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The Hamburg rutting test – Effects of HMA sample sitting time and test temperature variation

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HIGHLIGHTS

- The Hamburg Wheel Tracking Test (HWTT) is a rutting test for asphalt (HMA) mixes.
- Summer field rutting failures with HMA mixes that passed the HWTT in the laboratory.
- The study evaluated the laboratory HMA sample sitting time and HWTT test temperature.
- The HWTT test results suggested five days as the optimal HMA sample sitting time.
- Higher (>50 °C) and/or multiple HWTT test temperatures should also be considered.

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ABSTRACT

The Hamburg Wheel Tracking Test (HWTT) is a widely used routine laboratory test with a proven history of successfully identifying and screening hot-mix asphalt (HMA) mixes that are prone to rutting and/or susceptible to moisture damage (stripping). Based on Texas specification Tex-242-F, the HWTT is typically conducted at a single test temperature of 50 °C (122 °F) with 12.5 mm rut depth as the standard HMA pass-fail screening criteria. However, with the record high summer temperatures of the recent years in Texas, several premature field rutting failures have occurred with some HMA mixes that had passed the HWTT screening criteria in the laboratory. This laboratory study was thus initiated to review and evaluate if the current Texas HWTT protocol and its associated Texas test specification (Tex-242-F) are simulative of the current summer field conditions for routine HMA mix-design and screening to optimize rutting resistance performance. Specifically, two key aspects were evaluated, namely the HMA sample sitting time and test temperature. The corresponding laboratory test results indicated that a maximum sample sitting time of five days should be consistently adapted, i.e., lab-molded samples should be tested within five days of fabrication, particularly for HMA mix-design screening purposes. For HMA mixes to be used in high temperature/stress environments, the study findings suggested that higher (>50 °C), and/or multiple HWTT test temperatures should be considered.

1. Introduction

Rutting is one of the major distresses occurring in hot-mix asphalt (HMA) pavements; typically manifesting itself as longitudinal depressions in the wheel paths [1,2]. HMA rutting is mainly caused through shear deformation in the upper HMA layers under traffic loading [3–6]. One of the routine laboratory tests commonly used for mix-design screening and assessing the HMA rutting susceptibility is the Hamburg Wheel Tracking Test (HWTT). Traditionally run at a single test temperature of 50 °C (122 °F) in the laboratory under Texas specification Tex-242-F, the HWTT has been proven as a reliable test method to identify and screen HMA mixes that are prone to rutting and/or susceptible to moisture damage (stripping) [7–10]. However, the current summer pavement temperatures can reach as high as 60 °C, which makes the HMA more susceptible to rutting failure under heavy traffic loading [11]. In particular, with the record high summer pavement temperatures (>50 °C) of the recent years in Texas, several rutting failures have occurred in the field with some HMA mixes that had passed the

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HWTT in the laboratory. These failures occurred mostly in high shear stress locations, in particular with slow moving (accelerating/decelerating) traffic at controlled highway sections (stop–go intersections), in areas of elevated temperatures, heavy/high traffic loading, and/or where lower performance grade (PG) asphalt-binders have been used for cost optimization purposes, etc. [11,12].

Since improper HMA mix selection due to poor laboratory screening can undesirably lead to costly premature pavement failures, tying laboratory testing to field performance is very critical to ensure optimal field performance and minimization of maintenance/rehabilitation costs. For rutting and as stated above, this is particularly critical in areas of elevated temperatures (in summer), heavy/high slow moving traffic with longer loading times, and/or where lower PG asphalt binders are used. In the recent years, where summer pavement temperatures have been excessively high (i.e., over 50 °C), several districts in Texas have experienced premature HMA rutting and shear failures for some surface mixes, particularly at highway intersections; yet, these mixes had satisfactorily passed the HWTT screening criteria in the laboratory. Fig. 1 shows some examples of summer surface rutting failures, mostly at highway intersections, where the mixes had passed the HWTT in the lab [12].

