NEW MEXICO DEPARTMENT OF TRANSPORTATION

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Innovation in Transportation

EVALUATION OF RUTTING AND STRIPPING POTENTIAL OF SELECTED HMA/WMA MIXES USING HAMBURG WHEEL TRACKING DEVICE (HWTD) – REVIEW OF CURRENT PRACTICE

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16. Abstract

This report summarizes the state of practice of using the Hamburg Wheel Tracking Device (HWTD) test for predicting and evaluating the rutting and moisture susceptibility potential of hot mix asphalt (HMA) and warm mix asphalt (WMA). This report was prepared based on the literature review, with emphasis on what has been reported and documented in the last 10 years. To date, at least nine state Departments of Transportation (DOTs) have incorporated the HWTD test into their specifications for mix design and/or for construction quality assurance and/or quality control. To require HWTD testing, the most common approaches are to specify the maximum rut depth measured in the HWTD test either 1) for a single number of wheel passes varying the test temperature according to the performance grade (PG) binder, or 2) for a given test temperature varying the maximum number of passes for various PG binders. Other HWTD test results, such as the stripping inflection point and the stripping slope, have also been used in evaluating mixture performance.

The experience of Colorado DOT and Texas DOT, among few other state agencies, using the HWTD as a performance test has been documented in reports, presentations and papers and confirmed that the HWTD test is a good indicator of the rutting and moisture susceptibility (or stripping) potential of the mixtures. The findings of two documented long-term field monitoring and evaluation projects also confirmed the applicability of the HWTD test as a performance test. The performance of New Mexico mix designs under the HWTD test conditions is unknown and a very limited number of test results are available from two recent projects. The recommendations for an implementation phase to research the applicability of the HWTD test for HMA and WMA mix designs and production phases and test performance of the New Mexico mix designs are proposed.

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Hamburg Wheel Tracking Device, rutting, stripping, water susceptibility, mix design, specifications.

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PREFACE

This report was prepared by Dr. Paola Bandini and Dr. Douglas Cortes of the Civil Engineering Department at New Mexico State University for the New Mexico Department of Transportation (NMDOT) Research Bureau. The motivation of NMDOT to sponsor this project was the interest of this agency on assessing the effectiveness and reliability of the Hamburg Wheel Tracking Device (HWTD) test for predicting the rut depth and stripping (moisture susceptibility) potential of hot and warm asphalt mixtures, particularly those approved to be used in New Mexico.

The main objective of the report is to summarize the relevant literature on the HWTD test and best practices using this test as a performance measure in specifications for asphalt mix selection and construction quality assurance/quality control (QA/QC). This report was based on the information obtained from the literature review and corresponds to the initial phase of the research. The authors met biweekly with the NMDOT Technical Panel members to present and discuss the findings during the project from February to July of 2014.

The report summarizes the outcomes of the following project tasks:

Task 1A: Perform a literature search and review on the use of the HWTD test to predict rut depth and stripping potential of the hot mix asphalt (HMA) and warm mix asphalt (WMA).

Task 1B: Perform literature review of studies to determine rutting and stripping potential of HMA and WMA, and identify which state Departments of Transportation (DOTs) employ the HWTD, how the HWTD test has been integrated into the mix design and construction QA/QC specifications, and what test protocols have been adopted for HWTD testing.

Task 1C: Determine if any report in the Long Term Pavement Performance (LTPP) database contains information relevant to this project in which the HWTD test was used to assess rutting and stripping potential.

Task 1D: Evaluate and summarize the research reports on HMA and WMA mixtures using HWTD to minimize rutting and stripping in New Mexico pavement and in states with similar climates as New Mexico.

Task 1E: Synthesize the information collected in tasks A through D, primarily to document best practices in the use of HWTD testing for HMA and WMA design and construction QA/QC testing, with emphasis on mixes used in climates similar to those of New Mexico.

NOTICE

DISCLAIMER

ABSTRACT

This report summarizes the state of practice of using the Hamburg Wheel Tracking Device (HWTD) test for predicting and evaluating the rutting and moisture susceptibility potential of hot mix asphalt (HMA) and warm mix asphalt (WMA). This report was prepared based on the literature review, with emphasis on what has been reported and documented in the last 10 years. To date, at least nine state Departments of Transportation (DOTs) have incorporated the HWTD test into their specifications for mix design and/or for construction quality assurance and/or quality control. To require HWTD testing, the most common approaches are to specify the maximum rut depth measured in the HWTD test either 1) for a single number of wheel passes varying the test temperature according to the performance grade (PG) binder, or 2) for a given test temperature varying the maximum number of passes for various PG binders. Other HWTD test results, such as the stripping inflection point and the stripping slope, have also been used in evaluating mixture performance.

