., 60°C) and validated the laboratory test results with field performance data. The scope of work for the validation and implementation process included assisting the TxDOT districts, such as Laredo, with their routine mix-design screening and HMA shear strength testing.

17. Key Words HMA, Rutting, Shear, Permanent Deformation (PD), Stress, Strain, Shear Strength, Modulus, HWTT, Simple Punching Shear Test (SPST), Data Storage System (DSS)	18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Alexandria, Virginia 22312 http://www.ntis.gov

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 76	22. Price

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

IMPLEMENTATION OF THE HMA SHEAR TEST FOR ROUTINE MIX-DESIGN AND SCREENING: TECHNICAL REPORT

by

Lubinda F. Walubita
Research Scientist
Texas A&M Transportation Institute

Tito Nyamuhokya
Assistant Transportation Researcher
Texas A&M Transportation Institute

Sang Ick Lee
Associate Research Engineer
Texas A&M Transportation Institute

and

Adrianus Prakoso
Research Associate
Texas A&M Transportation Institute

Report 5-6744-01-R1
Project 5-6744-01
Project Title: Implementation of the HMA Shear Test for Routine Mix-Design and Screening

Performed in cooperation with the
Texas Department of Transportation
and the
Federal Highway Administration

Published: February 2019

TEXAS A&M TRANSPORTATION INSTITUTE
College Station, Texas 77843-3135

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 the 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 Lubinda F. Walubita.

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.

ACKNOWLEDGMENTS

This project was conducted in cooperation with TxDOT and FHWA. The authors thank Kevin Pete, the project manager, Joe Adams (the previous project manager), and all members of the project team for their participation and feedback.

TABLE OF CONTENTS

LIST OF FIGURES

Page

LIST OF TABLES

Page

LIST OF SYMBOLS AND ABBREVIATIONS

APT	Accelerated pavement testing
AV	Air void
CAM	Crack attenuating mix
CV	Coefficient of Variation
DSS	Data storage system
HMA	Hot mix asphalt
HWTT	Hamburg Wheel Tracking Test
L-D	Load-displacement
PG	Performance Grade
PFC	Permeable friction course
RAP	Reclaimed asphalt pavement
SGC	Superpave Gyratory Compactor
SPST	Simple Punching Shear Test
TxDOT	Texas Department of Transportation
TxME	Texas Mechanistic-Empirical
τ	Shear strength
γ	Shear Strain
G	Shear Modulus
R^2	Coefficient of determination

CHAPTER 1. INTRODUCTION

Under high temperatures, hot mix asphalt (HMA) pavements are prone to rutting and shear failure if subjected to heavy traffic loading, particularly in high shear location areas with slow moving (accelerating/decelerating) such as intersections or controlled stop-go zones. Unfortunately, in the recent years, pavements in several Texas districts have experienced an increased number of truck axle loads and volume due to improved economic activities such as agricultural, oil, gas, and energy industry (Quiroga et. al., 2012). In addition, the state of Texas has experienced prolonged periods of higher summer temperatures in the recent decades. Climate data collected from 2011 to 2017 at different weather stations in Texas show that there are places that have experienced temperatures above 100°F (38°C) for more than 300 days. For example, Laredo (along US 59) and Cotulla (along IH 35) recorded an average of 63 and 49 summer days per year of temperatures above 100°F (38°C), respectively (Weather Underground, 2018). Furthermore, in 2016 alone, cities such as Austin, San Antonio, Dallas, Fort Worth, Galveston, and Bryan all recorded temperatures close to or above 110°F (43°C). During the same period, most of these cities experienced temperatures that lingered above 100°F (38°C) for more than 30 days (Brown et. al., 2016). Air and pavement surface temperatures stored in the data storage system (DSS) for Texas flexible pavements and overlays show that HMA pavements located in areas that have posted air temperatures at or above the 110°F were quickly heated up to about 140°F (60°C); see Figure 1 (Walubita et al., 2017).

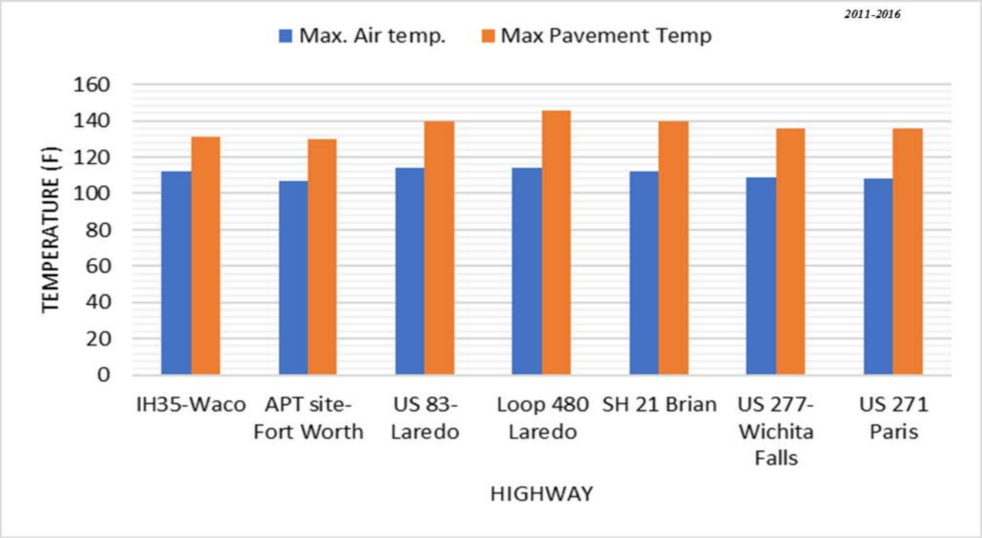


Figure 1. Temperature Extracts from the Data Storage System (Walubita et al., 2017).

The high level of traffic and temperatures in Texas have aggravated pavement rutting, permanent deformation, and shear failure of surface HMA mixes even for mixes traditionally passing the routine screening and laboratory testing using the Hamburg Wheel Tracking Test (HWTT) at 50°C. For example, recent studies showed excessive rutting of relatively new sections on US 96 (Beaumont District) and US 79 (Bryan District) where rut depths of above 1 inch were recorded for HMA mixes that had passed the routine HWTT test in the laboratory with rutting less than 0.5 inches; see Figure 2 (Walubita et al., 2014a, 2014b, and 2014c).

Figure 2. Surface Rutting on US 96 (Beaumont District).

In an effort to mitigate these surface rutting and shear failure distresses, Texas Department of Transportation (TxDOT) project 0-6744 *New HMA Shear Resistant and Rutting Texas for Texas Mixes* proposed several key modifications to the HWTT protocol to improve its ability to simulate field rutting conditions under extreme shear environments, including testing the HMA mixes at elevated temperatures (i.e., 60°C). Additionally, a new supplementary HMA shear test, namely the simple punching shear test (SPST), was developed that showed good potential to be considered as a supplement or surrogate to the HWTT for shear strength evaluation and screening of HMA mixes. This implementation project verified and refined the modified HWTT protocol and the proposed SPST test for screening HMA mixtures susceptible to rutting, permanent deformation, and shear failure. Specifically, researchers performed the SPST and traditional HWTT tests on HMA at both the standard (50°C) and elevated test temperatures (i.e., 60°C) and validated the laboratory test results with field performance data.

PROJECT OBJECTIVES

In order to implement the SPST protocol as a supplemental test to the HWTT, researchers:

- Assisted TxDOT with their routine mixture design screening and HMA shear strength testing.
- Conducted a pilot implementation of the findings of Project 0-6744 through assisting the districts with their design mixtures using the proposed SPST and modified HWTT protocol.
- Verified and refined the proposed test procedures with field performance data from in-service highway test sections.
- Performed parallel laboratory testing of HWTT and SPST at 50°C and 60°C, and validated the laboratory test results with field performance data.

RESEARCH METHODOLOGY AND WORK PLAN

To achieve the objectives of the project, researchers:

- Performed HWTT in accordance with the Tex-242-F test procedures on both HMA lab-molded and plant-produced mixes.
- Performed the SPST in accordance with the preliminary SPST testing protocol, specifications, and guidelines (drafts) as documented in Walubita et al. (2014c).
- Computed and compared the HMA-SPST output parameters (i.e., shear strength, shear modulus, and shear strain) to HWTT rutting criterion.
- Compared the SPST output to field performance.

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: Experimental Design and Testing.
- Chapter 3: Routine HMA Mix-Design Support.
- Chapter 4: Sensitivity Analysis.

- Chapter 5: Validation of the SPST Method.
- Chapter 6: Specification Modification and Development.
- Chapter 7: Conclusions and Recommendation.

Some appendices of important and additional data are also included at the end of the report. This includes the proposed SPST test procedure/specifications and the suggested modifications/enhancements to the HWTT Tex-242-F test procedures.

SUMMARY

This first chapter of the report overviewed the background and the work performed throughout the project. The chapter also described the research tasks, the research methodology, and the structuration of the report contents. Specifically, this report documents the work accomplished throughout the whole project period.

CHAPTER 2. LABORATORY EXPERIMENTATION AND TESTING

This chapter presents the materials and HMA design mixes routinely used in Texas pavements for surfacing that were assessed to fulfill the goals of this project. The procedure followed to make the HMA specimens including the fabrication, short-term oven aging, and specimens cutting are also discussed. The laboratory testing procedures are also described.

HMA SPECIMEN FABRICATION

Table 1 lists the mix types and other HMA mix variables such as asphalt-binder performance grade (PG), reclaimed asphalt pavement (RAP) content, aggregate size, and asphalt-binder content in the experimental matrix. The experimental matrix comprised of HMA mixes of fine-graded (crack attenuating mix [CAM] and Type F), dense-graded (Type C and Type D), coarse-graded (Type B), and permeable friction course (PFC) mixes. As shown in Table 1, the HMA comprised of both laboratory-prepared mixes from raw materials (asphalt-binder and aggregates) and plant-produced mixes sampled from various highways and accelerated pavement testing (APT) sites in the field during construction. For the lab-prepared mixes, the study followed the TxDOT test procedure to prepare the laboratory mixes (Tex-204-F) (TxDOT, 2018). The raw materials for Type C and D mixes were collected from Laredo and Chico, respectively, to prepare HMA specimens in the lab. The detailed standard constituents of the mix types as used in Texas can be found in Appendix A (TxDOT, 2017).

Table 1. The Experimental Matrix: SPST-HWTT Parallel Testing.

HMA Type	NMAS	PG	Asphalt-Binder %	RAP%	Hwy/ Lab	HWTT 50°C	HWTT 60°C	SPST 50°C	SPST 60°C
Type B	3/4	64-22	4.7	21.9	IH 35	✓	✓	✓	✓
Type C	3/8	70-22	5.2	20	Loop 480	✓	✓	✓	✓
Type C	3/8	64-22	4.8	20	SH 21	✓	✓	✓	✓
Type D	3/8	70-22	5.3	16	FM 2100	✓	✓	✓	✓
CAM	#4	76-22	7.0	0	SH 121	✓	✓	✓	✓
PFC	1/2	76-22	6.0	FC=.3%	US 271	✓	✓	✓	✓
Type D	3/8	64-22	5.2	20	US 59	✓	✓	✓	✓
Type C	3/8	64-22	4.8	20	US 83	✓	✓	✓	✓
Type D	3/8	64-22	5.3	15	US 82	✓	✓	✓	✓
Type F	3/8	76-22	7.4	0	US 271	✓	✓	✓	✓
Type B	3/4	64-22	5.0	15	APT	✓	✓	✓	✓
Type C	1/2	70-22	5.2	0	FM 1887	✓	✓	✓	✓
Type C	3/8	64-22	4.7	0	Lab	✓	✓	✓	✓
Type C	3/8	64-22	5.2	0	Lab	✓	✓	✓	✓
Type C	3/8	64-22	5.7	0	Lab	✓	✓	✓	✓
Type C	3/8	70-22	4.7	0	Lab	✓	✓	✓	✓
Type C	3/8	70-22	5.2	0	Lab	✓	✓	✓	✓
Type C	3/8	70-22	5.7	0	Lab	✓	✓	✓	✓
Type C	3/8	76-22	4.7	0	Lab	✓	✓	✓	✓
Type C	3/8	76-22	5.2	0	Lab	✓	✓	✓	✓
Type C	3/8	76-22	5.7	0	Lab	✓	✓	✓	✓
Type C	3/8	64-22	5.2	15	Lab	✓	✓	✓	✓
Type C	3/8	64-22	5.2	20	Lab	✓	✓	✓	✓
Type C	3/8	64-22	5.2	25	Lab	✓	✓	✓	✓
Type D	3/8	64-22	4.5	0	Lab	✓	✓	✓	✓
Type D	3/8	64-22	5.0	0	Lab	✓	✓	✓	✓
Type D	3/8	64-22	5.5	0	Lab	✓	✓	✓	✓
Type D	3/8	70-22	4.5	0	Lab	✓	✓	✓	✓
Type D	3/8	70-22	5.0	0	Lab	✓	✓	✓	✓
Type D	3/8	70-22	5.5	0	Lab	✓	✓	✓	✓
Type D	3/8	76-22	4.5	0	Lab	✓	✓	✓	✓
Type D	3/8	76-22	5.0	0	Lab	✓	✓	✓	✓
Type D	3/8	76-22	5.5	0	Lab	✓	✓	✓	✓

Legend: Hwy = Highway for plant-mix materials sampled from the field; Lab = laboratory prepared mixes; Testing; N/A = Not Applicable; FC = Fiber Content; ✓= test performed for a given mix at different temperatures

As illustrated in Figure 3, the experiments used typical cylindrical Hamburg-sized HMA samples with 6-inch in diameter and 2.5-inch thick molded using the Superpave gyratory compactor (SGC) to 7±1 percent air voids (AVs) (i.e., 93±1 percent density [except for PFC mixes where 20±2 percent AV was targeted]), for both the SPST and HWTT tests (TxDOT 2014 and TxDOT 2015). For each test temperature (50°C and 60°C), two and three replicate samples for HWTT and SPST tests, respectively, per HMA mix-design variable, were fabricated using both lab-prepared and plant-produced mix materials for SPST-HWTT parallel testing.

Figure 3. Typical HMA Samples for the SPST and HWTT Tests.

Prior to mixing, batched HMA mix ingredients (asphalt and aggregates) were subjected to standardized oven mixing temperatures (shown in Table 2) for 2 hours followed by thorough mixing in a hot bucket. After that, the mixtures were put back in the oven to undergo a short-term oven aging at different temperatures depending on the asphalt-binder grade (stiffness) as shown in Table 2. Note that the plant-produced HMA mixes from the field (highways and APT sites) or premixed lab HMA mixes required an extra 1.5 hours oven aging to break the solid HMA mixes and spread in open trays, prior to molding (TxDOT 2015, TxDOT 2005, and AASHTO 2001).

Table 2. HMA Mixing, Short-Term Oven Aging, and Compaction Temperatures.

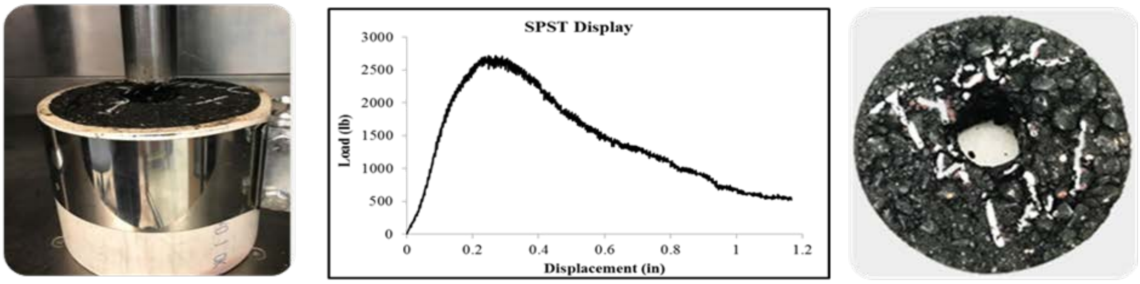
Asphalt-Binder PG Grade	Mixing Temperature	Oven Aging Temperature*	Molding/Compaction Temperature
PG 64-22	290°F (143°C)	275±5°F (135±3°C)	250°F (121°C)
PG 70-22	300°F (149°C)	275±5°F (135±3°C)	275°F (135°C)
PG 76-22	325°F (163°C)	275±5°F (135±3°C)	300°F (149°C)
* 1.5 hr for plant and lab-premixed mixes to break down solid HMA			

After molding the samples following the aforementioned procedures, researchers used a single blade saw to obtain the required HWTT specimen dimensions. On the other hand, HMA specimens for SPST tests require no cutting. The SPST protocol requires fullsize specimen as is directly obtained from SGC compaction. In addition, volumetric parameters of the HMA samples were determined in accordance with ASTM D2726 to record the actual AV of the fabricated specimens (ASTM, 2017). Researchers discarded all HMA specimens that did not meet the AV requirement (i.e., 7 ± 1 percent for all mixes except for PFC at 20 ± 2 percent) (TxDOT, 2004). In order to ensure consistency and limit effects of oxidation, researchers made sure that all the lab-molded specimens, from both raw and plant-produced mix materials, were tested within five days after molding. If for some reason this window of timeframe was not feasible, the HMA samples were kept in a freezer (0°C) for all days prior to testing (Walubita et al. 2016).

THE SIMPLE PUNCHING SHEAR TEST

The SPST experiments were performed using a universal testing machine following the SPST protocol developed in the TxDOT project 0-6744 (Walubita et al., 2014b, 2014c). The SPST procedure is relatively simple. As illustrated in Figure 4, the test requires a sample aligned on a special base with a hole at the center, strapped to restrict lateral, and punched with a displacement-controlled through load. On average, the SPST testing to failure takes less than 20 minutes with the real-time load-displacement (L-D) data being recorded and displayed on the computer. In this study, each HMA specimen was confined in a metal collar strap tightened at 20 psi lateral pressure using a torque wrench.

