EVALUATION OF HAMBURG RUT TESTER FOR FIELD CONTROL OF HOT MIX ASPHALT (HMA)

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I* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
^{o}F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^{o}C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
^oC	Celsius	1.8C+32	Fahrenheit	^oF
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

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Evaluation of Hamburg Rut Tester for Field Control of Hot Mix Asphalt (HMA)

Introduction

The following report summarizes the work accomplished to date on a two-year (a 1-year extension to include MIST testing was approved for FY 2012) study on Evaluation of Hamburg Rut Tester for Field Control of Hot Mix Asphalt (HMA).

The Asphalt Pavement Analyzer (APA) and AASHTO T 283, *Resistance of Compacted Bituminous Mixture to Moisture-Induced Damage*, are currently used in mix design by ODOT to evaluate rutting and moisture damage potential of hot mix asphalt (HMA) mixtures. AASHTO T 283 is also used for field control of HMA mixtures. ODOT is moving toward replacing the APA with the Hamburg Rut Tester (OHD L-55). Variability of AASHTO T 283 field test results have always been an issue and currently ODOT does not check rutting potential of field produced mixtures. The Hamburg rut tester is being used by other DOTs, most notably TXDOT (1), to monitor field produced mixtures for rutting and moisture susceptibility. Use of the Hamburg rut tester needs to be evaluated for field control of HMA mixtures in Oklahoma.

The objective of this study is to gather sufficient AASHTO T 283 and OHD L-55 data from laboratory prepared (mix design) samples and field produced mix from across Oklahoma to determine if OHD L-55 can be implemented to monitor field produced mixtures for rutting and/or moisture susceptibility and to develop draft implementation plans (draft test methods /specifications) if test results warrant implementation.

Task 1 Literature Review

There is a wealth of information available in the literature on tests for moisture susceptibility and rutting. The amount of literature is an indication that solutions to these problems have not been completely solved. Moisture damage or stripping is generally thought to be an aggregate and binder compatibility problem and is, therefore, local in nature. The literature review for this study will concentrate on literature from surrounding states to determine how they have implemented the Hamburg Rut Tester, if at all, and whether and how it is used to replace or supplement moisture damage testing (AASHTO T 283 or equivalent).

Numerous test methods have been developed in the past to predict moisture susceptibility of HMA mixes. However, no test has received wide acceptance. This is generally thought to be due to their low reliability and lack of satisfactory relationship between laboratory and field conditions. Test methods used in the past include boiling water tests (ASTM D 3625 or variations), static immersion tests (AASHTO T 182), Lottman test (NCHRP 246), modified Lottman test (AASHTO T 283), Tunnicliff-Root (ASTM D 4867) and immersion-compression tests (AASHTO T 165). As a part of the Strategic Highway Research Program (SHRP) a net adsorption test and the Environmental Conditioning System (ECS) Test were developed (2). Neither procedure caught on but the net adsorption test has received further study in recent years including work performed at Texas A&M (3), OU (4) and OSU (5).

At about the same time as SHRP, interest grew in proof testing HMA mixtures and the Hamburg rut tester and the APA were introduced. The Hamburg originally tested pavement slabs under water at an elevated temperature and was considered a torture test. It has been modified to accept laboratory compacted pills. The APA tests beams or pills at elevated temperatures and can operate either wet or dry. Many agencies originally adopted the APA, which was more readily available, but the Hamburg has been steadily gaining acceptance since it became commercially available.

Cross (6) investigated the use of the APA to evaluate both rutting and stripping; however, the use of the APA to detect moisture susceptible mixtures has never gained wide acceptance. Aschenbrener (7) evaluated several test procedures to predict moisture susceptible mixtures and found none completely acceptable. Aschenbrener recommended modifications to the Hamburg procedure and since that time several agencies have made changes/modifications to the procedure and some have adopted the Hamburg for control of rutting and moisture damage of HMA mixtures (1,7). The Hamburg is now routinely used for evaluation of HMA mixtures (8,9).

However, as shown by Aschenbrener (7), slight modifications to test procedures are often necessary before an empirical test procedure can be adopted for use with local materials and environmental conditions.