Based on the foregoing background, this laboratory study was conducted to review and evaluate if the current Texas HWTT protocol and its associated test specification are simulative of the current summer field conditions for HMA mix-design and screening to optimize rutting resistance performance. Specifically, two key aspects were evaluated and are discussed in this paper; namely the HMA sample sitting time and HWTT test temperature. In the subsequent sections, the Texas HWTT protocol and Tex-242-F specification are described, followed by the laboratory experimental plan. Laboratory test results are then presented and analyzed. The paper then concludes with a synthesis and summary of the key findings and recommendations.

2. The HWTT protocol and Tex-242-F specification

Based on the Texas Tex-242-F specification, the current the HWTT protocol consists of the following test parameters: 0.7 kN (158 lb) vertical load at a wheel speed of 52 passes per minute up to 20,000 passes at 50 ± 1 °C (122 °F) in a water bath [9]. The HWTT protocol is routinely used to determine and quantify the HMA premature failure susceptibility due to weak aggregate structure, inadequate asphalt-binder stiffness, moisture damage (stripping), and other factors including inadequate adhesion between the asphalt-binder and aggregates. Fig. 2 shows a pictorial illustration of the HWTT equipment along with a sample loading configuration.

The HMA pass-fail screening criteria is based on a measured maximum rut depth of 12.5 mm (<12.5 mm) and the number of HWTT load passes to failure (or test termination), whichever comes first. The applicable number of HWTT load passes is a function of the PG asphalt binder as follows: PG 64-XX = 10,000 passes; PG 70-XX = 15,000 passes; and PG 76-XX = 20,000 passes [9,12,13]. Two aspects associated with the current HWTT protocol and the Texas Tex-242-F specification were investigated in this laboratory study and are discussed in this paper, namely: HMA sample sitting time and test temperature variation.

2.1. HMA sample sitting time and oxidative aging effects

As at the time of this study, the Texas Tex-242-F specification did not specify any time limits within which to test the lab-molded HMA samples after molding/fabrication. HMA samples are tested randomly without consideration of the sitting time from the time of molding to the actual time of testing, i.e., the sitting time can variably be 1 day, 3 days, 5 days, 1 week, 2 weeks, etc., before the samples are actually tested. This can particularly be an issue when comparatively evaluating HMA mixes. Also, if some samples are variably tested after a long sitting time period after molding/fabrication, there could be some possible short-term oxidative aging effects and stiffening up of the HMA that could impact the HWTT test results. To ensure consistency, it is better that lab-molded samples are consistently tested in a similar timely manner.

Specifically, for routine HMA mix-design screening, it is in fact desired that the HWTT samples be tested as soon as practically possible after molding/fabrication. Therefore, it was deemed necessary in this study to investigate and specify an acceptably reasonable sample sitting time so as to ensure consistency. Thus, the following sample sitting times at room temperature were comparatively studied and are discussed in this paper: 1 day, 3 days, 5 days, 7 days (1 week), and 14 days (2 weeks) [14].

As stated above, HWTT samples for routine HMA mix-design screening should desirably be tested within the shortest practically possible time period after molding/fabrication so as to minimize any short-term oxidative aging effects of the asphalt binder on the laboratory test results. However, circumstantial factors such