1. Specimen and base
2. Specimen on the base
3. Specimen-base aligning
4. Securing collar-strap

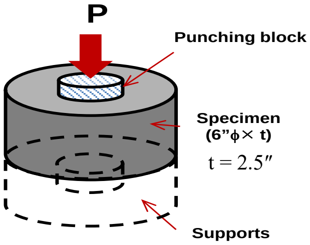


5. Loading
6. Real time data display
7. Specimen after test

Figure 4. Typical SPST Test Setup.

To punch the sample, a punching metal block with a diameter of 1.5 inches at a monotonic rate of 0.5 in/min was applied to the HMA specimen after the desired test temperatures had been achieved in accordance with the SPST protocol (Walubita et al., 2014a, 2014b, and 2014c). During SPST testing, the test temperature was observed through a thermocouple wire inserted into the center core of a dummy sample placed in the same chamber along with the tested sample. Table 3 presents the SPST parameters.

Table 3. The SPST Test Parameters.

#	Item	Description
1	Schematic	
2	Test objective	Characterization of HMA shear resistance properties
3	Specimen dimension	2.5" (63.5 mm) thick × 6.0" (152.4 mm) ϕ
4	Loading mode	Monotonic axial compressive loading. Displacement controlled (axial continuously increasing displacement)
5	Sitting load	8 lb (0.036 kN) or sitting stress of 0.29 psi (2 kPa)
6	Loading rate (mm/s)	0.2 mm/s (0.50 in/min)
7	Specimen confinement	Yes (20 psi)
8	Loading head diameter	1.5" (38.1 mm) dimeter
9	Test temperatures	50 ± 2°C (122°F) and 60 ± 2°C (140°F)
10	Data capturing frequency	Every 0.10 second (except temperature; at least every 5 seconds)
11	Test termination	2.49" (63.2 mm) vertical RAM movement
12	Total test time	≤ 10 minutes
13	Measured parameters	Temperature, time, load, & shear deformations
14	Number of specimen replicates per test condition	≥3
15	Target specimen AVs	7 ± 1% for all HMA mixes, except PFC mixes at 20 ± 2%.
16	Specimen temperature conditioning time	≤ 3 hr (it is recommended to monitor the temperature from a thermocouple wire inserted inside a dummy specimen that is also placed in the same temperature chamber as the test specimens)

THE HAMBURG WHEEL TRACK TEST

Currently, TxDOT follows the designation Tex-242-F test procedure for HWTT testing to determine the premature failure susceptibility of HMA mixes and screen HMA materials susceptible to rutting and shear failure (TxDOT, 2018). This study followed the testing protocol and the HWTT machine shown in Figure 5. The HWTT machine consists of two wheels for load-passes, Linear Variable Differential Transducer for rut depth measurement, and water bath to control the test temperatures (TxDOT, 2018). The machine can accommodate two pairs of HWTT samples, which allowed testing two HMA mixes at the same time for each test temperatures (50°C and 60°C). It took about 7 hours to complete single test. Table 4 shows a summarized example of the HWTT rut report in accordance with Tex-242-F (TxDOT, 2017; Walubita et al., 2014c).

Figure 5. Typical HWTT Test Setup.

Table 4. HWTT Rut Data Report (Plant-Mix of FM 1887 at 50°C).

Wheel Passes	Rut Depth (in.)
5,000	-0.09
10,000	-0.12
15,000	-0.17
20,000	-0.25

SUMMARY

This chapter simply laid out the HMA mixes used to evaluate the current HWTT and SPST testing procedures. The chapter discussed the fabrication process and all measures taken to obtain good HMA specimens for the implementation process. Moreover, in a simple form, the HWTT and SPST testing of the HMA specimen was also described.

CHAPTER 3. ROUTINE DISTRICT HMA MIX-DESIGN SUPPORT

This chapter presents the work performed to assist the TxDOT districts with their routine HMA mix-design screening and HMA shear strength testing. Routine SPST-HWTT screening testing for various HMA mix-designs was completed for various districts, including the following:

- Atlanta district
- Bryan district
- Laredo district
- Paris district
- Pharr district

HWTT-SPST ROUTINE TESTING AND HMA MIX SCREENING

For assisting the TxDOT districts with their routine HMA mix-design screening, the HWTT and SPST tests were conducted using the test procedures described in Chapter 2 of this report (TxDOT, 20018 and Walubita et al., 2014c). The SPST and HWTT tests were performed at temperatures of 50°C and 60°C using the following pass-fail screening criteria:

- $SPST: HMA\ Shear\ strength\ (\tau) = \begin{cases} 300\ psi\ @50°\text{C} \\ 200\ psi\ @60°\text{C} \end{cases}$
- $HWTT: Rut\ depth \leq 0.5\ inches\ @\ 50\ ℃\ and\ 60\ ℃$

HMA mixes not meeting the above criteria were deemed unsatisfactory for use in high-temperature high shear-stress environments. Although left to the District Engineer's discretional decision, recommendations for redesigning through mix-design changes such as the binder content, binder grade, RAP/RAS content, aggregate gradation, aggregate type, etc., were accordingly made.

HMA MIXES AND TEST RESULTS

The HMA mixes evaluated mostly included Type C and D mixes as well as some Type B and Type F mixes. The laboratory test results for the routine mix-design screening and HMA shear strength testing to support the districts are listed in Appendix B. With regards to the HWTT testing, most of the HMA mixes passed at 50 °C, but failed at 60 °C. After several iterative mix-design adjustments, however, most of the mixes passed both the HWTT and SPST criteria – see Appendix B. An example is given below for Type C and D mixes for Laredo and Pharr districts, respectively:

a) Laredo District: Type D (PG 70-22) mix; HWTT rut depth = 5.00 mm at 50 °C; HWTT rut depth = 11.3 mm at 60 °C; HMA shear strength = 323 psi at 50 °C, and HMA shear strength = 238 psi at 60 °C.
b) Pharr District: Type C (PG 70-22) mix; HWTT rut depth = 3.28 mm at 50 °C; HWTT rut depth = 11.1 mm at 60 °C; HMA shear strength = 302 psi at 50 °C, and HMA shear strength = 203 psi at 60 °C.

As theoretically expected, almost all the coarse-graded Type B mixes, typically used as rut-resistant base-layer mixes, passed both the HWTT and SPST criteria at 50 and 60 °C, respectively – see example in Appendix B for Laredo District. In changing the mix-design variables to meet the HWTT-SPST screen criteria, however, care should be exercised to balance other performance indices such as crack resistance, etc.

SUMMARY

The chapter outlined the HWTT-SPST work done to assist the TxDOT districts with their routine HMA mix-design screening and HMA shear strength testing. While most mixes failed the HWTT at 60°C, the SPST test was able to adequately screen the mixes for HMA shear resistance and rutting propensity at 60°C temperatures.

CHAPTER 4. SENSITIVITY ANALYSIS

In the course of implementing the SPST protocol, researchers evaluated the SPST sensitivity to HMA mix-design variables and correlated with the traditional HWTT procedure when running at both the standard (50°C) and elevated test temperatures (i.e., 60°C). For each HMA mix, researchers conducted parallel SPST and HWTT testing on HMA samples fabricated at 7±1 percent AVs (i.e., 93±1 percent density) from raw materials and plant-mixtures and thereafter assess the following aspects:

- The SPST sensitivity to HMA mix-design variables such as the asphalt-binder type/grade, asphalt-binder content, aggregate type/gradation, and RAP content.
- Correlation and validation of the proposed SPST procedure against the traditional HWTT procedure when running at both the standard (50°C) and elevated temperatures (60°C).
- Reliable statistical correlation between the HMA shear and rutting parameters obtained from the SPST and HWTT methods, respectively, so that the tests can be used alternately or in lieu of one another.

The subsequent sections describe the findings from the assessment of the sensitivity analysis of the SPST and HWTT testing. The findings cover the following key areas:

- Evaluated the SPST sensitivity to HMA mixes.
- Correlated and validated the SPST and HWTT procedures.
- Established some correlations between the HMA shear and rutting parameters obtained from SPST and HWTT, respectively.

SPST SENSITIVITY TO HMA MIX-DESIGN VARIABLES

To perform the SPST sensitivity to different HMA mix-design parameters, the following HMA mix-design variables were considered as:

- Asphalt-binder contents.
- Asphalt-binder type/grade.
- Aggregate type/gradation.
- RAP contents.

For each of the analyzed mix-design variable, three data points were established to assess sensitivity. For example, in assessing the asphalt-binder content, the data points were 4.7, 5.2, and 5.7 percent (i.e., optimum content ± 0.5 percent). Similarly, the assessment of asphalt-binder types/grades was performed using PG 64-22, PG 70-22, and PG 76-22 whereas the RAP contents were 15, 20, and 25 percent (i.e., 20±5 percent).

Asphalt-Binder Contents

Increased asphalt-binder content has a negative (decreasing) effect on the HMA shear strength determined from SPST testing. For different HMA mixes as shown in Figure 6, the HMA shear strength of the mixes reduced with an increase in the asphalt-binder content. Figure 6 also shows that the HMA shear strength at the standard temperature (50°C) is higher than one at the elevated temperature (60°C) at the same asphalt-binder content. Likewise, the HMA rut depth from the HWTT tests increased with increasing asphalt-binder content as expected (see Figure 7).

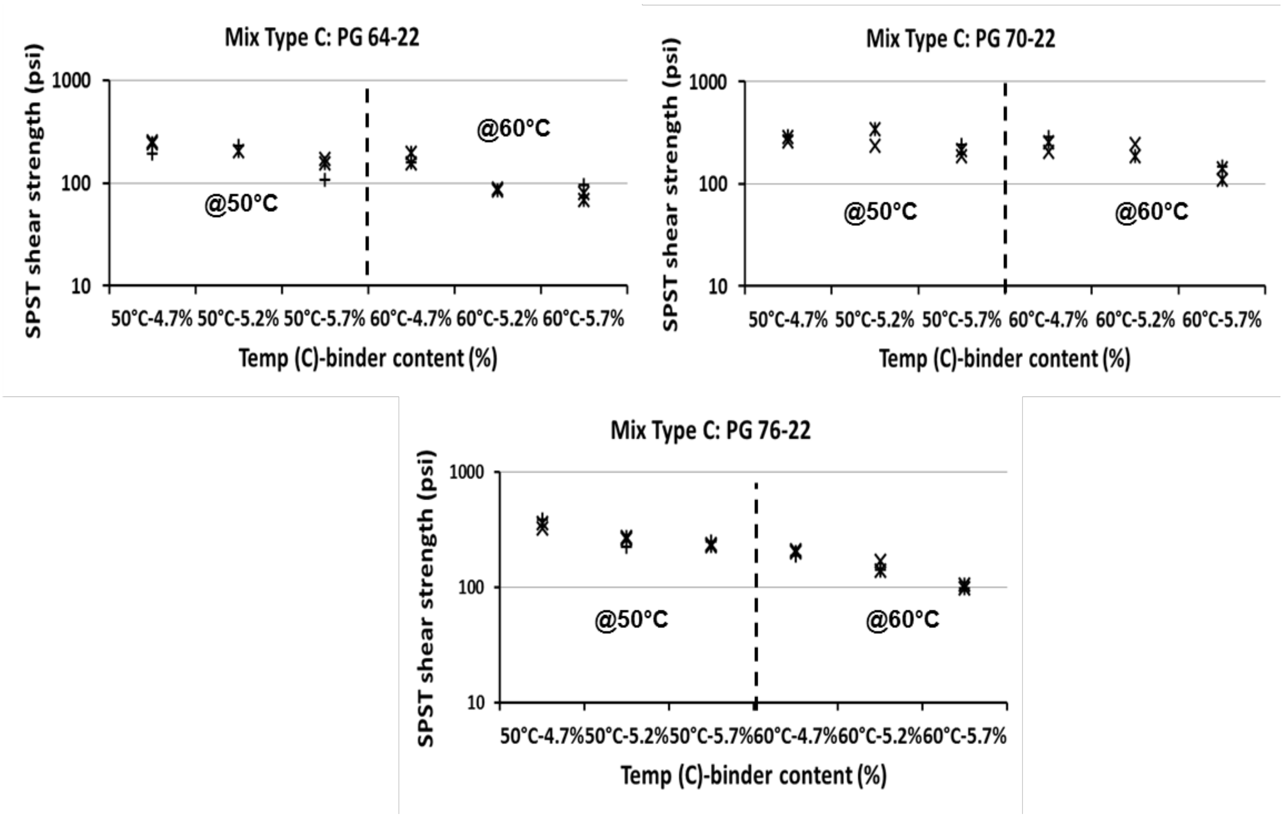


Figure 6. SPST Shear Strength versus Asphalt-Binder Content 5.2±0.5 Percent at 50 and 60°C.

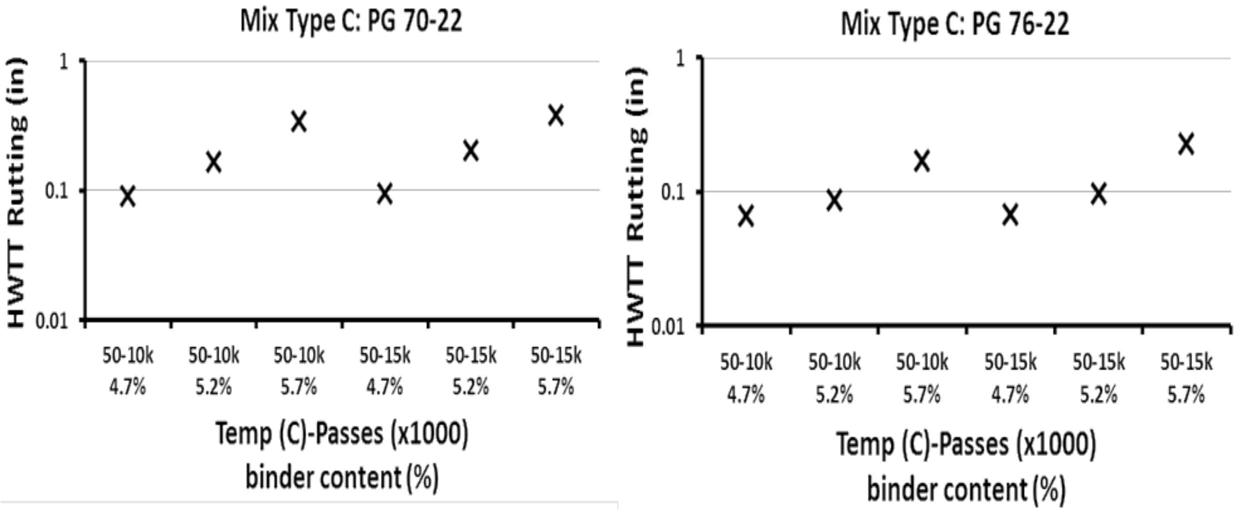


Figure 7. HWTT Rutting versus Asphalt-Binder Content 5.2±0.5 Percent at 50°C.

Asphalt-Binder Type/Grade

To assess the sensitivity of the asphalt binder types to the SPST and HWTT, the test was performed using three asphalt PG grades, including PG 64-22, PG 70-22, and PG 76-22. Also, three mixes were molded with different binder contents (4.7, 5.2, and 5.7 percent) to assess the correlation with the asphalt contents. As theoretically expected, increasing asphalt-binder grade (i.e., changing from PG 64-22 to PG 76-22) has a positive (increasing) effect on the HMA shear strength of the SPST at different asphalt-binder contents, as shown in Figure 8. Likewise, the rut depth from the HWTT tests reduced with increasing asphalt-binder PG as shown in Figure 9. Generally, higher asphalt-binder PG is more resistant to rutting and shear failure.

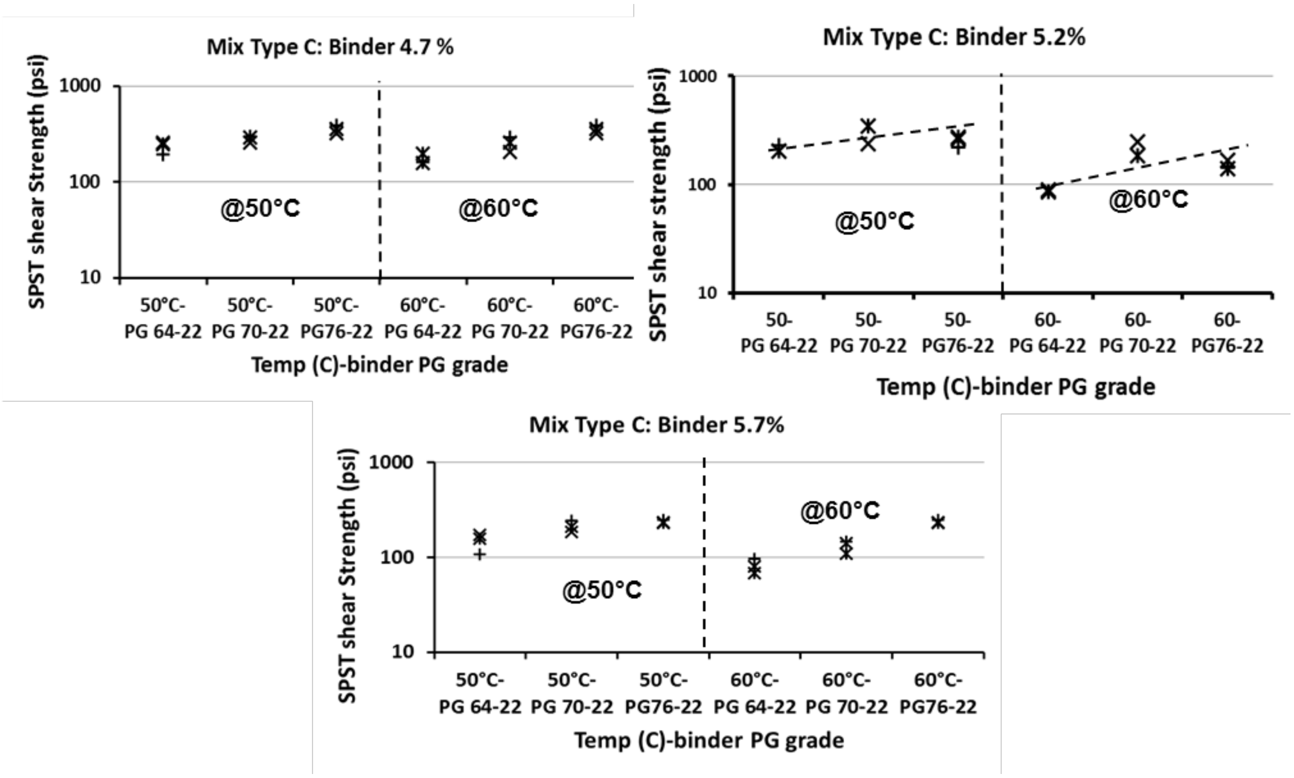


Figure 8. SPST Shear Strength versus Asphalt-Binder Grade at 5.2±0.5 Percent AC.