The experience of Colorado DOT and Texas DOT, among few other state agencies, using the HWTD as a performance test has been documented in reports, presentations and papers and confirmed that the HWTD test is a good indicator of the rutting and moisture susceptibility (or stripping) potential of the mixtures. The findings of two documented long-term field monitoring and evaluation projects also confirmed the applicability of the HWTD test as a performance test. The performance of New Mexico mix designs under the HWTD test conditions is unknown and a very limited number of test results are available from two recent projects. The recommendations for an implementation phase to research the applicability of the HWTD test for HMA and WMA mix designs and production phases and test performance of the New Mexico mix designs are proposed.

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The authors of this report would like to acknowledge the members of the Technical Panel of the New Mexico Department of Transportation (NMDOT), which included (in alphabetical order) Parveez Anwar, PE, James M. Gallegos, PE, Dr. David Hadwiger, Jeffrey S. Mann, PE, and Robert S. Young, PE, of NMDOT, and Luis Melgoza of the New Mexico Division Office of the Federal Highway Administration (FHWA). The members of the Technical Panel participated in productive discussions and meetings with the authors throughout the project and reviewed this report.

The authors also thank Robert McCoy, PE, State Research Implementation Engineer, NMDOT Research Bureau, for his continuous support with regard to project meetings and technical discussions, and for serving as NMDOT project manager for this project.

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REVIEW OF LITERATURE ON THE HAMBURG WHEEL TRACKING TEST

EQUIPMENT DESCRIPTION

The Hamburg Wheel Tracking Device (HWTD) was developed by Esso A.G. in Hamburg, Germany in the 1970s. The equipment was introduced into the United States in the early 1990s (1). Since then, it has been modified to test cylindrical specimens. Colorado, Texas and Utah were among the first states to consider the use and application of the Hamburg Wheel Tracking (HWTD) test (2). In essence, the HWTD consists of one or more steel wheels, automated wheel pass counter and rut measurement system, a water bath for temperature control (heated), and a specimen mounting system (Figure 1). The test rolls a steel wheel over the compacted asphalt-concrete (AC) specimen, core or slab to evaluate the resistance to rutting and moisture susceptibility of asphalt mixtures. Even though there are several configurations available commercially, the most common setup includes two steel wheels.

The HWTD apparatus is described in the Texas Department of Transportation’s (TxDOT) test specification TEX-242-F “*Test Procedure for Hamburg Wheel-Tracking Test*.” The HWTD is electrically powered and computer-controlled, and has fully automated data acquisition. In the standard equipment, the steel wheels are 8 in. (203.6 mm) in diameter and 1.87 in. (47 mm) in width. The load applied by the wheel on the test specimen is 158 ± 5 lb (705 ± 22 N), which corresponds to a very high contact pressure. The wheels roll over the test specimens (or slabs) at a rate of approximately 50 to 52 passes per minute, at a maximum velocity of approximately 1.1 ft/s (0.305 m/s) when passing on the middle point of the specimen (or slab).