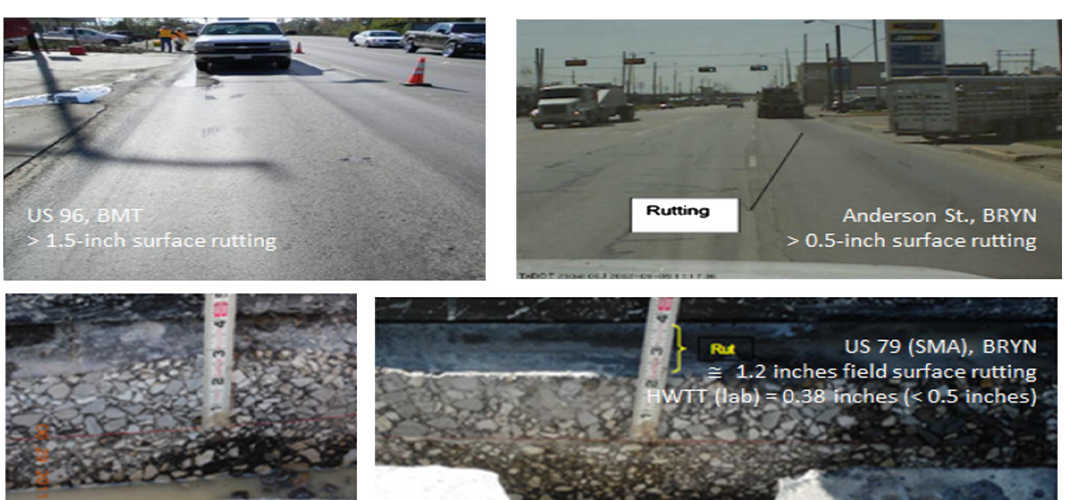

Fig. 1. Examples of premature and surface rutting on some Texas highways.

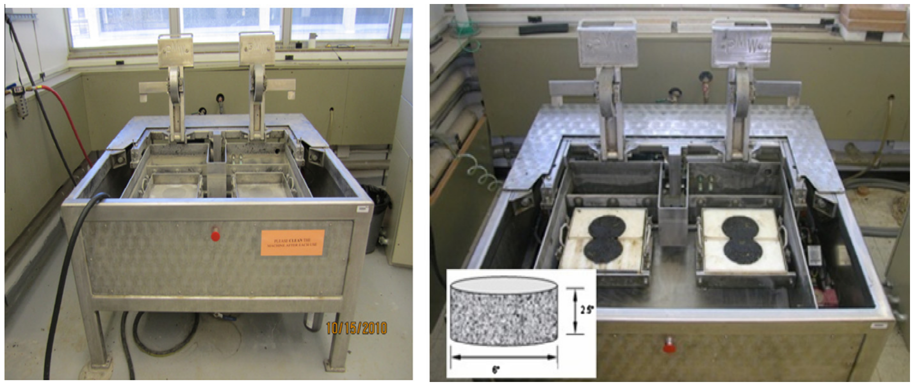

Fig. 2. The HWTT device.

Table 1
Field temperatures on selected highways and HMA mix details.

#	Mix label	HMA mix type	HMA mix-design	Highway	District (climate)	Max. Avg. temperature recorded in 2011–2014 (°C)	
						Air	Pavement @ 1 inch depth
1	B1	Type B	4.6% PG 64–22 + Limestone + 30% RAP	IH 35	Waco (M)	44.4	55.2
2	B2	Type B	4.2% PG 64–22 + Bridgeport Rock/Sand + 30% RAP	APT site	Fort worth (WC)	41.7	54.4
3	C1	Type C	4.6% PG 64–22 + Limestone + 17% RAP	US 83	Laredo (DW)	45.6	60.0
4	C2	Type C	5.2% PG 64–22 + Basalt/Traprock + 1% Lime + 20% RAP	Loop 480	Laredo (DW)	45.6	63.1
5	C3	Type C	4.1% PG 64–22 + Limestone/Dolomite + 1.0% Lime + 17% RAP + 3% RAS	SH 21	Bryan (WW)	44.4	60.0
6	D1	Type D	5.4% PG 64–22 + Limestone/Dolomite + 15% RAP	US 277	Wichita falls (DC)	42.8	57.5
7	F1	Type F	6.8% PG 76–22 + Sandstone	US 271	Paris (WC)	42.2	57.8
Average						43.8	58.3

Legend: APT = Accelerated Pavement Testing; Avg. = Average; DC = Dry-Cold; DW = Dry-Warm; M = Moderate; Max = Maximum; WC = Wet-Cold; WW = Warm-Warm; RAP = Recycled (reclaimed) Asphalt Pavement: RAS = Recycled (reclaimed) Asphalt Shingles.

as the need for sample density measurements may not permit to test the HWTT samples the same day or one day after molding/fabrication. And thus, there is an inherent need to consider and accommodate such practicalities. Therefore, the maximum sample sitting time period incorporated in the laboratory test matrix and investigated in this study was 14 days.