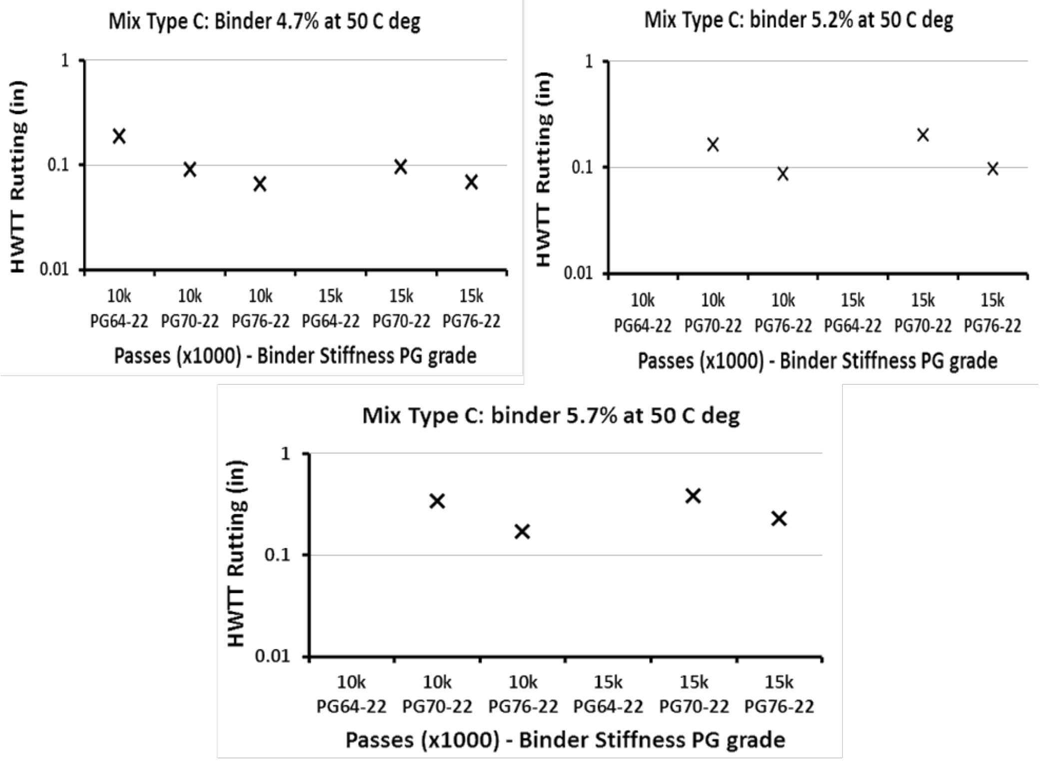


Figure 9. HWTT Rutting versus Asphalt-Binder Grade at 5.2±0.5 Percent AC.

RAP Contents

Most Texas mixes have a cap for RAP percentage of 20 percent. However, this study comparatively evaluated HMA mixes at three RAP contents including 15, 20, and 25 percent (i.e., 20±5 percent) to assess the sensitivity of SPST on the RAP contents in HMA mixes. The test results have indicated that HMA shear strength and rutting resistance improved with increased RAP content as would be theoretically expected (Figure 10). However, for the HWTT testing, most of the HMA mixes with RAP were prematurely failed, especially at higher temperatures.

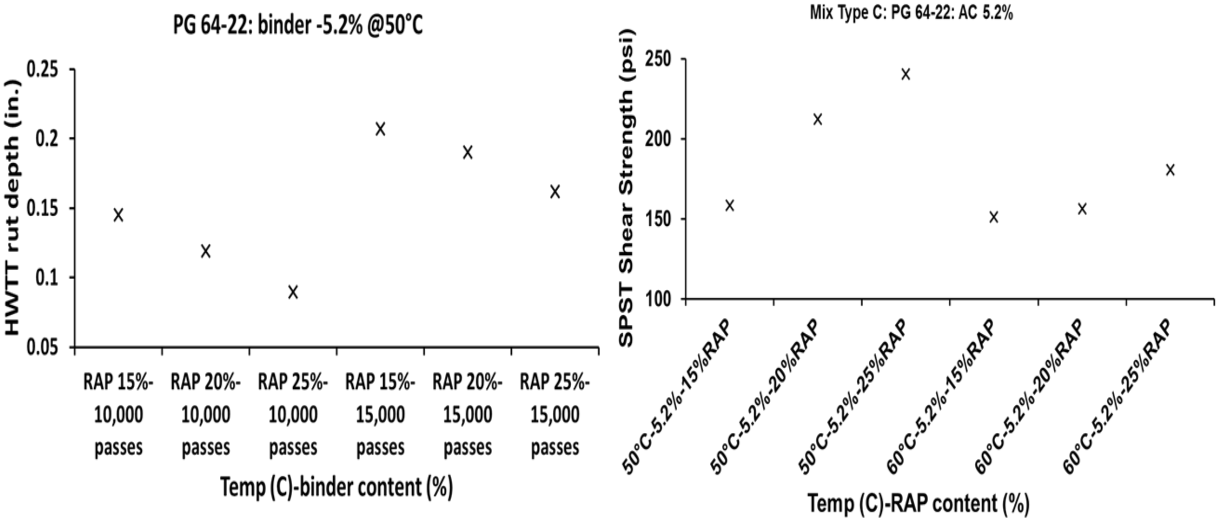


Figure 10. RAP Content versus HWTT Rutting and SPST shear strength at 50°C

CORRELATION AND VALIDATION OF THE TEST PROCEDURES

In addition to the sensitivity analysis of SPST on the HMA mix-design variables and test temperatures, other characteristics of SPST as simplicity, dependability, and reliability were also comparatively evaluated to assess the validity and correlate the SPST to the traditional HWTT test. The SPST-HWTT correlation is further discussed in the subsequent. The SPST test is proven to be relatively simple, practical, cost-effective, and time efficient. The SPST takes less than 20 minutes to complete a single test, whereas the HWTT takes up to 7 hours to complete a single test. Thus, multiple HMA mixes or mix-design variables can be evaluated with the SPST in a single day, which is very ideal for daily routine HMA mix-design and mix screening for shear strength and rutting mitigation.

Researchers found out that HWTT results were interpretable at the standard test temperature of 50°C (Figure). Nevertheless, at the elevated temperature (60°C) and a higher number of wheel passes, the HWTT could not adequately determine the rutting depths, as most of the HMA specimens failed or collapsed prematurely as shown in Figure . Figure exemplifies irregular HWTT response plot with moisture damage and stripping at an early stage (less than 3,000 wheel passes) at 60°C. Due to the irregular pattern, the number of HWTT load passes to failure were overstated (projected 4,000 passes < recorded 5,000 passes at cut off point), which suggests that corrections are needed for the HWTT at elevated temperatures (at 60°C and above). The correction procedure is discussed in subsequent chapters, including the modified HWTT protocol. On the other hand, the SPST could satisfactorily yield interpretable results at both test temperatures.

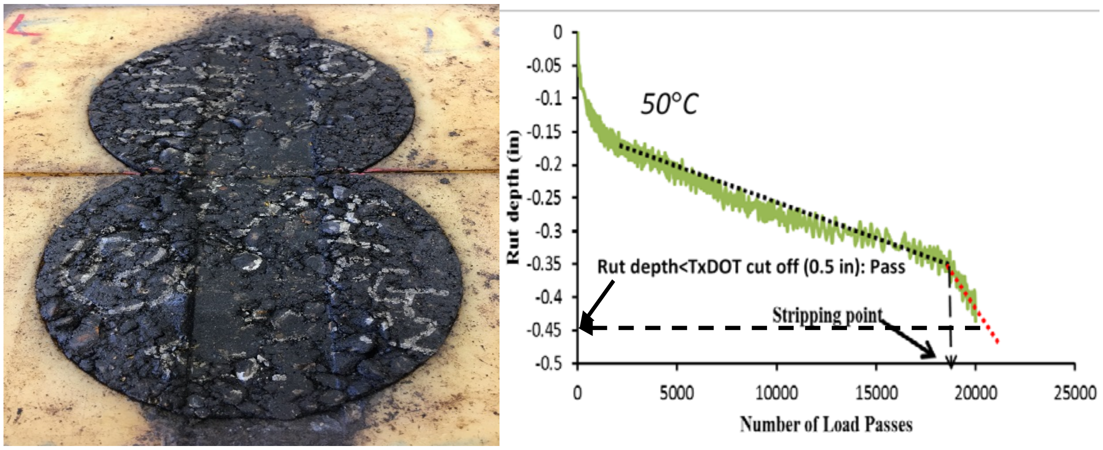


Figure 11. Example of Typical HWTT Response at 50°C.

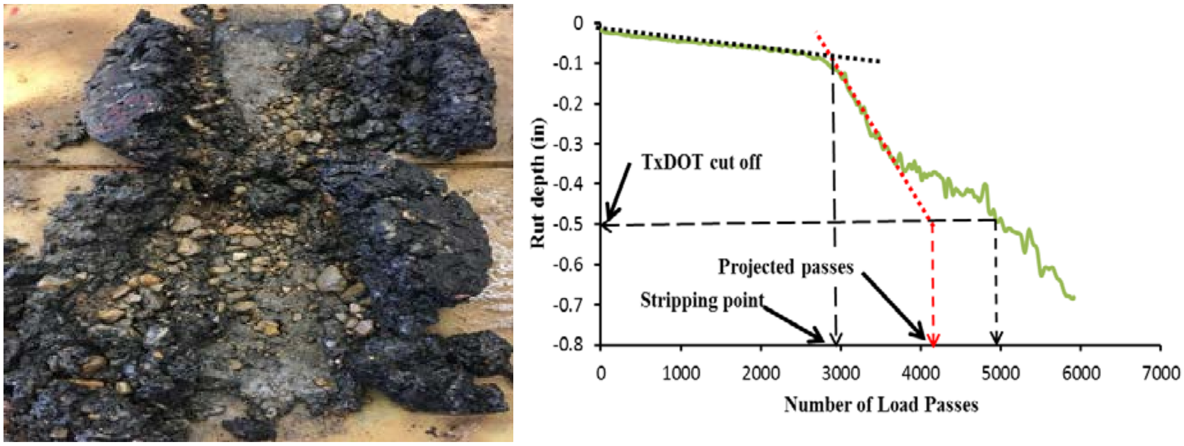


Figure 12. Example of HWTT Response and Premature Specimen Failure at 60°C.

Based on the standardized three replicate samples tested for different HMA mixes, mix-design variables, and test temperatures, researchers determined the coefficient of variation (CV) to measure repeatability and variability of SPST. In this study, a CV of 30 percent (i.e., CV ≤ 30 percent) was used as a threshold measure of repeatability and variability (Walubita et al., 2014c). As shown in Table 5, the CV values of SPST ranges from 1 percent and 21 percent, which is evident that the SPST produces fairly repeatable test results marked by the CV values that are well within the 30 percent threshold.

Table 5. SPST Test Results.

Mix	**SPST Shear Strength Results**									
	50°C					**60°C**				
	1	**2**	**3**	**AVG**	**CV**	**1**	**2**	**3**	**AVG**	**CV**
Type C (FM 1887)	296	349	351	332	8%	213	224	244	227	6%
Type D (FM 2100)	222	223	188	211	8%	217	217	187	207	7%
Type B (APT)	304	296		300	1%	223	229	235	229	2%
Type C (SH304)	261	244	278	261	5%	207	224	214	215	3%
Type C/ PG64-22/4.7%	255	244	193	231	12%	158	198	161	172	11%
Type C/ PG64-22/5.2%		204	231	217	6%	89	86		87	2%
Type C/ PG64-22/5.7%	173	157	107	146	19%	80	68	96	81	14%
Type C/ PG70-22/4.7%	259	289	294	281	5%	207	256	289	251	13%
Type C/ PG70-22/5.2%	236	345		291	19%	245	185		215	14%
Type C/ PG70-22/5.7%	185	212	241	213	11%	141	110	147	133	12%
Type C/ PG76-22/4.7%	324	356	383	355	7%	207	202	186	198	4%
Type C/ PG76-22/5.2%	313	308	292	304	3%	228	239	142	203	21%
Type C/ PG76-22/5.7%	234	229	248	237	3%	97	104	98	100	3%
Type D/PG64-22/4.5%/ Chico	189	266	268	241	15%	270	234	238	247	6%
Type D/PG64-22/5%/ Chico	185	213	212	203	6%	200	197	170	189	7%
Type D/PG64-22/5.5%/ Chico	162	150	158	157	3%	-	-	-	-	-
Type D/PG70-22/4.5%/ Chico	265	240	271	259	5%	200	228	247	225	9%
Type D/PG70-22/5%/ Chico	203	228	239	223	7%	184	208	223	205	8%
Type D/PG70-22/5.5%/ Chico	196	200	203	200	1%	151	176	184	170	8%
Rap/ PG 64-22/15%/ Laredo	152	166		159	5%	149	152	153	151	1%
Rap/ PG 64-22/20%/ Laredo	295	226	199	240	17%	157	138		147	6%
Rap/ PG 64-22/25%/ Laredo	239	243		241	1%	160	183	199	181	9%
Type D/PG76-22/4.5%/Chico	303	280	318	300	5%	272	300	272	281	5%
Type D/PG76-22/5%/Chico	296	302	306	301	1%	180	268	239	229	16%
Type D/PG76-22/5.5% /Chico	198	253	220	224	10%	219	200	163	194	12%

CORRELATION BETWEEN HMA SHEAR AND RUTTING PROPERTIES

In this study, the SPST shear parameters were comparatively evaluated with the rutting properties obtained from the HWTT. The primary output results obtained from the SPST is the shear L-D curve and the routine HMA shear properties including HMA shear strength (τ), shear strain (γ), and shear modulus (*G*). Each shear parameter can be determined using the following equations:

$$\tau = \frac{\text{Peak load}}{\text{x-area}} \quad [1]$$

$$\gamma = \frac{\text{Displacement @ Peak load}}{\text{Sample thickness}} \quad [2]$$

$$G = \frac{\tau}{\gamma} \quad [3]$$

Plant-Produced HMA Mixes

At first, researchers performed correlation between properties obtained from SPST and HWTT using the plant-mixed HMA and realized that the shear strength of the SPST has a relatively good relationship with the HWTT rut depth as compared to the other two shear parameters (shear modulus and shear strain). As shown in Figure , for correlation with HWTT rutting depth, a coefficient of determination (R^2) of 85 percent was observed with the shear strength, whereas an R^2 value as poor as 5.0 percent was observed with the shear strains. With exception of shear strain, both SPST shear strength and shear modulus relationship to HWTT rut depths follows a power law as illustrated in Figure .

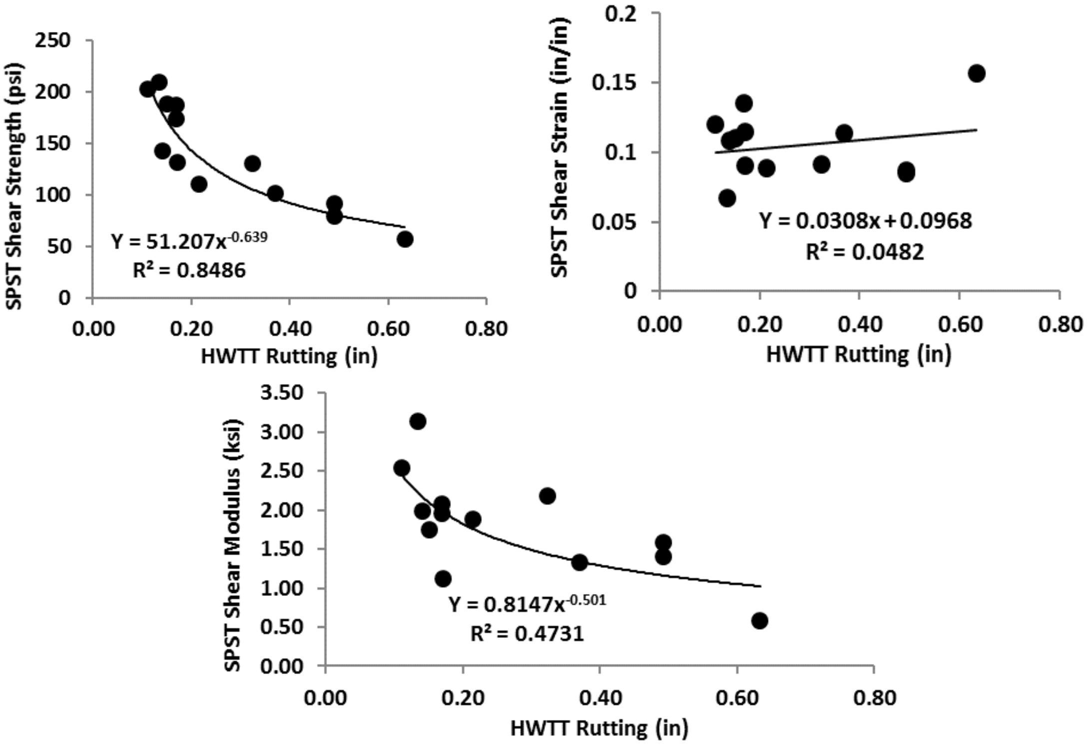


Figure 13. SPST Shear Parameters versus HWTT Rutting.