Task 2 Evaluation of Laboratory Produced Samples

Each ODOT approved mix design requires AASHTO T 283 testing and contractors, on a limited basis, are sending OHD L-55 (Hamburg) samples to the ODOT Central Lab for testing. A CD of sorted mix designs from ODOT's mix design web page that contained mixes with AASHTO T 283 TSR results and Hamburg test results (OHD L-55) was supplied by ODOT for statistical analysis.

The preliminary statistical analysis consisted of performing correlation analysis of the entire data set and the data sorted by PG Grade and mix type. Correlation analysis returns Pearson's correlation coefficient R. If this coefficient is squared you get the coefficient of determination or R^2 from the more familiar regression analysis. A positive R value means that as one value increases so does the other. A negative R means that as one value increases the other value decreases. The results of the correlation analysis for all of the data and the data sorted by PG Grade and mix type are shown in tables 1-3, respectively.

There is no correlation of Hamburg rut depths with TSR or ITS. That is not unexpected as the ODOT data base would only contain mixtures that passed the Hamburg and TSR tests, resulting in clustered data.

TABLE 1 RESULTS OF CORRELATION ANALYSIS

Pearsons Correlation Coefficient R			
	Rut Depth	ITS	TSR
Rut Depth	1.00	-0.31	-0.18
n	183	181	183
ITS	-0.31	1.00	-0.13
n	181	181	181
TSR	-0.18	-0.13	1.00
n	183	181	183

TABLE 2 RESULTS OF CORRELATION ANALYSIS, By PG Grade

Pearsons Correlation Coefficient R			
PG 76-28			
	Rut Depth	ITS	TSR
Rut Depth	1.00	-0.40	-0.13
n	46	44	46
ITS	-0.40	1.00	-0.03
n	44	44	44
TSR	-0.13	-0.03	1.00
n	46	44	46
PG 70-28, n = 26			
	Rut Depth	ITS	TSR
Rut Depth	1.00	-0.42	-0.23
ITS	-0.42	1.00	-0.26
TSR	-0.23	-0.26	1.00
PG 64-22, n = 111			
	Rut Depth	ITS	TSR
Rut Depth	1.00	-0.23	-0.21
ITS	-0.23	1.00	-0.13
TSR	-0.21	-0.13	1.00

TABLE 3 RESULTS OF CORRELATION ANALYSIS, By Mix Type			
Pearsons Correlation Coefficient R			
S-3, n = 55			
	Rut Depth	ITS	TSR
Rut Depth	1.00	-0.26	-0.29
ITS	-0.26	1.00	0.09
TSR	-0.29	0.09	1.00
S-4, n = 106			
	Rut Depth	ITS	TSR
Rut Depth	1.00	-0.35	-0.20
ITS	-0.35	1.00	-0.22
TSR	-0.20	-0.22	1.00
S-5, n = 16			
	Rut Depth	ITS	TSR
Rut Depth	1.00	-0.23	-0.21
ITS	-0.23	1.00	-0.13
TSR	-0.21	-0.13	1.00

In addition to correlation analysis, a frequency distribution plot of the AASHTO T 283 results was developed. The results are shown in the figure 1. As shown in figure 1, ODOT does not allow the production of HMA mixes that fail AASHTO T 283. However, failing test results are necessary to properly evaluate the Hamburg Rut Tester and the MIST. Therefore, the intent was to identify and sample mixes for testing and evaluation that met the following requirements:

- 3-4 mixes that require an anti-strip agent to pass AASHTO T 283,
- 3-4 mixes that pass AASHTO T 283 without anti-strip but with a TSR < 0.83,
- 3-4 mixes that pass AASHTO T 283 without anti-strip but with a TSR > 0.85.

Nine mixes were sampled and tested. Four mixes were sampled that required a liquid anti-strip agent to pass AASHTO T 283 and five mixes were sampled that did not require an anti-strip agent. Of these mixes, two were selected with TSRs in the low 0.80s. Belt feed samples of the blended aggregates were obtained and RAP was sampled for mixtures that contained recycled mix. Asphalt cement from the project was obtained to use with the materials, replicating the mix designs.