2.2. HWTT lab test specification and Texas summer field temperatures

Due partly to global warming and high pavement temperatures (i.e., >50 °C) in Texas summer, the HWTT loading parameters have become a challenge, particularly for surface HMA mixes used in high shear-stress locations such as intersections, urban stop–go sections, etc., or where a low PG asphalt binders are used. As can be noted from Table 1, the recently measured field pavement temperatures for some randomly selected in-service highways in Texas are substantially higher than the current Tex-242-F lab test temperature specification of 50 °C [9,14]. Note that the field temperatures reported in Table 1 represents an average of multiple temperature measurements at the selected highway locations during the summer periods of 2011–2014. At least, a minimum of four replicate temperature measurements were conducted at each selected highway location in Table 1 on different dates and times during the summer periods of 2011 through to 2014.

The overall average field pavement temperature shown in Table 1 is 58.3 °C while the maximum measured was actually 63.1 °C (US 83), which is way higher than the test temperature of 50 °C prescribed by the Tex-242-F test specification [9]. Evidently, this suggests a need to review the current Texas HWTT test temperature so as to better simulate these field temperatures in the laboratory. As presented subsequently, the HMA mixes in this study were evaluated at multiple test temperatures, ranging from 50 to 70 °C.

3. Experimental design plan – materials and HMA mixes

Five commonly used Texas mix types, namely: Type B, Type C, Type D, CAM (Crack Attenuating Mixture), and SMA (Stone Matrix [Mastic] Asphalt), with up to eight different HMA mix-design characteristics were evaluated and are listed in Table 2, including the mix type, highway, asphalt-binder type and content, aggregate type, etc. As documented elsewhere [14], these mixes were selected to geographically cover some of the main climatic zones of Texas, namely dry-warm (DW), wet-cold (WC), wet-warm (WW), and moderate (M) climatic regions.

For HWTT testing, the HMA samples for the mixes listed in Table 2 included both field-extracted cores from in-service highways and those molded from plant-mix or raw materials in the laboratory, respectively. With the exception of the field-extracted cores that were tested at the in-situ field density, all the lab-molded HMA samples were molded to a target compaction density (i.e., target degree of compaction) of 93 ± 1%, i.e., 7 ± 1% air voids (AV), as specified by the Texas Department of Transportation (TxDOT) standards [13]. Three replicate samples of each mix were tested with a coefficient of variation (COV) of 30% (i.e., COV ⩽ 30%) used as a threshold measure of repeatability and variability in the test data [12,14].

4. Laboratory test results and analysis

This section presents the results and the corresponding analyses of the HWTT sensitivity evaluation. However, it should be

Table 2
Materials and mix-design characteristics.

#	Mix type	District source	Climatic zone	Highway	Asphalt-binder	Aggregate	Asphalt-binder content (AC) (%)
1	Type B	Waco	M	IH 35	PG 64-22	Limestone + 30% RAP	4.6
2	Type C	Laredo	DW	Loop 480	PG 64-22 PG 70-22 PG 76-22	Crushed Gravel + 20% RAP	5.0
3	Type C	Laredo	DW	US 83	PG 64-28	Limestone + 17% RAP	4.6
4	Type C	Bryan	WW	SH 21	PG 64-22	Limestone + 17% RAP	4.8
5	Type D	Houston	WW	FM 2100	PG 64-22 PG 76-22	Limestone/Dolomite + RAP/RAS	5.3
5	Type C	Corpus Christi	M	US 181	PG 64-22	Limestone/Dolomite + 20% RAP	5.1
6	CAM	Paris	WC	SH 121	PG 64-22	Igneous/Limestone	7.0
7	SMA	Waco	M	IH 35	PG 76-22	Limestone/Dolomite	6.0
8	Type C	Laredo	DW	SS 260	PG 64-22 PG 76-22	Limestone/Dolomite + 17%RAP + 3%RAS	5.3

noted that these laboratory test results pertain only to the HMA mixes and the laboratory test conditions defined in this study. Therefore, the overall findings and conclusions may not be exhaustive.

4.1. Effects of HMA sample sitting time

Due to simple HMA sample preparation methods for the HWTT, test specimens can be practically ready for testing within one day of fabrication. However, the Tex-242-F test procedure, as at the time of this study, did not specify the allowable time frame between sample fabrication and testing, i.e., the HMA sample sitting time. Specifically, for routine HMA mix-design screening, HWTT samples should generally and desirably be tested as soon as practically feasible after fabrication.