Lab-Prepared HMA Mixes

The correlations were performed using the laboratory-prepared HMA mixes. The results showed that the shear strength correlates better with HWTT rutting. The relationship between the SPST shear strength and HWTT rut depth follows a power law with an R^2 of 63 percent and 54 percent for 10,000 and 15,000 load passes, respectively, as presented in Figure . Note that since most HWTT specimens tested at 60°C failed prematurely, only useful data obtained at 50°C were compared to the SPST shear strength.

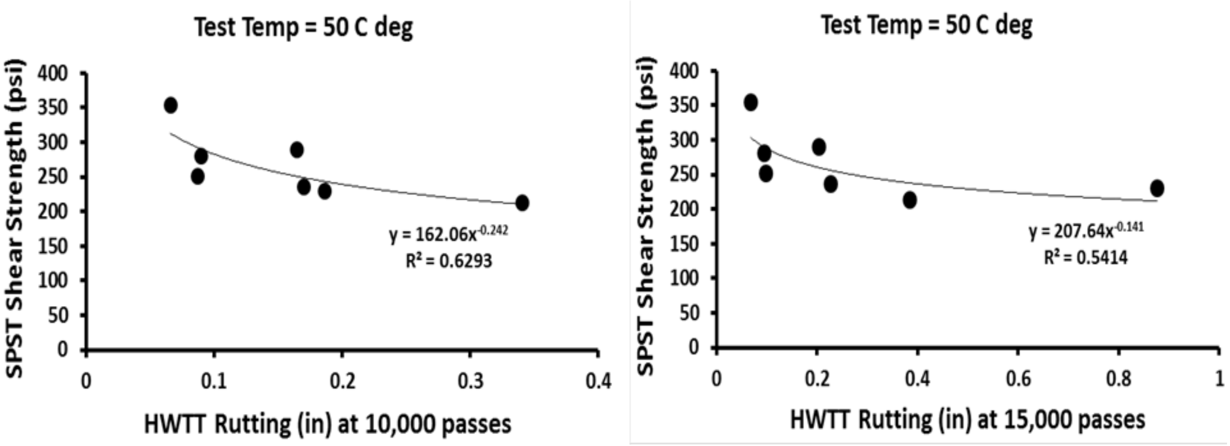


Figure 14. SPST Shear Strength and HWTT Rutting at Different HWTT Load Passes.

SUMMARY

In this chapter, the SPST and HWTT tests were comparatively evaluated using plant-produced and lab-mixed HMA specimens at 50 and 60°C test temperatures. Also, the study evaluated SPST sensitivity to different HMA mix-design variables and assessed its validity against the HWTT test method. For the HMA mixes, mix-design variables, and test conditions considered, the test results and key findings have indicated a good performance-predictive correlation between HMA shear strength (SPST) and rut depth (HWTT). Moreover, the study indicated that to characterize HWTT rutting at higher temperatures (i.e., 60°C), the HWTT procedure needs modifications to avoid over/understating the results. As theoretically expected, the test results also showed that the HMA shear strength of SPST is lower at the standard test temperature (50°C) than the elevated temperature (60°C). Overall, the findings indicate that balancing and optimizing the mix-design variables with consideration of field temperature conditions is imperative to ensure adequate HMA shear strength and satisfactory performance.

CHAPTER 5. VALIDATION OF THE SPST METHOD

This chapter mainly discusses the relationship between field rutting and the SPST-HMA shear properties. Furthermore, the work in this chapter validates the SPST criteria for rutting. In total, nine field test sections were monitored and evaluated for validating the SPST alongside the traditional HWTT.

IN-SERVICE FIELD TEST SECTIONS

In total, nine field test sections were evaluated and monitored for SPST validation. Although the initial project target was five test sections, five in-service field highway test sections were added to have more data points for optimal SPST validation. Table 6 lists the test sections used for the SPST validation.

Table 6. In-Service Field Highway Test Sections.

Hwy	PVMNT Type	Mix Type	Date of Construction	Climatic Region	Max PVMNT Temp.	AADTT
US 59	Overlay-HMA-LTB	Type D	Apr 2011	Wet-Cold	135.5 °F	1502
LP 480	New Construction	Type C	Jun 2012	Dry-Warm	145.5 °F	60
SH 121	Overlay-HMA-CTB	CAM	Oct 2011	Wet-Cold	137.5 °F	468
SH 21	Overlay-HMA-FB	Type C	Jul 2012	Wet-Warm	127.5 °F	560
IH 35	New Construction	Type B	Oct 2011	Moderate	131.3 °F	53
US 83	Overlay-HMA-PCC	Type C	Aug 2012	Wet-Cold	104.43 °F	110.2
US 271	Overlay-HMA-FlexBase	Type F	Nov 2011	Wet-Cold	77 °F	417.5
SH 44	Overlay-HMA-FlexBase	Type D	Jun 2014	Moderate	87.17 °F	342.01
SH 304	New Construction	Type C	Oct 2014	Moderate	93.67 °F	208.6

Note: AADTT = average annual daily truck traffic; CAM = cracking attenuating mixture; CTB = cement treated base; FB = flexible base; Hwy = highway; LTB = lime treated base; PVMNT = pavement;

SPST-HMA SHEAR PROPERTIES AND FIELD RUTTING PERFORMANCE

Figure shows the SPST L-D response curves for the HMA materials of the nine field test sectionsFigure 15.. Laboratory testing was performed at 50°C for validation and analysis of the SPST in a temperature-controlled chamber using the universal testing machine.

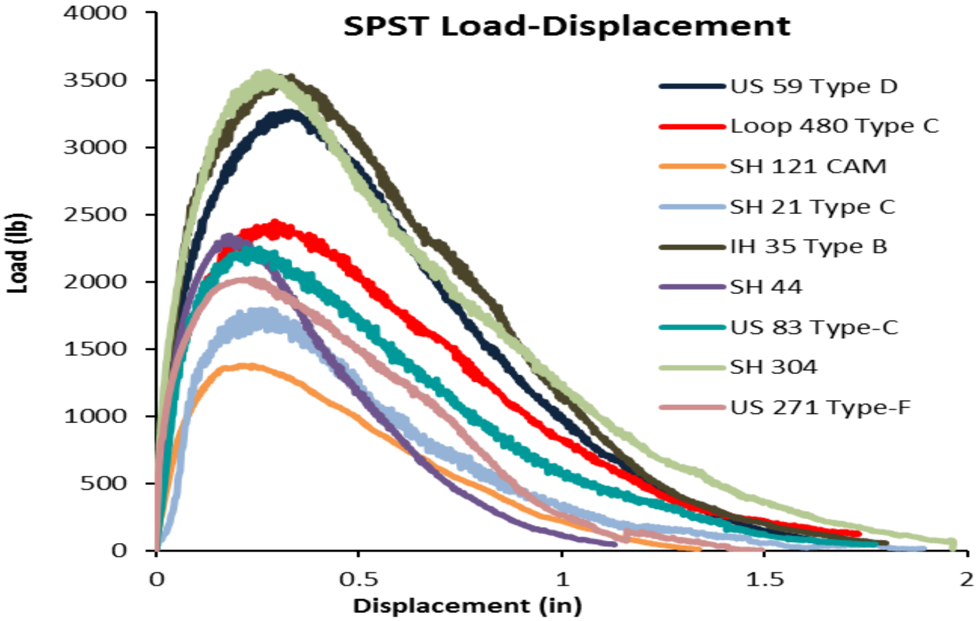


Figure 15. SPST L-D for HMA Mixes of Test Sections.

The shear strength derived from the SPST was statistically compared to field rutting to validate its applicability. Note that the field rut depths were measured at the pavement surface, which includes total rutting of all the pavement layers. However, the SPST validation requires only the rutting performance of the surface layers. Therefore, in here, the Texas Mechanistic-Empirical (TxME) pavement thickness design software was used to determine the conversion factors used to estimate the rut depth of the HMA surface layers. Table 7 shows the conversion factors, field, and estimated HMA surface layer rutting. The results show that currently none of the field sections surpassed the terminal rutting of 0.5 inches.

Table 7. Field HMA Rutting of Test Sections.

Highway	Mix Type	SPST Shear Strength (psi)	Measured Total Rut Depth (in.)	Conversion Factors from TxME	Estimated Surface Layer Rut Depth (in.)
US 59	Type D	420	0.20	0.190	0.04
LP 480	Type C	321	0.18	0.022	0.03
SH 121	CAM	178	0.11	0.818	0.09
SH 304	Type C	456	0.02	0.400	0.01
SH 21	Type C	228	0.13	0.692	0.09
IH 35	Type B	453	0.07	0.286	0.02
SH 44	Type D	292	0.13	0.615	0.08
US 271	Type F	257	0.03	1.000	0.03

CORRELATION OF FIELD RUTTING VERSUS THE SPST SHEAR STRENGTH

Figure 16 shows the correlation of the SPST shear strength and the rutting performance of the HMA surface layers based on the latest field measurements. Figure 16 also shows that the rut depths of the HMA surface layer versus the SPST shear strength for each test section have a fairly good correlation, which is represented by a power function. The correlation shows that surface rutting reduced for HMA mixtures with higher SPST shear strength as theoretically expected.

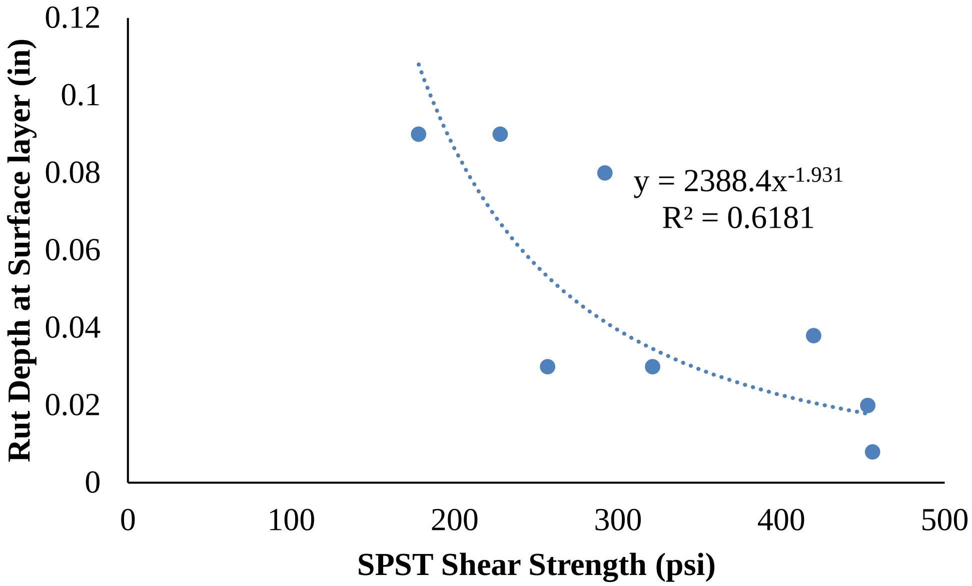


Figure 16. SPST Shear Strength versus Field Rutting.

SPST RUTTING CRITERIA

Based on project 0-6744 findings, the proposed SPST pass-fail screening criteria for HMA mixes at 50°C (122°F) was tentatively set at shear strength (τ) $\geq$ 300 psi (2.07 MPa) (Walubita et al., 2014c). In this report, a comparison of rutting of HMA mixes under the laboratory HWTT test and the associated SPST shear strength was performed. The mixes used for the analysis included two HMA mixes from SH 121 and US 271. The rest of the HMA mixes from the selected field test sections in Table 7 did not fail under the HWTT rutting test.

Researchers added laboratory prepared Type C and D mixes typically used for Laredo and Chico (Wise County), respectively. As shown in Figure 17, the minimum HMA shear strength failure criterion falls at around 320 psi for 50°C (122°F) test temperature. The estimate is based on the R^2 value of about 66 percent, which is a good number, given that there are numerous variables that affect rutting, especially in the field.

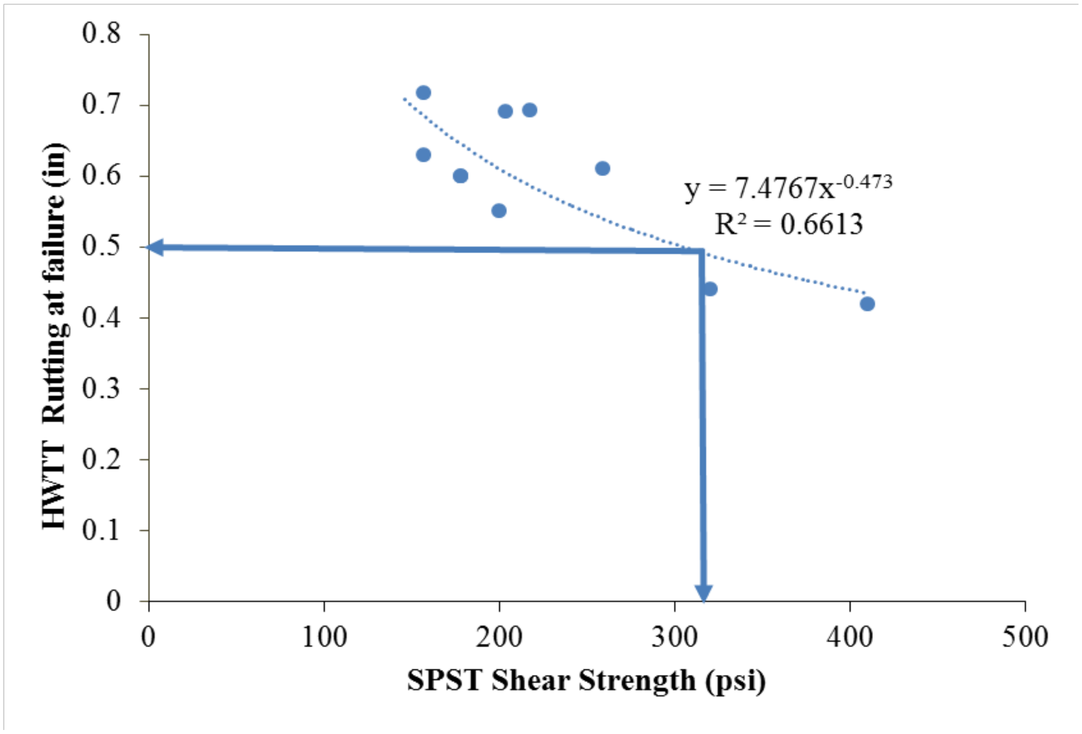


Figure 17. SPST Shear Strength versus HWTT Rutting at Failure.

A poor correlation value (R^2 = 34 percent) was observed for tests performed at HWTT 60°C, since most HMA mixes fail prematurely at the elevated temperature as was explained earlier in this report (Figure 18). About 50 percent of the tested mixes failed at or below 5,000-wheel passes. The early stripping due to high-temperature water bath was the major source of the problem. Nevertheless, researchers critically assessed the tests data and found that a few mixes sustained at the high temperatures are of PG 76 binder mix design. Table 8 shows some HMA mixes that passed HWTT criteria (rut < 0.5 in.) at 50°C and 60°C and their corresponding shear strength to substantiate the proposed SPST screening criteria. The mixes identified have minimum shear strength of about 200 psi at 60°C. Likewise, the HMA mixes show minimum shear strength of about 300 psi at 50°C.

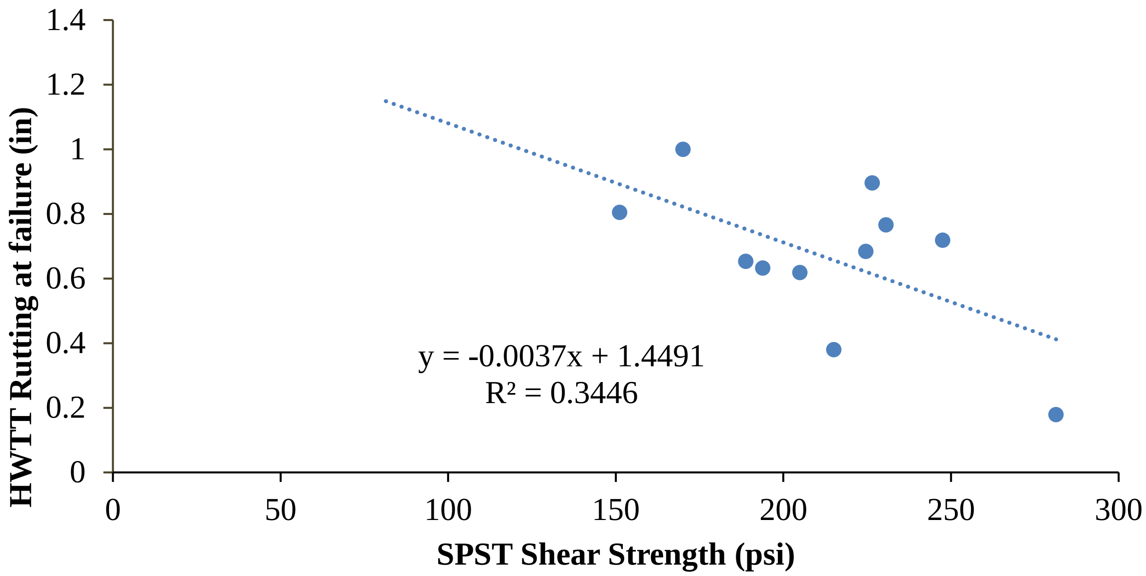


Figure 18. SPST Shear Strength versus HWTT Rutting at Failure.