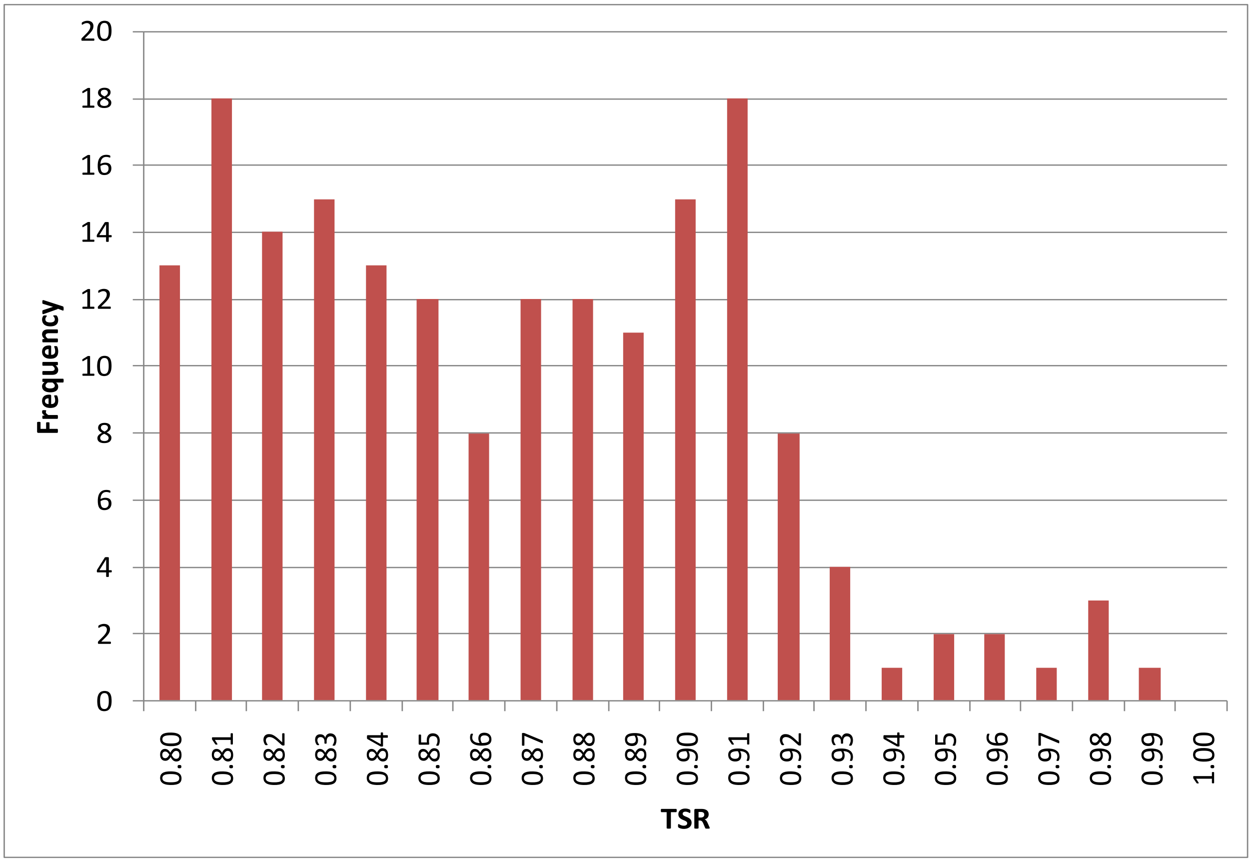

Figure 1 Frequency analysis of AASHTO T 283 results.

Mixes that required anti-strip were tested in the Hamburg Rut Tester (OHD L-55) with and without anti-strip agent. Mixes that did not require anti-strip were tested in the Hamburg Rut Tester at the field produced asphalt content and with an additional 0.5% asphalt. All testing for task 2 is complete. The mixes and testing matrix for task 2 are shown in tables 4 and 5.