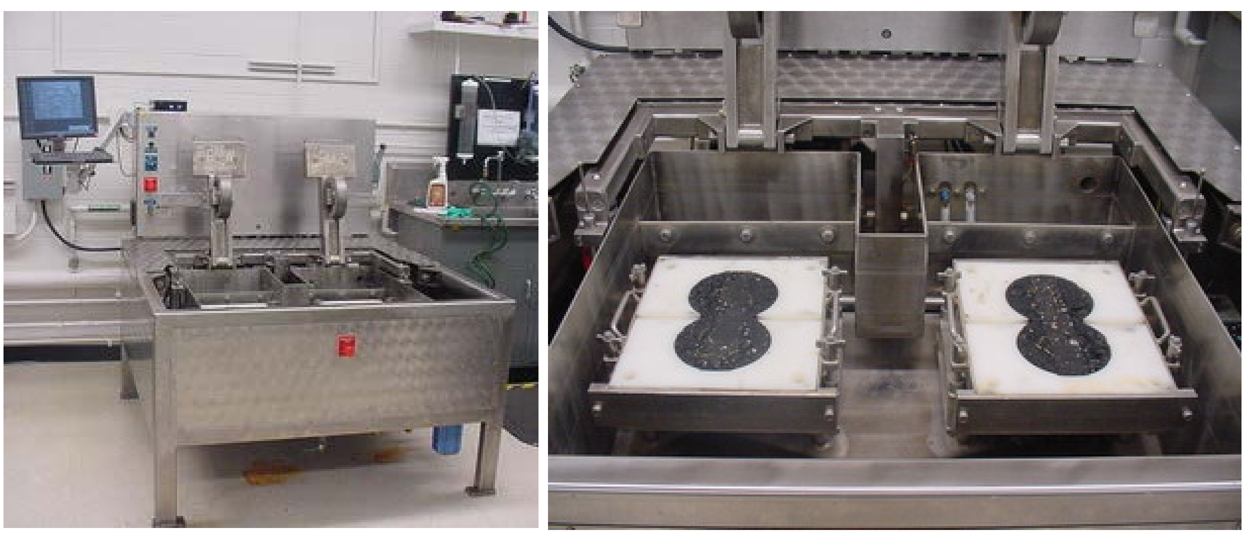

FIGURE 1 Hamburg Wheel Tracking Device (left) and detail of the mounting system with cylindrical specimens in the temperature-controlled water bath (right) (3)

The test samples are placed inside stainless steel trays that are firmly attached to the HWTD in the water bath. The samples should not be allowed to shift, tilt or move during testing. The trays containing the samples should allow free circulation of water on all sides.

The water bath temperature can be set within ± 4^o F (± 2^o C) in the range of 77^o F and 158^o F (25^o C and 70^o C). The HWT test is generally performed with water bath temperatures between 40^o C and 50^o C; however, the test temperature should be selected based on the grade of the asphalt binder of the test specimen. The water bath should include a mechanical circulating system that helps maintain the water temperature constant throughout the tank for the duration of the test.

The HWTD uses a linear variable differential transducer (LVDT) to measure the rut depth on each AC specimen during the test. The rut depth (or wheel impression) is measured at the midpoint of the wheel path on the specimen's top. The Tex-242-F requires the LVDT to have a precision of 0.0004 in. (0.01 mm) over a minimum range of 0.8 in. (20 mm). The system should be able to measure the rut depth at least every 100 wheel passes without stopping the wheel.

TEST SPECIMENS, CORES AND SLABS

The HWTD can be used to test:

- laboratory compacted (or molded) slabs,
- laboratory compacted (or molded) cylindrical specimens, and
- wet saw-cut field compacted core specimens or wet saw-cut field slabs from asphalt pavements.

The AC mixture can be produced in the laboratory or in the field (loose mix). The laboratory molded Superpave specimens are compacted with a Superpave gyratory compactor according to ASTM D6925-09 "*Standard Test Method for Preparation and Determination of the Relative Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor*." Typically, gyratory-compacted (cylindrical) specimens are mounted one in front of the other to provide the required path length for the wheels, as shown in Figure 1. The laboratory molded specimens should be compacted to a specified density of 93 ± 1%. In the United States, several state DOTs such as those of Utah, Texas and Colorado specify the HWTD on cylindrical specimens. High-density polyethylene (HDPE) molds are used for cutting and testing the cylindrical specimens in the HWTD. The plan view of a typical HDPE mold is shown in Figure 2. The thickness of the mold is 60 mm.

The laboratory molded cylindrical specimens are 6 in. (150 mm) in diameter and 2.4 ± 1 in. (62 ± 2 mm) in height. Field core specimens are 6 ± 0.1 in. (150 ± 2 mm) in diameter. However, field cores with larger diameter (10 in. = 254 mm) can be tested in the HWTD. Field slabs are approximately 10.25 in. (260 mm) wide, 12.5 in. (320 mm) long, and 1.5 in to 4 in. (38 mm to 100 mm) thick. Typically, the field cores and slabs are 1.5 in (138 mm) thick but their thickness may be adjusted by wet-saw cutting to fit the size of the available mounting trays.