Table 8. Example HWTT (Rutting) and SPST (Shear Strength) Results.

HMA Mixes	HWTT Rut (in.)		SPST Shear Strength (psi)	
	at 50°C	at 60°C	at 50°C	at 60°C
Type C/PG 76-22/4.7% AC/Laredo	0.07	0.20	354.71	198.40
Type C/PG 76-22/5.2% AC/Laredo	0.105	0.44	304.29	203.06
Type D/PG 76-22/4.5% AC/Chico	0.07	0.18	300.41	281.33
Type C (SH 304)	0.10	0.39	311.10	215.01
Type D/PG 76-22/5% AC/Chico	0.12	0.23	300.98	228.94
Type B/APT site/Arlington	0.18	0.48	300.18	226.52
Laboratory screening criteria	≤ 0.50	≤ 0.50	≥ 300	≥ 200

AC = Asphalt-binder content

SUMMARY

This chapter covered research works that included field validation of the SPST method alongside the HWTT. In addition, the chapter validated the SPST selection criteria based on the data collected in the field and laboratory. Overall at this point, the SPST method can be a good supplement of HWTT method especially at higher temperatures where the HWTT test results seem to be doubtful.

CHAPTER 6. SPECIFICATION MODIFICATION AND IMPROVEMENTS

This chapter summarizes the modification of the HWTT test procedure (Tex-242-F) to improve its ability to simulate the current prevailing field rutting conditions. As well, the SPST procedure developed in TxDOT project 0-6744 was improved and modified for predicting the HMA field rutting/shear performance as a supplement or surrogate to the HWTT. The modifications of HWTT and SPST test procedures were based on the findings through this project summarized in the preceding chapters.

PROPOSED MODIFICATION OF THE HWTT PROCEDURE

Since one of major issues of the HMA pavements in Texas is increasing air and pavement temperatures, researchers focused on the assessment of the HMA rutting criteria at the elevated temperature (i.e., 60°C). Thus, an alternated analysis procedure of HWTT data obtained at the elevated temperature was mainly proposed in the modification of the current HWTT test procedure (Tex-242-E). Appendix C presents the draft of the proposed HWTT test procedure. The proposed modifications are discussed below:

- During the HWTT sensitivity evaluation, most HMA specimens failed rapidly when subjected to the elevated temperatures (60°C). On the other hand, the HMA specimens using asphalt-binder PG 76 are sustained at the HWTT temperature of 60°C without premature failure. Based on this observation/finding, it was recommended that HMA mix with less than PG 76 may be subjected to HWTT testing at 60°C only for the evaluation of moisture damage and stripping. Nevertheless, all rutting data from specimens survived at the HWTT testing should be evaluated to determine if adjustments are needed as explained in Section 6.5 of the proposed HWTT test procedure.
- In case of doubtful results obtained from the HWTT testing that the slope of the HWTT plot after the stripping point subdivides itself into more than one, the number of HWTT load passes to failure may be overstated. To establish the actual load passes corresponding to the recommended TxDOT rut cut-off point, the slope after stripping point should be extended to intersect a horizontal line from 0.5 in. (12.5 mm). From the intersection of the two lines, draw a vertical line to touch the horizontal axis and establish the new load passes corresponding to failure point, as illustrated in Figure 19. The

adjustment procedure is presented in Note 13 of the proposed HWTT test procedure (Appendix B).

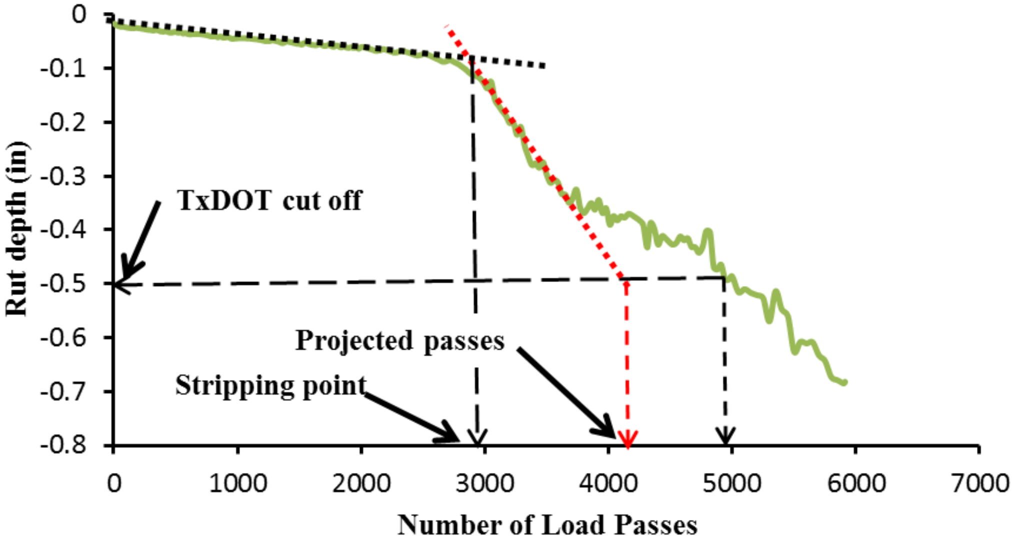


Figure 19. Typical HWTT Responses at 60°C.

ENHANCEMENTS TO THE DRAFT SPST TEST PROCEDURE

A draft SPST test procedure was developed and proposed through TxDOT project 0-6744. In this implementation project, the draft test procedure was modified and improved based on the extensive laboratory tests, sensitivity evaluation, field validation, and comparative analysis of lab and field data. Appendix D presents the draft of the improved SPST test procedure. The critical modifications are discussed below:

- The major outputs of the SPST are HMA shear strength, shear strain, shear modulus, shear strain energy, and shear strain energy index. Of all these SPST shear parameters, only shear strength and shear strain energy index were found to have a good correlation with field rutting and HWTT testing. The two parameters are dependent of each other since the shear strain energy index is a derivative of the shear strength. That is, if shear strength is acceptable, the shear strength energy is also acceptable. However, the HMA shear strength is the most practical parameter for TxDOT engineers to evaluate and screen the HMA mixes since it is simple to be calculated using the test output.
- Following a series of the sensitivity analysis and validations of SPST shear parameters to HMA rutting parameters and field performance of selected test sections, researchers

proposed a screening criterion for HMA shear resistance properties at the standard and elevated temperatures (50°C and 60°C, respectively) as follows:

$$HMA\ shear\ strength\ (\tau) \geq \begin{cases} 300\ psi\ at\ 50℃ \\ 200\ psi\ at\ 60℃ \end{cases}$$

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

The rutting or permanent deformation is one of the typical distresses occurring on the flexible pavement. The distress is a failure mode of concerns, particularly under heavy traffic loading, high-temperature climate, and severe shear stress conditions such as highway intersections and urban stop-go sections, or where lower PG has been used. Recently, Texas has experienced an increased heavy truck traffic volume due to improved economic activities such as the energy industry. Also, with the record summer temperatures in recent years, several rutting failures have occurred with HMA mixes that had passed the HWTT. In the TxDOT project 0-6744, several key modifications to the HWTT test procedure were proposed to simulate the field rutting condition under extreme shear environments at the elevated temperature (60°C). Also, the SPST procedure was developed as a supplement and surrogate to the HWTT for shear strength evaluation of HMA mixes.

This study was undertaken to conduct a pilot implementation of the findings of project 0-6744 findings through verifying and refining the proposed HWTT and SPST test procedures with extensive lab testing and field performance data from in-service highway test sections. This chapter summarizes the overall findings and conclusions drawn from this study.

HMA PARALLEL SPST-HWTT TESTING AND SENSITIVITY ANALYSIS

The parallel SPST and HWTT testing were conducted to evaluate the SPST sensitivity to HMA mix-design variables and correlate the SPST procedure to the HWTT at both standard and elevated test temperatures (i.e. 50°C and 60°C). The key findings are listed below:

- Increased asphalt-binder content has a negative effect on the HMA shear strength determined from SPST testing. The HMA shear strength at the standard temperature (50°C) is higher than one at the elevated temperature (60°C) at the same asphalt-binder content. Likewise, the HMA rut depth from the HWTT tests increased with increasing asphalt-binder content as expected.
- Increased asphalt-binder grade that was changed from PG 64-22 to PG 76-22 resulted in increasing HMA shear strength of the SPST at different asphalt-binder contents. Likewise, the rut depth from the HWTT tests reduced with increasing asphalt-binder PG.

- Three HMA mixes with different RAP contents (15, 20, and 25 percent) were evaluated to assess the sensitivity. The SPST shear strength was improved with increased RAP contents while most of the HMA mixes with RAP were prematurely failed for the HWTT testing.
- While the SPST could satisfactorily yield interpretable results at both 50°C and 60°C test temperatures, the HWTT test could not adequately determine the rutting depths at the elevated temperature (60°C). Most of HWTT HMA specimens failed or collapsed prematurely, and irregular HWTT response plots were obtained with moisture damage and stripping at early stage (less than 3,000-wheel passes) at 60°C. It is suspected that the elevated temperatures of HWTT water bath have triggered early moisture damage and stripping, which led to premature failure of the HMA specimens and irregular rutting patterns.
- The SPST produces fairly repeatable test results marked by the CV values that are well within the 30 percent threshold.
- From the correlation between properties obtained from SPST and HWTT using the plant-mixed HMA, the shear strength of the SPST has a relatively good relationship with the HWTT rut depth as compared to the other two shear parameters (shear modulus and shear strain). With HWTT rutting depth, an R^2 of 85 percent was observed with the shear strength, whereas an R^2 value as poor as 5 percent was observed with the shear strains.
- With the test results using the lab-mixed HMA samples, the correlations between the SPST shear strength and HWTT rut depth follow a power law with an R^2 of 63 percent and 54 percent for 10,000 and 15,000 load passes, respectively.

VALIDATION OF SPST WITH FIELD DATA

The shear strength derived from the SPST was statistically compared to field rutting to validate its test procedure and applicability, and the findings can be summarized as follows:

- The validation was performed using nine highway test sections determined by pavement type, surface HMA mix, climate, and traffic volume. The field performance data were collected periodically, including rutting depths. The TxME software was used to estimate the field rutting contribution of the relevant HMA layer from the total surface rut depth measured from field survey.

- The SPST shear strength versus the rut depths of corresponding HMA surface layer for each test section have a fairly good correlation, which is represented by a power function. The correlation shows that surface rutting reduced for HMA mixtures with higher SPST shear strength as theoretically expected.

SPECIFICATION MODIFICATION AND IMPROVEMENT

Based on the findings through this project, the current HWTT test procedure was modified to improve the ability to simulate the current prevailing field rutting conditions. Moreover, the SPST procedure developed in TxDOT project 0-6744 was modified to improve and modify for predicting well the HMA field rutting/shear performance as a supplement or surrogate to the HWTT. The works can be summarized as follows:

- It was recommended that HMA with less than PG 76 may be subjected to HWTT testing at 60°C only for the evaluation of moisture damage and stripping. Nevertheless, all rutting data from specimens that survived the HWTT should be evaluated to determine if adjustments are needed (Section 6.5 in Appendix B).
- When the slope of HWTT plot after the stripping point subdivides itself into more than one, the slope after stripping point should be extended to intersect a horizontal line from 0.5 in. to establish the actual load passes corresponding to the recommended rut cut-off point. From the intersection of the two lines, draw a vertical line to touch the horizontal axis and establish the new load passes corresponding to the failure point (Note 13 in Appendix B).
- Of all these SPST shear parameters, the shear strength was found to have good correlations with the field performance and HWTT testing data. Also, this parameter is the most practical for engineers to evaluate HMA mixes.
- Based on the sensitivity analysis and field validations of SPST parameters using HMA testing and field performance data, the following screening criteria for HMA shear resistance properties at 50°C and 60°C are recommended:

$$HMA\ shear\ strength\ (\tau) \geq \begin{cases} 300\ psi\ at\ 50℃ \\ 200\ psi\ at\ 60℃ \end{cases}$$

REFERENCES

American Association of State Highway Transportation Officials – AASHTO (2001). *AASHTO PP2: Practice for Short and Long Term Mixture Conditioning of Hot Mix Asphalt* (HMA). AASHTO, Washington, D.C.

Brown, Angela K. (2016). "Record Heat Scorches Texas." ABC News, Fort Worth, Texas. http://abcnews.go.com/US/story?id=95877&page=1, Accessed July 2017.

ASTM Standard D2726 - 17, *Standard Test Method for Bulk Specific Gravity and Density of Non-Absorptive Compacted Asphalt Mixtures*, ASTM International, West Conshohocken, PA, 2017.

Brown, E. R., Kandhal, P. S., and Zhang, J. (2001), *Performance Testing for Hot Mix Asphalt*, National Center for Asphalt Technology, NCAT Report 01-05, Auburn, Alabama.

Quiroga C.A., Fernando E.G., Oh J.H. (2012). *Energy Developments and the Transportation Infrastructure in Texas: Impacts and Strategies.* Report 0-6498-1. Texas A&M Transportation Institute, College Station, Texas.

Texas Department of Transportation (2014). *Test Procedure for Hamburg Wheel-Tracking Test*. TxDOT Designation: Tex-242-F, TxDOT, Austin, Texas.

Texas Department of Transportation (2015). *Superpave Gyratory Compacting of Test Specimens of Bituminous Materials*: Tex-241-F, TxDOT, Austin, Texas.

Texas Department of Transportation (2017). *Mixture Selection Guide for Flexible Pavements*. ftp://ftp.dot.state.tx.us/pub/txdot-info/des/specs/flexpave.pdf Browsed November 2017.

Texas Department of Transportation. (2005). *Laboratory Method of Mixing Bituminous Mixtures.* TxDOT Designation: Tex-205-F, TxDOT, Austin, Texas

Texas Department of Transportation (2004). *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges*. Texas Department of Transportation. Austin, Texas.

Texas Department of Transportation (2018). *Online Test Procedures (200-F series).* Texas Department of Transportation. Austin, Texas. Accessed August 2018.

Walubita, L. F., Faruk, A. N., and Lee, S. I.,(2014a). *Tech Memo Task 5&6: Development of a Supplementary HMA Rutting-Shear Test and Sensitivity Evaluation – The Simple Punching Shear Test (SPST).* Tech Memo submitted to TxDOT on March 3rd, 2014. Texas A&M Transportation Institute, College Station, TX.

Walubita, L. F., Faruk, A. N., Lee, S. I., Nguyen, D., Hassan, R., and Scullion, T. (2014b). *HMA Shear Resistance, Permanent Deformation, and Rutting Tests for Texas Mixes: Year-1 Report.* Technical Research Report 0-6744-1. Texas A&M Transportation Institute. The Texas A&M University System, College Station, TX.

Walubita, L. F., Faruk, A. N., Lee, S. I., Nguyen, D., Hassan, R., and Scullion, T. (2014c). *HMA Shear Resistance, Permanent Deformation, and Rutting Tests for Texas Mixes: Final Year-2 Report* (No. FHWA/TX-15/0-6744-2). Texas A&M Transportation Institute.

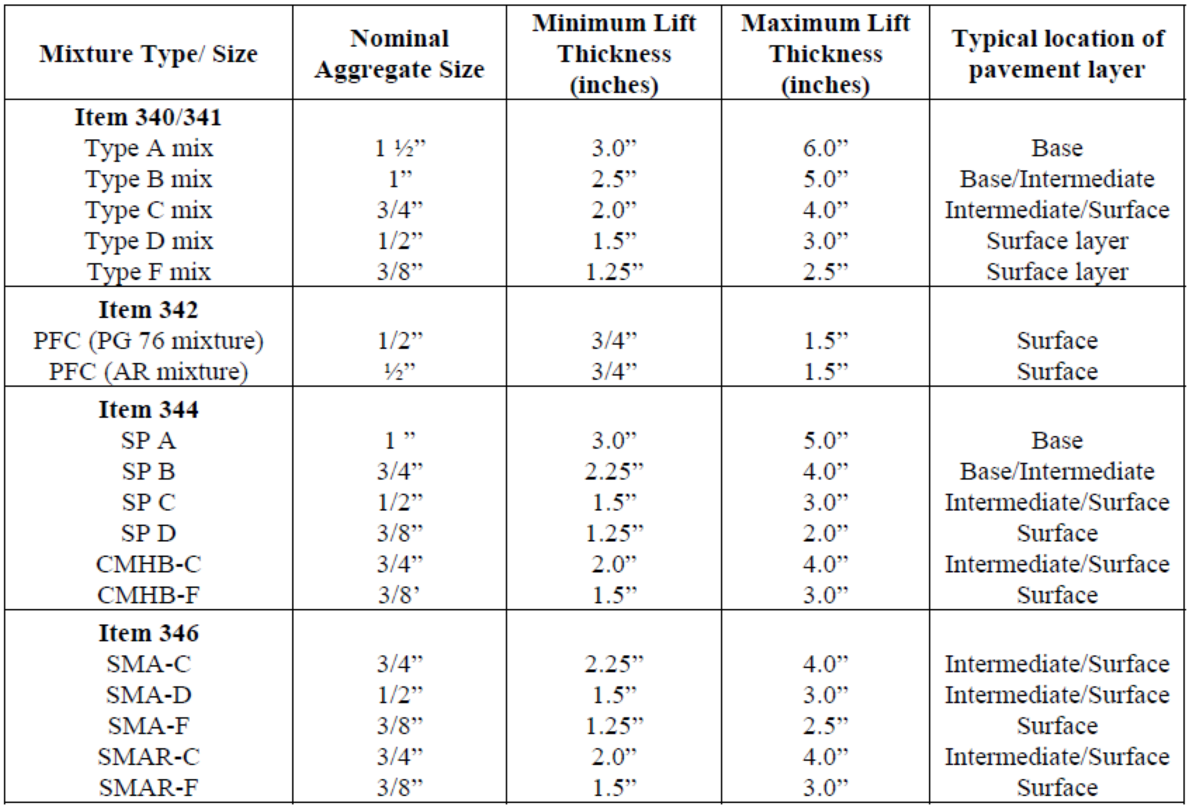
Walubita, L. F., Faruk, A. N., Zhang, J., Hu, X., Lee, S. (2016). *The Hamburg rutting test – Effects of HMA sample sitting time and test temperature variation*. Journal of Construction and Building Materials.