Several studies have shown that sample sitting time has a considerable effect on HMA laboratory test results due to the oxidizing and short-term aging effects of the asphalt binder that have a tendency to stiffen up the HMA [12–15]. Therefore, with a view of studying the effects of sample sitting time on the HWTT rutting response parameters, two most commonly used HMA mixes (Type C and D) on Texas highways were tested in the HWTT setup with varying the sitting times from 1 up to 14 days; all run up to 20,000 load passes based on the PG 76-22 asphalt binder in Table 2 (i.e., SS 260 and FM 2100). As previously stated, HWTT samples for routine HMA mix-design screening should desirably be tested within the shortest practically possible time period after molding/-fabrication so as to minimize any oxidative aging effects of the asphalt binder on the lab test results. Therefore, the maximum sitting time period incorporated in the laboratory test matrix and investigated in this study was 14 days. The corresponding HWTT rutting response curves are shown in Fig. 3.

As shown in Fig. 3, the sample sitting time, indeed, has significant effects on the HWTT rutting responses of the HMA mixes. Particularly, the rutting resistance of the FM 2100-Type D mix considerably improves when tested 7 and 14 days after fabrication, respectively. The HWTT response curves were further analyzed to obtain the HWTT rutting parameters presented in Fig. 4.

Fig. 4 clearly shows that the rutting resistance of the HMA mixes evidently improved with increased sample sitting time. At 20,000 load passes, both mixes would fail the HWTT specification ($Rut_{max} \geqslant 12.5$ mm) if tested within three days of sample fabrication. However, if the sample sitting time exceeds five days, both mixes pass the HWTT at 20,000 load passes.

The shape of the rutting response curves also improves (turning from convex to the more desirable concave shapes) as the HMA sample is left untested for longer sitting-time durations; a significant change occurs beyond five days in both Figs. 3 and 4 [14]. The rutting response curves are almost overlapping in Fig. 4a from 7 days onwards. Also, in Fig. 4, a significant change in both the shape and slope of the curves appears to occur after a sample sitting time of 5 days, particularly for Fig. 4b. Thus, for the mixes evaluated and in consideration that HWTT samples for routine HMA mix-design screening should desirably be tested as soon as they are fabricated, five days appears to be the optimal sitting time within which to test the HMA sample in the HWTT.

Although limited to only two mixes, the results in Figs. 3 and 4 imply that, in the absence of a specified sample sitting time, samples are often tested at random times and not soon after fabrication as would be desired; thus increasing the chances of misleading laboratory rutting performance evaluations. For example, a mix could misleadingly pass the HWTT in case that the HMA samples were tested after a longer sitting time period; then the mix may fail prematurely in the field. This aspect is synonymous to what is currently being observed in Texas: some HMA mixes are passing the HWTT in the laboratory but failing prematurely in the field. Without ruling out the other potential effects of design, pavement structure, construction, traffic, and environment (climate), sample

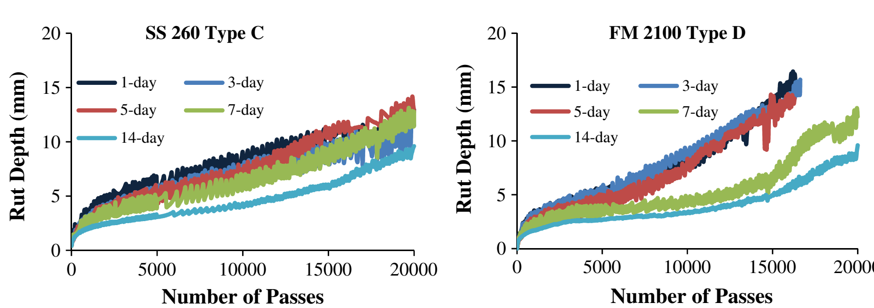

Fig. 3. HWTT rutting curves for varying HMA sample sitting time.