Table 4 Test Matrix for Task 2, Mixes With Anti-Strip

Mix ID	Hamburg		T 283
	with Anti-Strip	with out Anti-Strip	with Anti-Strip
Roberts-Arkhola	X	X	X
Alva-Venture	X	X	X
Kansas-Venture	X	X	X
J&R Sand	X	X	X

Table 5 Test Matrix for Task 2, Mixes Without Anti-Strip

	Hamburg		T 283
Mix ID	Optimum	Optimum	Optimum
	AC	+ 0.5% AC	AC
Haskell-Lemon	X	N/A	X
APAC-Tulsa	X	X	X
Altus-Dobson	X	X	X
Stillwater-Cummins	X	X	X
Silver Star	X	X	X

Task 3 Evaluation of Field Produced Samples

Plant produced mix was not available from each mix tested in Task 2. Plant produced mix was available from seven of the nine mixes tested in task 2. Plant produced mix was tested for maximum specific gravity (Gmm) in accordance with AASHTO T 209 and then the asphalt content was determined in accordance with OHD L-26 and the gradation of the recovered aggregate was determined in accordance with AASHTO T 30. Samples from task 2 were compacted at the asphalt content determined from plant produced samples. The Gmm determined from the plant produced samples was used for all voids calculations.

The plant produced mix was returned to the laboratory, reheated to the compaction temperature, and test samples of the required height and voids were fabricated. Samples of plant produced mix were tested for AASHTO T 283 and OHD L-55 (Hamburg) testing. All testing for Task 3 is complete. The mixes and testing matrix for task 3 are shown in table 6.

Table 6 Test Matrix for Task 3, Plant Produced Mix

Mix ID	Anti-Strip	Hamburg	T 283
Roberts-Arkhola	Yes	N/A	N/A
Alva-Venture	Yes	X	X
Kansas-Venture	Yes	X	X
J&R Sand	Yes	X	X
Haskell-Lemon	No	N/A	X
APAC-Tulsa	No	N/A	X
Altus-Dobson	No	X	X
Stillwater-Cummins	No	X	X
Silver Star	No	X	X
N/A Plant mix not available			

Task 4 Analysis of Data

Data obtained from tasks 2 and 3 will be analyzed using appropriate statistical techniques to determine the relationships between laboratory fabricated AASHTO T 283 test results and laboratory fabricated OHD L-55 test results. Results from field produced samples would be compared using the same techniques and the differences between field test results and laboratory fabricated test results will be evaluated. Data analysis is underway.

Work Planned for Year 2

Through an OTC project, OSU purchased a Moisture Induced Stress Tester (MIST). The MIST (shown to the right) is a new sample conditioning device designed to simulate the stripping mechanisms caused by the cyclic loading and unloading of tire pressure on an asphalt pavement. The MIST replaces the moisture conditioning sequences of AASHTO T 283 with a more realistic sample conditioning, reducing the time required to evaluate moisture susceptibility of HMA mixes.

A one year extension was requested in FY 2011 to include MIST testing. The extension was approved for FY 2012. The objective of the extension is to gather MIST data from the samples tested in tasks 2 & 3 to determine the ability of the MIST to identify moisture susceptible mixtures.

Tasks
The objectives of the MIST study would be accomplished by completing the following tasks.

Task 1 Literature Review: There is still interest in the mechanisms that cause rutting and a national seminar (10) was held on this topic in 2003. Even though AASHTO T 283 and its modifications are still used, and the Hamburg Rut Tester is gaining acceptance, there was a need voiced at the seminar (10) for a procedure that more closely simulates stripping mechanisms caused by cyclic loading and unloading of tire pressure on an asphalt pavement.

Preliminary work by the MIST developers indicate that sample swelling after conditioning in the MIST is related to moisture susceptibility. The MIST conditions AASHTO T 283 sized samples (150 mm dia., 95 mm tall, 7±1.0% voids) that can be further tested for conditioned tensile strength and compared to unconditioned samples for tensile strength ratio as in AASHTO T 283.

Task 2 Obtaining Field Produced and Laboratory Prepared Samples: At a minimum, the same mixtures samples in Tasks 2 and 3 of year 1 will be tested in the MIST. Samples that require a liquid anti-strip will be tested with and without the anti-strip with the MIST. Table 7 shows the test matrix for MIST testing.