Walubita, L. F., Lee, S. I., Faruk, A. N., Scullion, T., Nazarian, S., and Abdallah, I. (2017). *Texas Flexible Pavements and Overlays: Year 5 Report—Complete Data Documentation* (No. FHWA/TX-15/0-6658-3). Texas A&M Transportation Institute.

Weather Underground. https://www.wunderground.com. Webpage. Browsed July 2018.

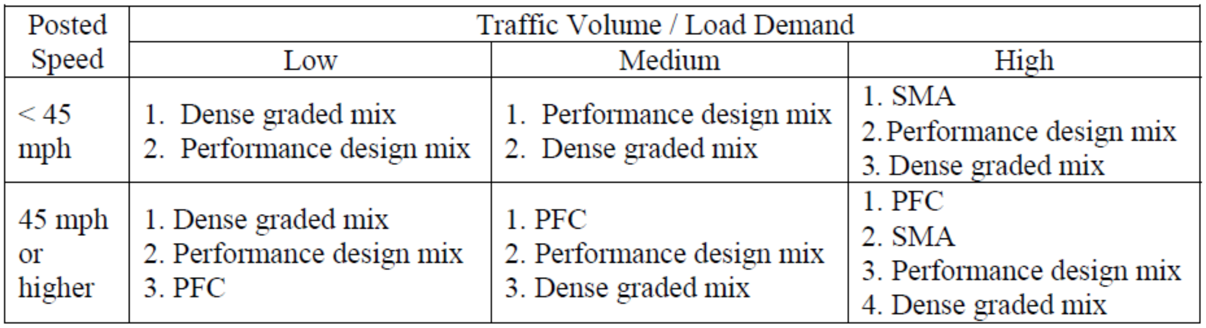
APPENDIX A: TYPICAL TEXAS HMA MIX CHARACTERISTICS

Table A-1. Summary of HMA Mix Types, Sizes, and Uses.



Mixture Type/ Size	Nominal Aggregate Size	Minimum Lift Thickness (inches)	Maximum Lift Thickness (inches)	Typical location of pavement layer
Item 340/341				
Type A mix	1 ½”	3.0”	6.0”	Base
Type B mix	1”	2.5”	5.0”	Base/Intermediate
Type C mix	3/4”	2.0”	4.0”	Intermediate/Surface
Type D mix	1/2”	1.5”	3.0”	Surface layer
Type F mix	3/8”	1.25”	2.5”	Surface layer
Item 342				
PFC (PG 76 mixture)	1/2”	3/4”	1.5”	Surface
PFC (AR mixture)	½”	3/4”	1.5”	Surface
Item 344				
SP A	1 ”	3.0”	5.0”	Base
SP B	3/4”	2.25”	4.0”	Base/Intermediate
SP C	1/2”	1.5”	3.0”	Intermediate/Surface
SP D	3/8”	1.25”	2.0”	Surface
CMHB-C	3/4”	2.0”	4.0”	Intermediate/Surface
CMHB-F	3/8’	1.5”	3.0”	Surface
Item 346				
SMA-C	3/4”	2.25”	4.0”	Intermediate/Surface
SMA-D	1/2”	1.5”	3.0”	Intermediate/Surface
SMA-F	3/8”	1.25”	2.5”	Surface
SMAR-C	3/4”	2.0”	4.0”	Intermediate/Surface
SMAR-F	3/8”	1.5”	3.0”	Surface

Table A-2. Recommended Choices for Surface HMA Mixes.



Posted Speed	Traffic Volume / Load Demand		
	Low	Medium	High
< 45 mph	1. Dense graded mix 2. Performance design mix	1. Performance design mix 2. Dense graded mix	1. SMA 2. Performance design mix 3. Dense graded mix
45 mph or higher	1. Dense graded mix 2. Performance design mix 3. PFC	1. PFC 2. Performance design mix 3. Dense graded mix	1. PFC 2. SMA 3. Performance design mix 4. Dense graded mix

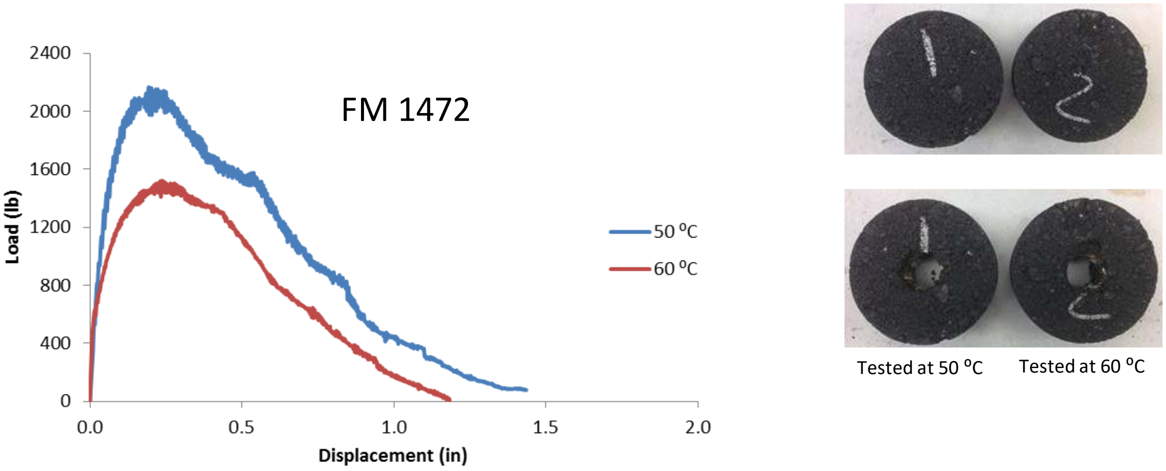
APPENDIX B: EXAMPLE HWTT-SPST TEST RESULTS FOR DISTRICT SUPPORT

Table B-1. Example HWTT-SPST Results for Laredo District HMA Mix-Designs.

Mix ID	Hwy	Mix	HWTT rut depth at LRD lab (mm)		SPST shear strength (psi)	
			@ 10k passes	@ 15k passes	@ 50 ^oC	@ 60 ^oC
LRD-1	Loop 517	Type C	5.14	7.02	247.48	186.87
LRD-2	FM 1472	Type C	5.07	9.74	275.16	193.75
LRD-3	FM 1472	Type D	4.54	9.45	286.73	201.20
LRD-4	-	Type B	2.15	6.31	327.15	253.37
LRD-5	-	Type D (PG 70-22)	4.36	5.00	322.92	238.47

Table B-2. Example HWTT-SPST Results for Atlanta, Bryan, and Pharr Districts HMA Mix-Designs.

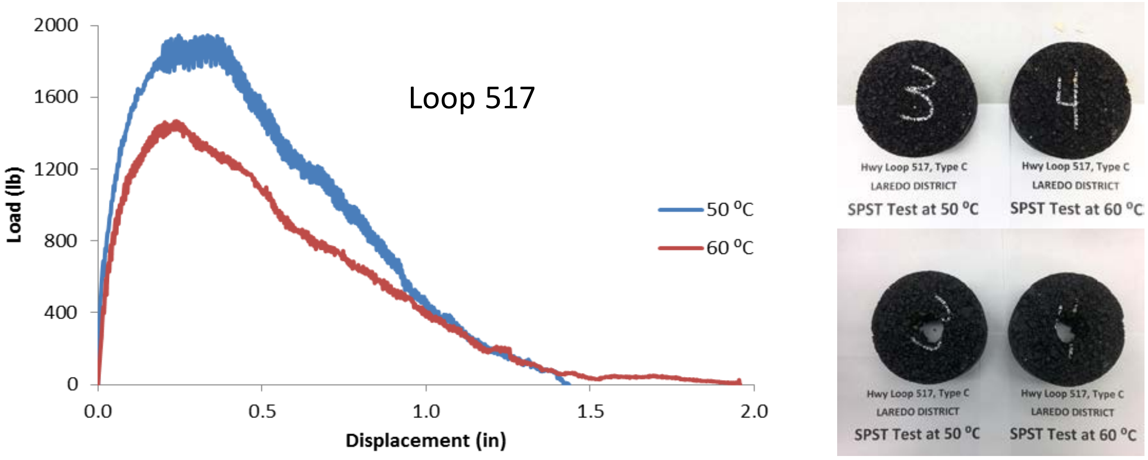
Mix ID	Hwy	Mix	HWTT rut depth after 20k passes (mm)		SPST shear strength (psi)	
			@ 50 ^oC	@ 60 ^oC	@ 50 ^oC	@ 60 ^oC
ATL	-	Type C	4.34	12.5 @ 10,050	196.73	151.23
PHR	-	Type D	3.85	12.5 @ 8700	281.83	-
PHR	-	Type C	3.28	11.09	301.87	203.16
BRY	-	Type D	7.01	12.34	311.02	198.76



Tested at 50 °C Tested at 60 °C

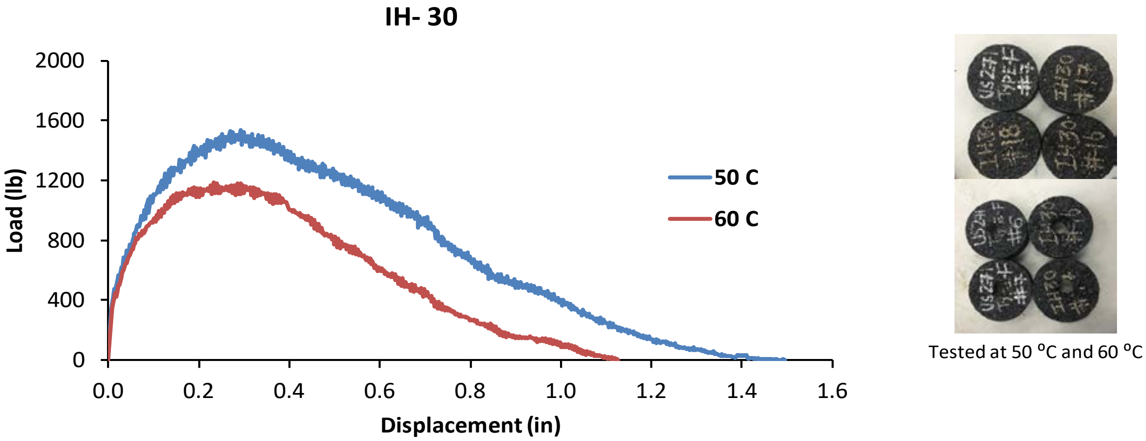
Sample #	Test temp.	Shear Strength (psi)	Shear Strain (in/in)	Shear Mod. (ksi)	SSE (kJ/m^2)
S# 1	50 °C	275.16	0.077	3.55	32.62
S# 2	60 °C	193.75	0.095	2.04	21.04

Figure B-1. Example SPST Results – Laredo District, Type C (PG 70-22) Mix.



Sample #	Test temp.	Shear Strength (psi)	Shear Strain (in/in)	Shear Mod. (ksi)	SSE (kJ/m^2)
S# 3	50 °C	247.48	0.134	1.85	30.9
S# 4	60 °C	186.87	0.096	1.95	23.37

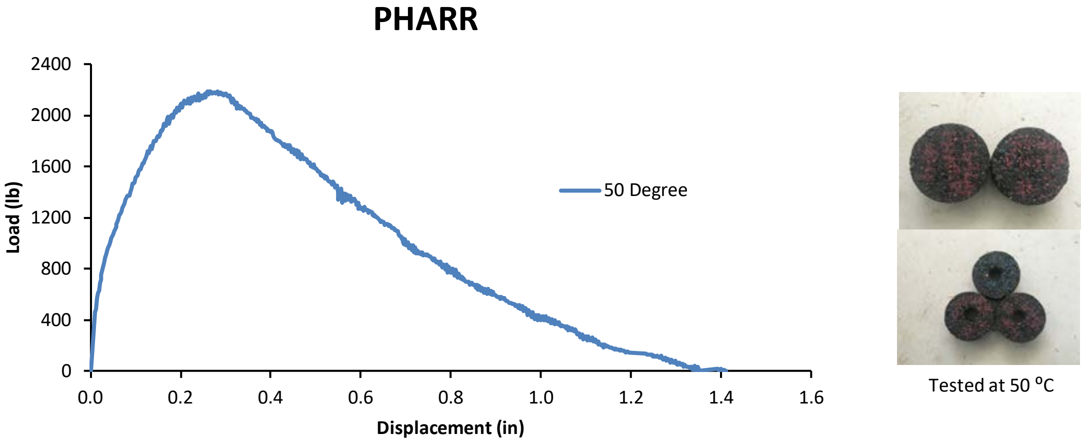
Figure B-2. Example SPST Results – Laredo District, Type D (PG 70-22) Mix.



Tested at 50 °C and 60 °C

Sample #	Test temp.	Shear Strength (psi)	Shear Strain (in/in)	Shear Mod. (ksi)	SSE (kJ/m^2)
S# 1	50 °C	205.46	0.115	1.79	22.09
S# 2	60 °C	188.01	0.120	1.56	18.37

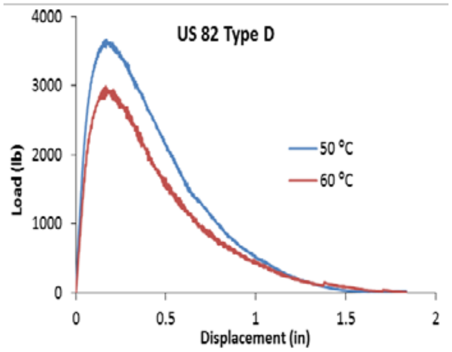
Figure B-3. Example SPST Results – Atlanta District, Type D (PG 64-22) Mix.



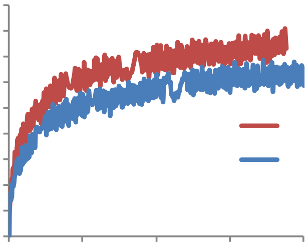
Tested at 50 °C

Sample #	Test temp.	Shear Strength (psi)	Shear Strain (in/in)	Shear Mod. (ksi)	SSE (kJ/m^2)
S# 1	50 °C	301.87	0.107	2.742	23.259
S# 2	60 °C	203.16			

Figure B-4. Example SPST Results – Pharr District, Type C (PG 70-22) Mix.



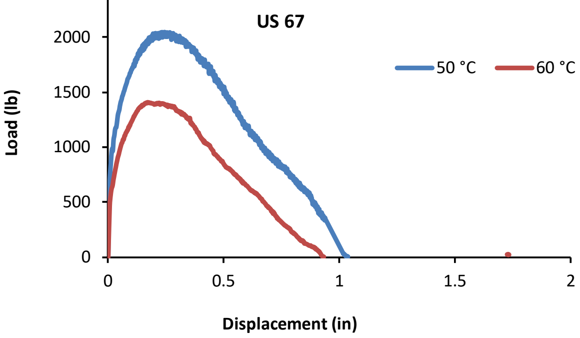
Sample ID	Shear Strength (psi)		Shear Strain (in/in)		Shear Mod. (ksi)		SSE (kJ/m^2)	
	50 °C	60 °C	50 °C	60 °C	50 °C	60 °C	50 °C	60 °C
S #1	325	259	0.074	0.072	4.38	3.61	34.74	25.79
S #2	324	239	0.060	0.067	5.36	3.60	32.99	25.29
S #3	292	269	0.066	0.066	4.40	4.05	27.34	23.54
Average	314	256	0.067	0.068	4.72	3.75	31.69	24.87
COV	5.96%	5.93%	10.22%	4.43%	11.90%	6.85%	12.21%	4.74%



Rut$_{max}$ (mm)		N_d		Rut$_{\Delta}$ (mm)		SF	
°	°	°	°	°	°	°	
3.43	4.04			2.71	3.23		

Figure B-5. Example SPST-HWTT Results – Paris District, Type D (PG 64-22) Mix.

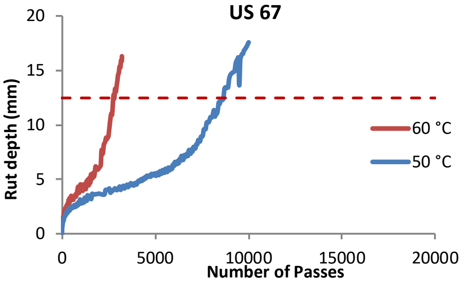
SPST results



Sample ID	Shear Strngth (psi)		Shear Strain (in/in)		Shear Mod. (ksi)		SSE (kJ/m^2)	
	50 °C	60 °C	50 °C	60 °C	50 °C	60 °C	50 °C	60 °C
S#1	298	214	0.10	0.07	2.78	3.12	19.29	11.56
S#2	298	145	0.09	0.11	3.22	1.30	14.76	6.98
Avg	298	179	0.10	0.09	3.00	2.21	17.03	9.27
COV	*0.2%*	*27.4%*	*8.8%*	*33.2%*	*10.4%*	*57.9%*	*18.8%*	*34.9%*

Atlanta Type D

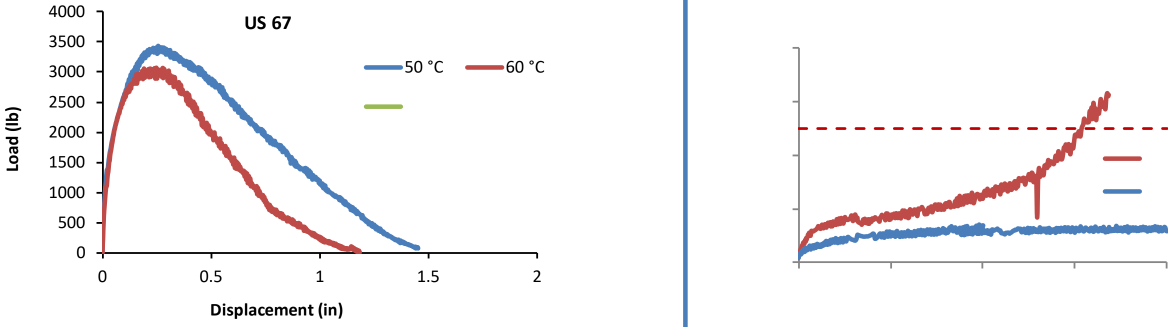
HWTT results



Rut$_{max}$ (mm)		Failure Cycles N_d		Rut$_{\Delta}$ (mm)		Shape Factor, SF	
50 °C	60 °C	50 °C	60 °C	50 °C	60 °C	50 °C	60 °C
12.5	12.5	8655	2803	5.63	5.55	0.901	0.88

Figure B-6. Example SPST-HWTT Results – Atlanta District, Type D (PG 64-22) Mix.