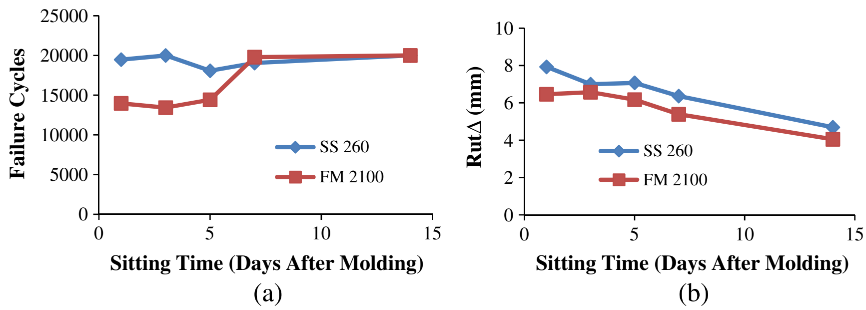

Fig. 4. Effects of HMA sample sitting time on HWTT rutting results.

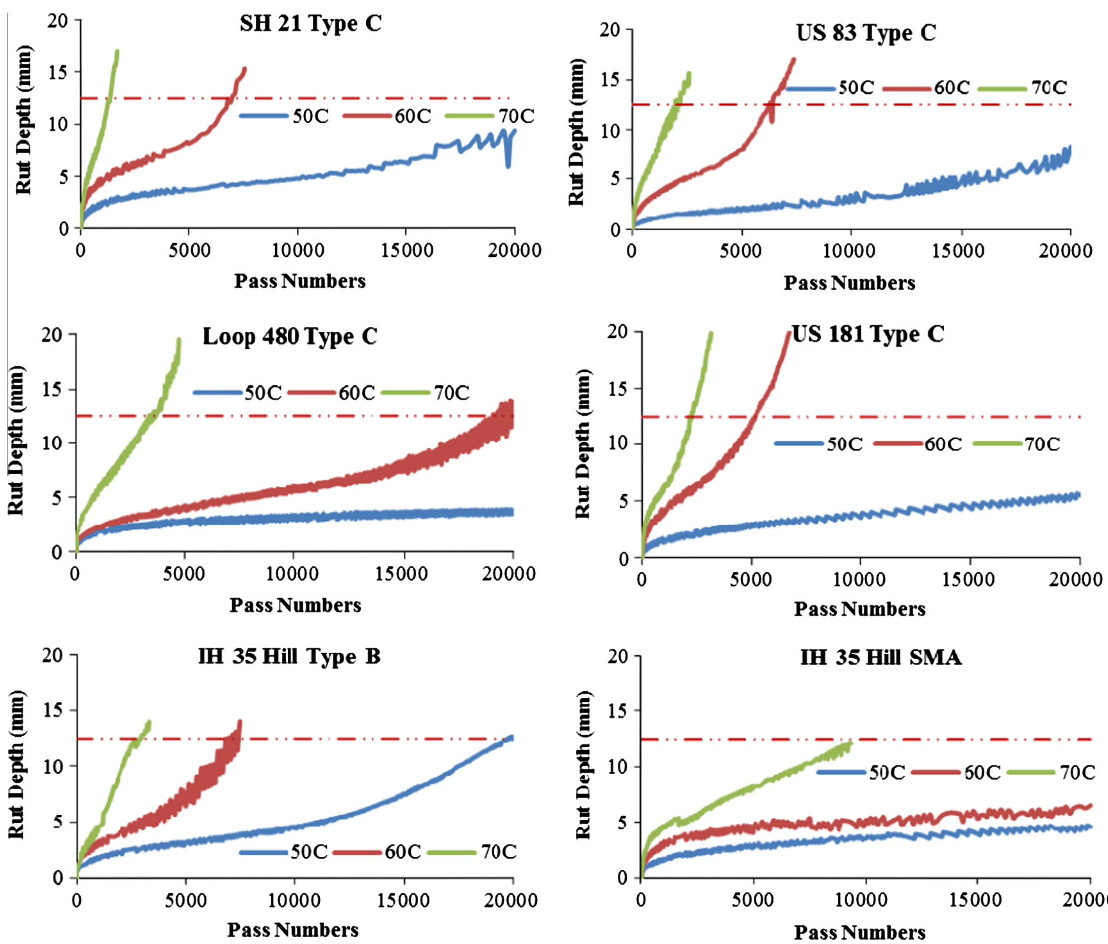

Fig. 5. HWTT rutting curves for test temperature variation.

sitting time and possible HMA stiffening effects due to oxidative aging could be one contributing cause for the premature failures in the field. Thus, to ensure consistency, it is proposed that all HWTT samples be consistently tested within five days after fabrication [14]. In general, HWTT samples for routine HMA mix-design screening should desirably be tested as soon as they are fabricated, if practically feasible, so as to minimize the oxidative aging effects of the asphalt binder on the test results.