Table 7 Testing Matrix for MIST Testing

Mix ID	Anti-Strip	with Anti-Strip	with out Anti-Strip	Field Mix
Roberts-Arkhola	Yes	X	X	X
Alva-Venture	Yes	X	X	X
Kansas-Venture	Yes	X	X	X
J&R Sand	Yes	X	X	X
Haskell-Lemon	No	N/A	N/A	N/A
APAC-Tulsa	No	N/A	N/A	N/A
Altus-Dobson	No	N/A	X	X
Stillwater-Cummins	No	N/A	X	X
Silver Star	No	N/A	X	X
N/A Not applicable				

***Task 3 & 4 Evaluation of Laboratory and Field Produced Samples**:* Samples for MIST testing will be conditioned in accordance with the manufacturer's recommendations. MIST sample conditioning involves cyclic loading to 40 psi of a sample submerged in 40^{o}C water. After conditioning the mixtures will be brought to 25^{o}C and tested for volume change by determining the saturated surface dry and submerged mass. The samples are then tested for conditioned tensile strength and tensile strength ratio determined by using the control (unconditioned) samples from AASHTO T 283.

Task 5 Analysis of Data: Data obtained from tasks 3 and 4 would be analyzed using appropriate statistical techniques to determine the relationships between laboratory fabricated AASHTO T 283 test results, OHD L-55 test results and MIST results. Results from field produced samples would be compared using the same techniques and the differences between field test results and laboratory fabricated test results will be evaluated. The objective is to compare MIST results with AASHTO T 283 and Hamburg results to determine if the MIST or the Hamburg is better suited to monitor field produced mixtures for moisture susceptibility and to develop draft implementation plans (draft test methods /specifications) if test results warrant implementation.

Time Schedule

The proposed work schedule, by work task, is shown in table 8.

Table 8 Proposed Year 2 Work Schedule

	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Task 1												
Task 2												
Task 3												
Task 4												
Task 5												
Task 6												
Quarterly Reports												

References

1. *Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges.* Texas Department of Transportation, Austin, TX, June 2004.
2. Roberts, Kandhal, Brown, Lee and Kennedy. *Hot Mix Asphalt Materials, Mixture Design and Construction*. NAPA Education Foundation, 2nd Edition, Lanham, MD, 1996.
3. Lytton, R.L., Masad, E.A., Zollinger, C., Bulut, R., and Little, D. (2005). Measurements of Surface Energy and Its Relationship to Moisture Damage. FHWA/TX-05/0-4524-2 Research Report, Texas Transportation Institute, College Station, Texas.
4. Cross, Zaman, et al. *Warm Mix Asphalt: Moisture Damage Potential and Performance Issues.* Draft Final Report. Oklahoma Transportation Center, 2008.
5. Bulut, Rifat. *WMA Pavements in Oklahoma: Moisture Damage and Performance Issues.* OTC project 10.1-06, Oklahoma Transportation Center, March 2010.
6. Cross, Stephen A. and Michael D. Voth. *Evaluation of Anti-Stripping Agents Using the Asphalt Pavement Analyzer*. Report No. K-TRAN: KU-99-3. Kansas Department of Transportation, Topeka, Kansas, June 2001, 103 pp.
7. Aschenbrener, et al. "Comparison of Several Moisture Susceptibility Tests in Pavements of Known Field Performance." *Journal*, Association of Asphalt Paving Technologists, Vol. 64, Portland, OR, 1995, pp. 96-129.
8. Scullion, et al. *Design and performance Evaluation of very Thin Overlays in Texas.* Report FHWA/TX-09/0-5598-2. Texas Transportation Institute, Texas A&M University, College Station, Texas, June 2009.
9. Zhou, et al. *Integrated Asphalt (Overlay) Mixture Design, Balancing Rutting and Cracking Requirements.* Report FHWA/TX-06/0-5123-1. Texas Transportation Institute, Texas A&M University, College Station, Texas, October 2006.
10. Moisture Sensitivity of Asphalt Pavements, A National Seminar. TRB, National Research Council, San Diego, CA, February 4-6, 2003.