SPST results **HWTT results**



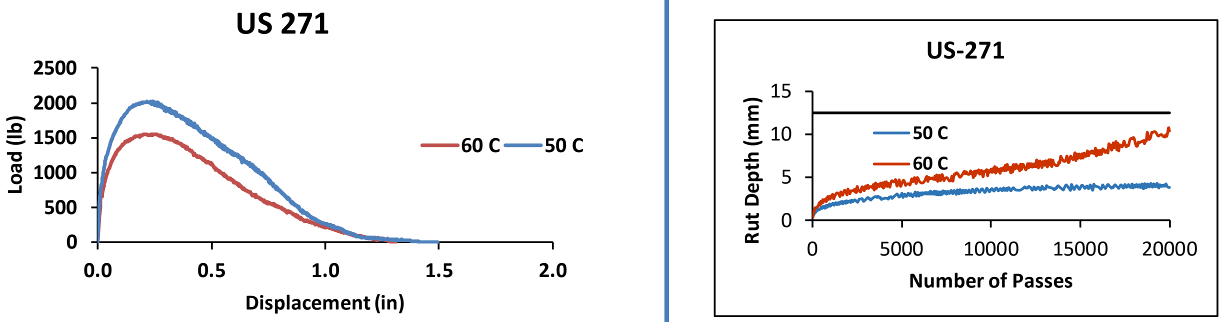
Sample ID	Shear Strngth (psi)		Shear Strain (in/in)		Shear Mod. (ksi)		SSE (kJ/m^2)	
	50 °C	60 °C	50 °C	60 °C	50 °C	60 °C	50 °C	60 °C
S#1	468	332.93	0.109	0.077	4.28	4.3	50.5	21.7
S#2	410	455.94	0.103	0.11	3.98	4.3	54.09	31.4
Avg	439	394	0.106	0.092	4.135	4.307	52.307	26.541
COV	*9.4%*	*22.1%*	*4.3%*	*23.2%*	*5.1%*	*1.2%*	*4.8%*	*25.7%*

Rut$_{max}$ (mm)		Failure Cycles N_d		Rut$_\Delta$ (mm)		Shape Factor, SF	
50 °C	60 °C	50 °C	60 °C	50 °C	60 °C	50 °C	60 °C
3.56	12.5	20000	15631	2.76	5.78	1.551	0.926

Atlanta Type B

Figure B-7. Example SPST-HWTT Results – Atlanta District, Type B (PG 64-22) Mix.

SPST results **HWTT results**



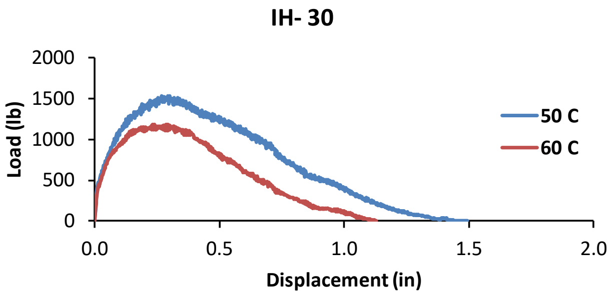
Sample ID	Shear Strngth (psi)		Shear Strain (in/in)		Shear Mod. (ksi)		SSE (kJ/m2)	
	50	60	50	60	50	60	50	60
S #1	237	201	0.08	0.08	3.04	2.42	24.86	18.31
S #2	280	199	0.10	0.10	2.84	1.98	20.65	14.40
Average	258	200	0.09	0.09	2.94	2.20	22.76	16.35
COV	3.50	0.01	0.00	0.00	0.01	0.05	0.39	0.47

Rut$_{max}$ (mm)		Failure Cycles N_d		Rut$_\Delta$ (mm)		Shape Factor, SF	
50 °C	60 °C	50 °C	60 °C	50 °C	60 °C	50 °C	60 °C
4.33	10.74	20000	20000	3.31	5.94	1.529	1.106

US 271

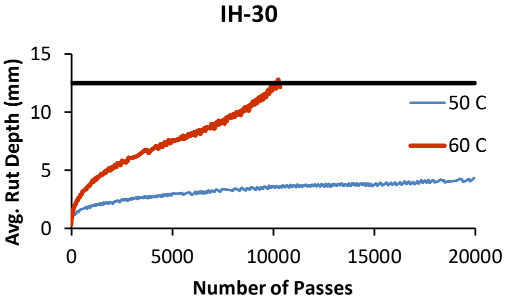
Figure B-8. Example SPST-HWTT Results – Atlanta District, Type F (PG 76-22) Mix.

SPST results



Sample ID	Shear Strngth (psi)		Shear Strain (in/in)		Shear Mod. (ksi)		SSE (kJ/m2)	
	50	60	50	60	50	60	50	60
S #1	205	135	0.11	0.12	1.79	1.16	22.09	8.83
S #2	188	167	0.12	0.09	1.56	1.79	18.37	11.46
Average	197	151	0.12	0.11	1.67	1.47	20.23	10.15
COV	0.77	3.33	0.00	0.00	0.02	0.13	0.34	0.34

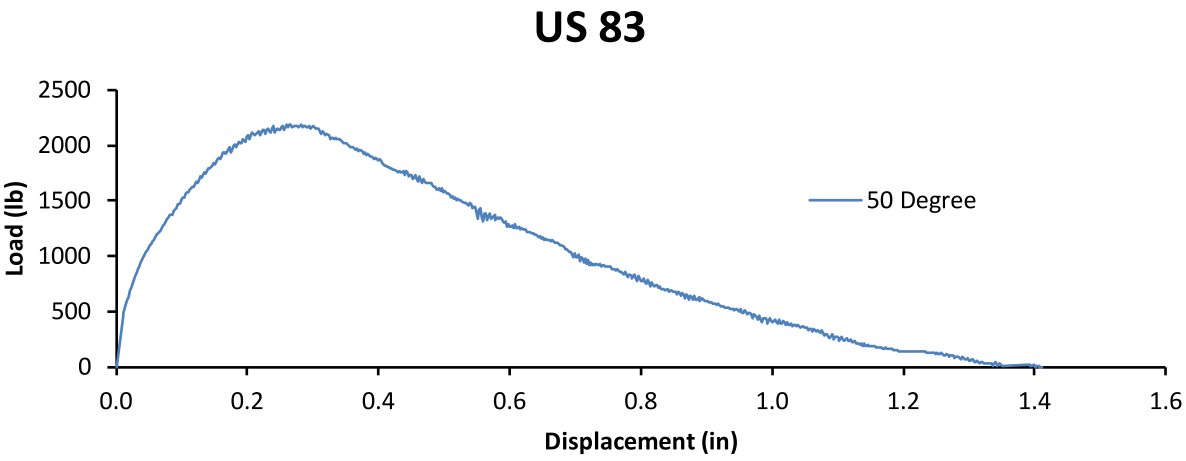
HWTT results



Rut_{max} (mm)		Failure Cycles N_d		Rut_{Δ} (mm)		Shape Factor, SF	
50 °C	60 °C	50 °C	60 °C	50 °C	60 °C	50 °C	60 °C
4.34	12.50	20000	10050	3.32	7.39	1.528	1.182

IH 30

Figure B-9. Example SPST-HWTT Results – Atlanta District, Type D (PG 64-22) Mix.



Sample ID	Shear Strngth (psi)		Shear Strain (in/in)		Shear Mod. (ksi)		SSE (kJ/m2)	
	50	60	50	60	50	60	50	60
S #1	270		0.11		2.49		25.45	
S #2	294		0.11		2.75		24.14	
Average	282		0.11		2.62		24.79	
COV	1		0.00		0.01		0.03	

Figure B-10. SPST Results – Pharr District, Type D (PG 64-22) Mix.

APPENDIX C: PROPOSED MODIFICATIONS TO THE HWTT AND TEX-242-F TEST PROCEDURE

Test Procedure for
HAMBURG WHEEL TRACKING TEST
TX DOT Designation: Tex-242-F
***Effective Date:* _____**

---

1. SCOPE

1.1 Use this test method to determine the premature failure susceptibility of bituminous mixtures due to weakness in the aggregate structure, inadequate binder stiffness, or moisture damage and other factors including inadequate adhesion between the asphalt binder and aggregate (stripping). *The test method measures the rutting susceptibility of bituminous mixtures in terms of the following rutting parameters: rut depth, number of passes to failure, normalized rutting area, and shape factor.*

1.2 The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

---

2. APPARATUS

2.1 *Wheel Tracking Device*, an electrically powered device capable of moving a steel wheel with a diameter of 8 in. (203.6 mm) and width of 1.85 in. (47 mm) over a test specimen.

2.1.1 The load applied by the wheel is 158±5 lb (705±22 N).

2.1.2 The wheel must reciprocate over the test specimen, with the position varying over time in sinusoidal motion.

2.1.3 The wheel must be capable of making 50±2 passes across the test specimen per minute.

Note 1— *For mixtures to be used in slow vehicle-speed areas such as intersections, urban city roads, etc., testing at lower and/or multiple HWTT wheel* *speeds should be considered as a supplement to the standard speed (50±2 passes/minute) (i.e., from 50 to as low as 35 passes/minute). In order to facilitate this, the HWTT wheel should have the capabilities to run at wheel speeds ranging from 35 to 50 passes per minute.*

2.1.4 The maximum speed of the wheel must be approximately 1.1 ft/s (0.305 m/s) and will be reached at the midpoint of the slab.

2.2 *Temperature Control System,* a water bath capable of controlling the test temperature within ±4°F (2°C) over a range of 77–158°F (25–70°C).

2.2.1 This water bath must have a mechanical circulating system to stabilize temperature within the specimen tank.

2.3 *Rut Depth Measurement System,* a Linear Variable Differential Transducer device capable of measuring the rut depth induced by the steel wheel within 0.0004 in. (0.01 mm), over a minimum range of 0.8 in. (20 mm).

2.3.1 The system should be mounted to measure the rut depth at the midpoint of the wheel's path on the slab.

2.3.2 Take rut depth measurements at least every 100 passes of the wheel.

2.3.3 This system must be capable of measuring the rut depth without stopping the wheel. Reference this measurement to the number of wheel passes.

2.3.4 The system should have a fully automated data acquisition and test control system (computer included).

2.4 *Wheel Pass Counter,* a non-contacting solenoid that counts each wheel pass over the test specimen.

2.4.1 Couple the signal from this counter to the rut depth measurement, allowing the rut depth to be expressed as a fraction of the wheel passes.

2.5 *Specimen Mounting System,* a stainless steel tray that can be mounted rigidly to the machine in the water bath.

2.5.1 This mounting must restrict shifting of the specimen during testing.

2.5.2 The system must suspend the specimen, allowing free circulation of the water bath on all sides.

2.5.3 The mounting system must provide a minimum of 0.79 in. (2 cm) of free circulating water on all sides of the sample.

---

3. MATERIALS

3.1 *Three high-density polyethylene (HDPE) molds*, shaped according to plan view in Figure 2 to secure circular, cylindrical test specimens. Use one mold for cutting the specimen and the other two for performing the test.

3.2 *Capping compound*, able to withstand 890 N (200 lb) load without cracking.

---

4. SPECIMEN

4.1 *Laboratory Molded Specimen*—Prepare specimens in accordance with Tex-205-F and Tex-241-F. Specimen diameter must be 6 in. (150 mm), and specimen height must be 2.5±0.1 in. (63.5±2.5 mm).

Note 2— *For consistency, test all specimens within 5 days of molding.*

Note 3—Mixtures modified with warm-mix asphalt (WMA) additives or processes must be oven cured at 275°F for a maximum of 4 hours before molding.

4.1.1 Density of test specimens must be 93±1 percent (or air void must be 7±1 percent).

Note 4—Mixture weights for specimens prepared in the laboratory typically vary between 2400 and 2600 g to achieve density due to different aggregate sources and mix types. *If necessary, a pre-molding procedure should be conducted to systematically achieve the desired specimen density (93±1 percent) for the laboratory-molded samples. The pre-molding procedure consists of molding at least three specimens, each with a different target density varied roughly between 87 percent and 92 percent and evaluating the resulting specimen densities for each. A target density versus obtained specimen density curve is drawn to determine the Optimum Molding Density that will yield the desired specimen density (93±1 percent); see example in Figure B-1.*

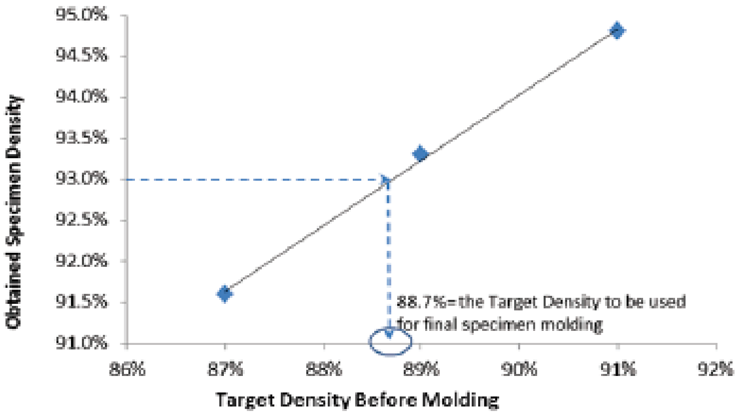


Figure C-1. Pre-molding Procedure.

4.2 *Core Specimen*—Specimen diameter must be 6±0.1 in. (150±2 mm). There is not a specific density requirement for core specimens.

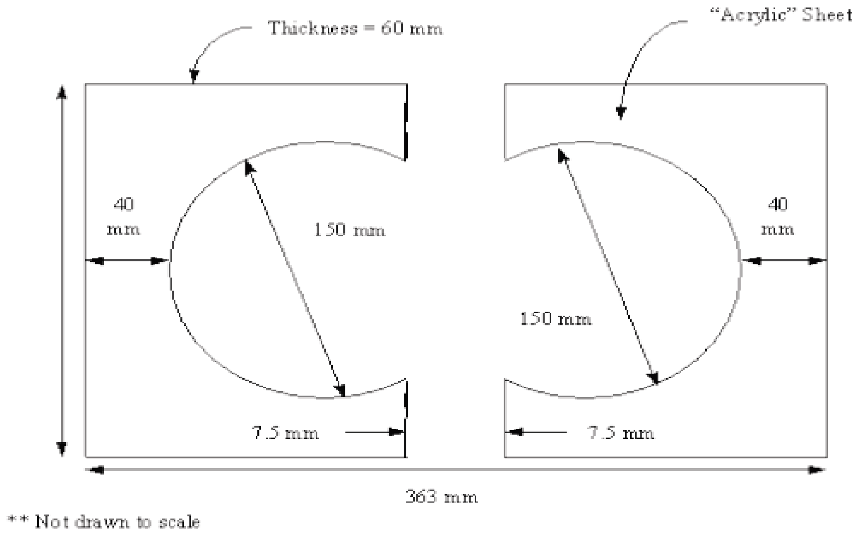


Figure C-2. Specimen Configuration for the Hamburg Wheel Tracking Device.

---

5. PROCEDURE

5.1 Use two cylindrically molded specimens meeting the requirements of Section 4.

5.2 Measure the relative density of specimens in accordance with Tex-207-F and Tex-227-F.

5.3 Place a specimen in the cutting template mold and use a masonry saw to cut it along the edge of the mold.

5.3.1 The cut across the specimen should be approximately 5/8 in. (16 mm) deep.

5.3.2 Cut the specimen to the dimensions shown in Figure 2 in order to fit in the molds required for performing the test.

5.4 For specimens 6 in. (150 mm) in diameter:

- Place the HDPE molds into the mounting tray and fit specimens into each one.
- Secure the molds into the mounting tray.

Note 5— Do not use the HDPE molds for core specimens greater than 6 in. (152 mm) in diameter.

Note 6— *Keep track of the top and bottom of the specimen according to the direction of sample compaction or traffic loading in the case of field cores. Always place the specimen in the HWTT machine such that the top surface of the specimen is in contact with the wheel (i.e., the direction of loading is parallel to the direction of sample compaction).*

5.5 For specimens greater than 6 in. (150 mm) in diameter:

- Mix capping compound.
- Spray the mounting tray with a light lubricant.
- Place specimen in the middle of the mounting tray.
- Spread the capping compound around the core specimen until level with the surface.
- Allow the capping compound to dry for a minimum of 24 hours.

5.6 Fasten the mounting trays into the empty water bath.

5.7 Start the software supplied with the machine and enter the required test information into the computer including adjusting speed where needed.