4.2. Effects of test temperature variation

As previously discussed, one of the issues of concern has been that many of the Texas' HMA mixes performed satisfactorily in the laboratory under the HWTT, but they fail prematurely by rutting, shoving, and/or shearing in the field. Based on the Tex-242-F test procedure, the HWTT is currently run only at 50 °C (122 °F). As can be noted from Table 1, this temperature is arguably insufficient to effectively capture the thermal conditions that the HMA mixes are currently experiencing in the field. This difference can be another explanation of the HMA mixes passing the HWTT in the laboratory but failing in the field when exposed to sustained elevated summer temperatures [14]. To check the adequacy of the current test procedure (Tex-242-F), six commonly used Texas mixes listed Table 2 with varying temperatures were evaluated, ranging from 50 to 70 °C (122–158 °F). Based on the previous findings regarding sample sitting time, all the HMA samples for temperature variation were tested within five days, averaging three days, from the actual date of molding/fabrication. The resulting HWTT rutting response curves for some selected mixes are shown in Fig. 5.

It is evident from Fig. 5 that the HWTT results of the HMA mixes are highly sensitive to test temperature. Three HMA mixes such as SH21, US83, and US181 failed ($Rut_{max} \geqslant 12.5$ mm at 10,000 passes for PG64-XXwhen the test temperature was increased from 50 to 60 °C (122–140 °F) while all the six HMA mixes failed when tested at 70 °C (158 °F). This response behavior was theoretically expected since at higher temperatures the HMA mixes get softer and thus, are more susceptible to rutting/shear failure. Nonetheless, these observations reinforce the concerns regarding the current HWTT test temperature (50 °C) as defined in the Tex-242-F specification. Clearly, these tested HMA mixes, which all pass the current HWTT specification, would be susceptible to field rutting failure when subjected to high pavement temperatures. This is of particular concern given the continued escalation of summer temperatures, which in the recent years averaged about 58.3 °C (136.9 °F) with some highways experiencing pavement temperatures even as high as 63 °C (145 °F) as listed in Table 1.

Table 3
HWTT test results and test temperature variation.

HMA mix description	Temperature (°C)	Rut_{max} (mm)	N_d
SH 21 Type C	50	9.4	20,000
	60	12.5	6964
	70	12.5	1347
US 83 Type C	50	8.2	20,000
	60	12.5	6391
	70	12.5	2063
Loop 480 Type C	50	3.6	20,000
	60	12.3	20,000
	70	12.5	3455
US 181 Type C	50	5.52	20,000
	60	12.5	5178
	70	12.5	2199
SS 260 Type C	50	12.1	20,000
	60	12.5	6505
	70	12.5	1890
FM 2100 Type D	50	12.5	13,429
	60	12.5	4851
	70	12.5	1063
IH 35 Type B	50	2.9	20,000
	60	8.5	20,000
	70	12.5	6992
IH 35 SMA	50	4.61	20,000
	60	6.6	20,000
	70	12.5	9849

The HWTT output data in Fig. 5 were further analyzed to generate the results presented in Table 3 and Fig. 6. The corresponding results and findings (Table 3 and Fig. 6) reinforce the discussion of the preceding sections regarding the high level of sensitivity of the HMA rutting parameters to temperature under HWTT testing. Rutting resistance of all the HMA mixes worsened considerably with increasing test temperature for all the HWTT parameters. Based on these findings and considering the current high field temperature trends as exemplified in Table 1, it is proposed that higher or multiple HWTT test temperatures (e.g., 50, 55, 60 °C [122, 131, 140 °F]) should be considered, particularly for HMA mixes to be placed in high temperature areas [14]. Perhaps even more critical is to consider running the HWTT at elevated and/or multiple temperatures for surface and near surface HMA mixes used in critical highway locations such as intersections, urban stop–go sections, high shear-stress locations, curves, etc., or where low PG asphalt binders are used.