Note 7— *For mixtures to be used in slow vehicle-speed areas such as intersections, urban city roads, etc., testing at lower and/or multiple HWTT wheel speeds should be considered in addition to the 50±2 passes/minute (i.e., from 50 to as low as 35 passes/minute). For these special slow vehicle-speed areas, any or all of the following HWTT wheel speeds can be considered: 50, 45, 40, and/or 35 passes /minute.*

5.8 Set the test temperature at 122±2°F (50±1°C) for all HMA specimens.

Note 8— *For mixtures to be placed in high-temperature areas, high shear stress locations, and urban stop-go environments (near intersections), consider testing* *the samples at multiple HWTT temperatures (i.e., 50°C and, 60°C) and report the test results for all the tested temperatures*.

5.8.1 Fill the water bath with the water and wait until the water temperature is at the desired test temperature.

5.8.2 Monitor the temperature of the water on the computer screen.

5.8.3 Saturate the test specimen in the water for an additional 30 minutes after reaching the desired water temperature.

5.8.4 Start the test after the test specimens have been in the water for 30 minutes at the desired test temperature. The testing device automatically stops the test when the device applies the number of desired passes or when reaching the maximum allowable rut depth.

6. CALCULATIONS

6.1 From the HWTT machine, save and extract the rut depth versus number of passes data for calculation of HWTT rutting parameters.

6.2 Measure and record the following parameters from the rut depth versus number of passes response:

- *Maximum Rut Depth* Rut_{max} *= Rutting after 20,000 load passes or 12.5 mm (whichever is smaller)*
- *Failure Cycles,* N_d *= Number of load passes to reach 12.5 mm rutting or 20,000 (whichever is smaller)*
- ΔA *= Area under the Rut depth versus number of passes (Figure B-3)*

Note 9— Rut_{max} and N_d *are the traditional HWTT parameters and can be obtained directly from the machine.*

Note 10— *The Area under the rut depth versus number of passes, A Δ, is calculated using the trapezoidal formula by dividing the area into* ***n*** *number of trapezoids. (Alternatively, Simpson's rule may be used to determine the area under the curve.)*

$$\Delta A = \frac{N_d}{2n}\left[f(x_0) + 2f(x_1) + 2f(x_2) \ldots + 2f(x_{n-1}) + f(x_n)\right]$$

Where $f(x_1)$ *and* $f(x_{i+1})$ *are rut depth values at the left and right end of each trapezoid, respectively.*

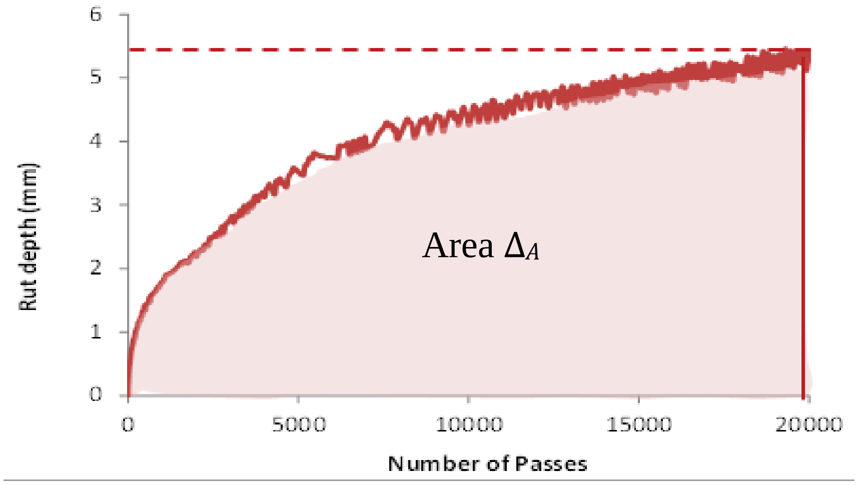


Figure C-3. HWTT Rut Depth versus Number of Load Passes Curve.

6.3 *Calculate the Normalized Rutting Area (Rut_Δ):*

$$Rut_\Delta = \frac{\text{Area under Rutting curve}}{N_d} = \frac{\Delta_A}{N_d}$$

Note 11— *the Normalized Rutting Area (Rut_Δ) parameter accounts for the rutting path-history of the sample. Higher Rut_Δ indicates poor rut resistance.*

6.4 *Calculate the Shape Factor (SF):*

$$SF = \frac{\text{Area under Rutting curve}}{\textit{Area under triangular curve}} = \frac{\Delta_A}{N_d \text{ x } 0.5 \text{ x } Rut_{max}} = \frac{\Delta_A}{\Delta_B}$$

Note 12— *the Shape Factor (SF) parameter indicates the shape of the rutting curve. SF > 1.25 indicates a convex rutting curve, which is less desirable for high-temperature areas, high shear stress locations, and urban stop-go sections in terms of the early rutting life of the HMA mix. SF is calculated based on the area under the curve and area under the curve in Figure B-4.*

SF ≤ 1.25 indicates a concave rutting curve, which is more desirable for high-temperature areas, high shear stress locations, and urban stop-go sections, particularly in terms of the early rutting life of the HMA mix.

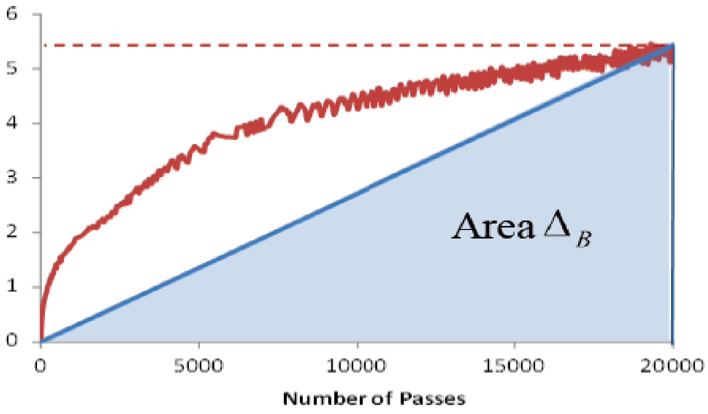


Figure C-4. HWTT-Area under Triangular Curve.

6.5 *Plot and assess the rut depth versus the number of passes response plot.*

Note 13— *Typical HWTT plot is divided into two slopes, one before and the other after the stripping point. However, in many instances especially at a higher temperature (60°C), the slope after the stripping point subdivides itself into more than one. If that happens, the number of HWTT load passes (N_d) to failure may be overstated. In order to establish the actual load passes corresponding to the recommended TxDOT rut cut-off point, the following should be considered as shown in Figure B-5.*

- *Extend the slope after stripping point to intersect a horizontal line from 0.5 in. (12.5 mm). From the intersection of the two lines, draw a vertical line to touch the horizontal axis and establish the new load passes corresponding to failure point.*

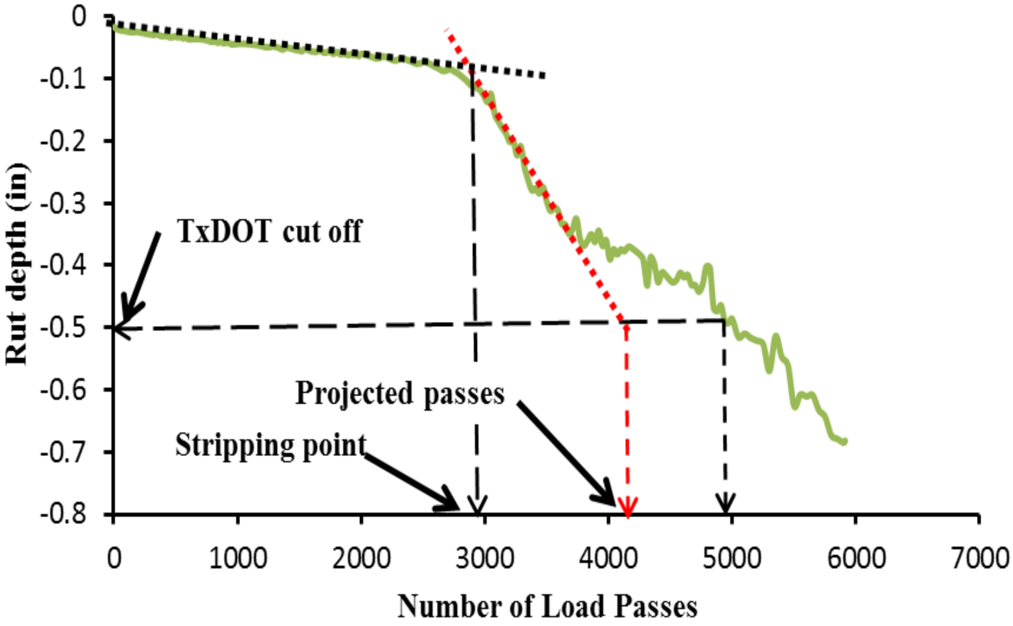


Figure C-5. Typical HWTT Responses at 60°C.

Note 14*— Apply the HWTT water bath temperature of 60°C only for HMA mixtures using PG 76 or above. HMA mixtures with lower PG grade will probably collapse due to early stripping. In case stripping is the only and primary reason for the test, HMA mixtures with less than PG 76 can also be subjected to HWTT testing at 60°C.*

---

7. REPORT

7.1 *Report the following for each specimen:*

- *Trimmed specimen density,*
- *Anti-stripping additive used,*
- *Test temperature,*
- *Maximum Rut Depth,* Rut_{max}*,*
- *Failure Cycles,* N_d*,*
- *Normalized Rutting Area,* $Rut\Delta$*, and*
- *Shape Factor, SF.*

---

8. ARCHIVED VERSIONS

8.1 Archived versions are available.

APPENDIX D: THE PROPOSED DRAFT TEST SPECIFICATION FOR SPST

Test Procedure for
THE SIMPLE PUNCHING SHEAR TEST (SPST)
TxDOT Designation: Tex-2XX-F
Effective Date:

1. SCOPE

1.1 This test method determines the shear properties of the compacted bituminous mixtures. The measurable and calculable shear parameters include shear strength, shear strain, shear modulus, shear strain energy, and shear strain energy index.

1.2 The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

2. APPARATUS

2.1 *Loading Press*, capable of applying a compressive load at a controlled deformation mode at the rate of 0.2 mm per second.

2.2 *Environmental chamber*, a temperature-controlled chamber capable of maintaining a temperature of up to 60°C.

2.3 *Loading Head*, a 1.5 in. diameter cylindrical metal head to be attached to the loading shaft of the Loading Press (Figure C-1).

2.4 *Loading Base*, consisting of a 6.0 in. diameter cylindrical metal base with a 2.5 in. diameter concentric opening. The height of the Loading Base is at least 2.5 in. to allow enough space for accommodating the dislodged parts of the HMA (Figure C-2).

2.5 *Sample Confinement*, made of a cylindrical enclosure and a collar strap to provide lateral confining pressure of about 20 psi to the sample (Figure C-3).

2.6 *Torque Wrench*, with a torque capacity of 25 in-lb and appropriate socket drive handle.

Figure D-1. Loading Head.

Figure D-2. Loading Base Pictorial Illustration.

Figure D-3. SPST Sample Confinement: Cylindrical Enclosure and Collar Strap.

---

3. SPECIMENS

3.1 *Laboratory-Molded Specimens*—prepare three specimens in accordance with Tex-241-F. Specimen diameter must be 6 in. (150 mm), and height must be 2.5±0.1 in. (63.5±2.5 mm). For consistency, test all specimens within 5 days of molding.

3.1.1 For WMA mixtures, select curing temperature and time according to binder grade, recycled materials, and target discharge temperature. Refer to Tex-241-F to mold WMA specimens.

Note 1—Cure WMA mixtures at 275°F for 4 hr±5 min. before molding. WMA is defined as HMA that is produced within a target temperature discharge range of 215°F and 275°F using WMA additives or processes.

3.1.2 Test specimen air void must be 7±1 percent, except for Permeable Friction Course (PFC) mixtures.

Note 2— Mixture weights for specimens prepared in the laboratory typically vary between 2400 and 2600 g to achieve the needed air-void due to different aggregate sources and mix types. A minimum of three pre-molded samples of different weight followed by interpolation to determine the actual weight that will produce samples with a target density of 7±1 percent air void.

3.1.3 For PFC mixtures, mold test specimens to 50 gyrations (N_{design}).

Note 3— Select the mixture weight for the molded PFC specimens based on the weight used in the mix design.

3.2 *Core Specimens*—Specimen diameter must be 6±0.1 in. (150±2.5 mm), and height must be a minimum of 1.5 in. (38 mm). There is not a specific density requirement for core specimens.

4. PROCEDURE

4.1 For laboratory-produced mixtures, proceed to Section 4.2. For plant-produced mixtures, proceed to Section 4.3. For roadway cores, proceed to Section 4.4.

4.2 Laboratory-Produced Mixtures:

4.2.1 Combine aggregates and prepare laboratory mixture as described in Tex-205-F.

4.2.2 Mold three specimens in accordance with Tex-241-F with the Superpave Gyratory Compactor (SGC).

4.2.3 Proceed to Section 4.4.

4.3 Plant-Produced Mixtures:

4.3.1 Sample the plant mixture in accordance with Tex-222-F.

4.3.2 Mold three specimens in accordance with Tex-241-F with the SGC.

4.3.3 Proceed to Section 4.4.

4.4 Measure and record the density, height, and diameter of each laboratory or plant-produced specimen or roadway core.

4.5 Place the specimens or cores, along with the testing apparatus (loading head, loading base, sample confinement), in the controlled temperature chamber for at least 3 hours to ensure a consistent temperature of 50±1°C throughout. Always monitor the temperature using a dummy sample.

Note 4—For mixes to be placed in high-temperature areas, high shear stress locations, and urban stop-go environments (near intersections), test the samples at multiple temperatures (i.e., 50°C and 60°C), and report the test results for all tested temperatures.

4.6 Attach the Sample Confinement to the specimen.

4.7 Carefully place the confined specimen on the Loading Base. Make sure the Loading Base and the specimen are concentrically placed below the Loading Head (Figure C-4).

Note 5— Keep track of the top and bottom of the specimen according to the direction of sample compaction or traffic loading in the case of field cores.

Figure D-4. SPST Specimen Setup.

4.8 Slowly lower the loading head to lightly seat on the surface of the specimen.

4.9 Apply the load at a controlled deformation rate of 0.2 mm per second. Capture and save the complete load versus deformation (L-D) response curve for subsequent data analysis.

4.10 An operator shall observe the development of the load-deformation response curve in real time. The operator shall stop the test when the shear load passes the maximum point and fallen back to zero point.

5. CALCULATIONS

5.1 Measure and record the following parameters from the load-displacement (L-D) response (Figure C-5):

- Peak (failure) shear load, P_{max}
- Failure shear deformation at peak load, D@P_{max}
- Area under the shear L-D response curve = ∫f (x) dx

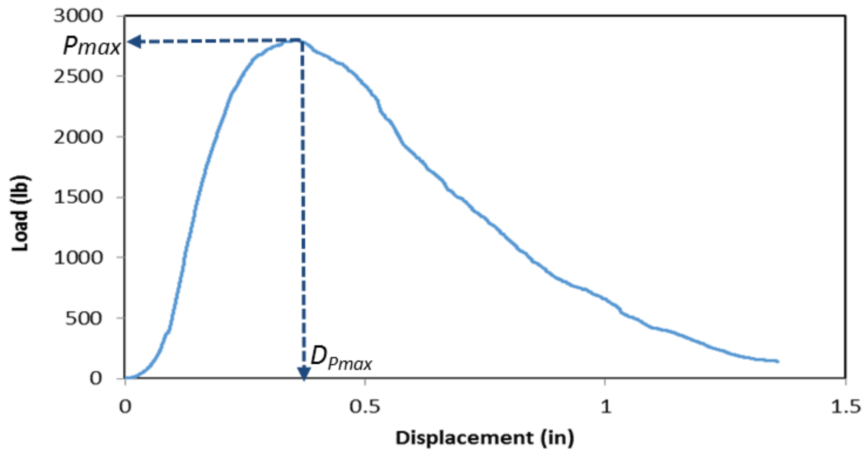


Figure D-5. Typical SPST L-D Curve.

Note 6—The Area under the shear L-D response curve, ∫f(x)dx may be approximated using trapezoidal rule *(Alternatively, Simpson's rule may be used to determine the area under the curve).*

$$\Delta A = \frac{N_d}{2n}[f(x_0) + 2f(x_1) + 2f(x_2) \ldots + 2f(x_{n-1}) + f(x_n)]$$

where $f\,(x_1)$ *and* $f\,(x_{i+1})$ *are rut depth values at the left and right end of each trapezoid, respectively.*

5.2 Calculate the HMA shear strength, τ (psi):

$$\tau = \frac{P_{max}}{\pi t d}$$

where, d = Diameter of the punching (loading) head = 1.5 in.

t = Thickness of the sample (in.)

5.3 Calculate the HMA failure shear strain at peak load, γ:

$$\gamma = \frac{D\ @\ P_{max}}{t}$$

where D = Displacement (in.)

5.4 Calculate the HMA shear modulus, *E* (psi):

$$E = \frac{\tau}{\gamma}$$

5.5 Calculate the shear strain energy, *SSE* (KJ/m^2):

$$SSE = \frac{Area\ Under\ Curve}{Sheared\ Surface\ Area} = \frac{1}{\pi t d} \int f(x)dx$$

5.6 Calculate the SSE Index:

$$SSE\ index = 10^3 \times SSE \frac{\gamma}{t\tau}$$

Note 7— Mixture selection criteria: The shear strength of the mixtures shall not be less than 300 psi (or SSE ≥ 25 kJ/m^2) at 50°C. The shear strength shall not drop below 200 psi (or SSE ≥17 kJ/m^2) at 60°C; otherwise, the HMA mixture shall be deemed too sensitive to temperature changes.

6. REPORT

6.1 Report the following for each specimen:

- Trimmed specimen density,
- Peak shear (failure) load,
- Failure shear deformation at peak load,
- HMA shear strength,
- HMA failure shear strain at peak load,
- HMA shear modulus,
- Shear strain energy,
- Shear strain energy index, and
- Additional comments.

7. ARCHIVED VERSIONS

7.1 Archived versions are available.