5. Summary and recommendations

In this study, the HWTT protocol was evaluated with the onus of proposing modifications and improvements to the current Tex-242-F test procedure such that it is more comprehensive to capture the field rutting performances of HMA mixes commonly used in Texas. Based on the HMA mixes evaluated, the key findings and recommendations drawn from this study are summarized as follows:

- Due partly to global warming, current pavement temperatures in some regions are very high, reaching as high as 63 °C in Texas, and sustained for longer periods. Also, due to HMA's visco-elastic nature, the HMA surface layers become very susceptible to rutting failure with increasing temperatures. Thus, evidently calling for consideration of higher (>50 °C) or multiple HWTT test temperatures, particularly for surface or near surface mixes.
- The HWTT rutting depth increases significantly with increasing temperature, with most HMA mixes failing at 70 °C (but passing at 50 °C). Therefore, in view of the recent increase in rutting failures under sustained high summer field temperature and high traffic stress environments, running the HWTT at higher and/or multiple test temperatures up to 60 °C (i.e., testing the mixes at 50, 55, and 60 °C, respectively) should be considered for HMA mixes to be placed in high temperature and high shear stress environments.
- The rutting-resistance of HMA mixes improves with increasing sample sitting time. Therefore, varied sample sitting times for HWTT testing can lead to misleading rutting performance prediction of the HMA mixes in the laboratory and thus, increasing the risk of premature early-life rutting failures in the field.

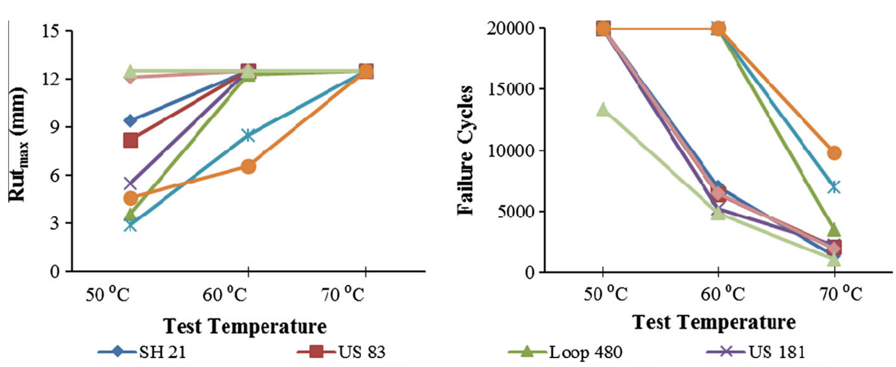

Fig. 6. Effects of temperature variation on HWTT rutting results.

Based on the results of this study, it is proposed that all lab-molded HWTT samples for routine HMA mix-design screening should be consistently tested within five days after fabrication. This helps to ensure consistency and minimize the possible effects of oxidative aging that can stiffen up the HMA and yield misleading results such as HMA mixes passing in the lab but failing prematurely in the field.

Overall, the recommended proposals to consistently test the HMA samples within five days after laboratory fabrication is not unreasonable and practically doable during the routine HMA mix-design screening process. Similarly, consideration of higher (>50 °C) and/or multiple HWTT test temperatures is critical for field performance optimization, particularly for surface or near surface HMA mixes used in high temperature and high stress environments. Consideration of these two aspects, i.e., optimal HWTT sample sitting time (⩽5 days) and additional high test temperatures (55 and 60 °C) as part of the routine HMA mix-design screening process, will no doubt contribute to designing of superior performing HMA mixes with respect to rutting resistance. However, additional lab testing with more HMA mixes (including CAM, PFC, SMA, Type B, Type F, SuperPave, etc.) along with correlations and validation with field rutting performance data is strongly recommended.

Lastly, it should be noted that the laboratory test results reported in this paper pertain only to the HMA mixes and the laboratory test conditions defined in this study. Therefore, the overall findings and conclusions may not be exhaustive.

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