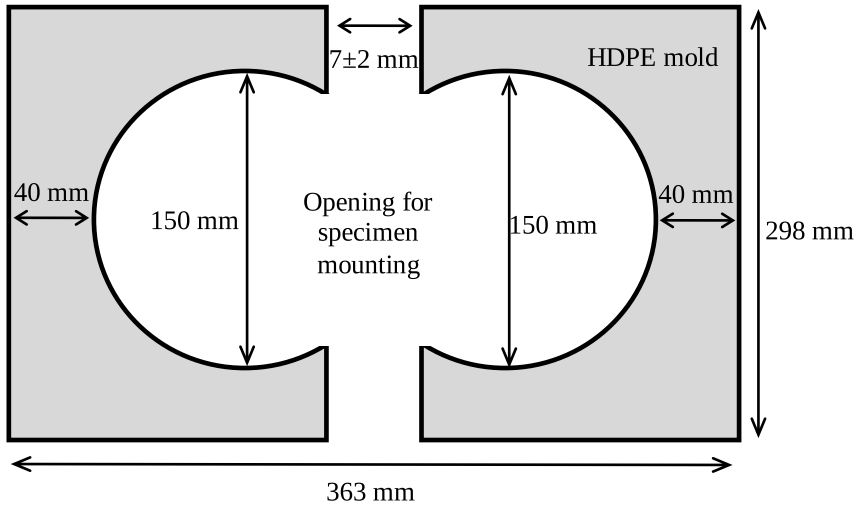

FIGURE 2 Plan view (sketch) of a typical HDPE mold used to place the cylindrical test specimens in the HWTD (not drawn to scale)

TEST PROCEDURE AND STANDARDS

The procedure for the HWTD test is described in the AASHTO T 324-11 *"Standard Method of Test for Hamburg Wheel-Track Testing of Compacted Hot-Mix Asphalt (HMA)."* This test method describes the procedure for testing rutting and moisture susceptibility of HMA pavement samples in the HWTD. The scope of the AASHTO T 324 standard includes that "the test method is used to determine the premature failure susceptibility of HMA due to weakness in the aggregate structure, inadequate binder stiffness, or moisture damage. This test method measures the rut depth and number of passes to failure."

Many of the state DOTs that have adopted the HWTD test in their specifications have also produced modified versions of AASHTO T 324 for internal use in the agency. In most cases, the modifications serve to clarify or provide details in regard to the specimen preparation and/or aging conditions, number of test replicates, and processing and reporting of test results, or to adapt the procedure to the performance of specific mixture types. Some of the state agencies that have adopted their own versions of the testing protocol for the HWTD test are:

- California DOT (LLP-AC2 Test 4, August 14, 2012) (4)
- Colorado DOT (CP-L 5112-14, revised June 1, 2013) (5)
- Illinois DOT (Illinois Modified AASHTO T 324)
- Iowa (Materials I.M. 319, April 16, 2013) (6)
- Montana (MT 334-11, September 2, 2011) (7)
- Oklahoma (OHD L-55, July 14, 2009) (8)
- Texas DOT (TEX-242-F, June 2009) (9)
- Utah DOT (MOI 8-990, November 2005) (10)
- Washington State DOT (FOP for AASHTO T 324, August 2013) (11)

According to a 2013 report for the Iowa DOT (12), in 2007 two state DOTs reported having the requirement of HWTD test in their specifications. In the following years, the number of agencies in the United States (U.S.) requiring HWTD test in the specifications increased, including California, Illinois, Iowa, Kansas, Louisiana, Montana, Oklahoma, Texas, and Utah. Other state DOTs and contractors have acquired the HWTD equipment for research projects and/or are evaluating the method for possible adoption including Florida, Wyoming and Nevada.

TEST DATA AND REPORTING

Rut Depth Data from the HWTD Test

The standard HWTD test method consists of recording rut depth (or permanent deformation) versus the number of passes of the wheel over the AC specimen surface. Figure 3 illustrates a typical curve resulting from the HWTD test data. The rutting curve has three distinct sections. The initial part of the curve, for the first hundreds to a thousand passes, shows an initial permanent deformation of the sample referred to as "post-compaction consolidation" or "consolidation." This initial deformation corresponds to compaction of the HMA sample after the laboratory or field compaction.

The second part of the curve has a flatter slope and it represents the progressive rutting before the moisture damage begins to contribute to permanent deformation. The slope of this section of the curve is called "creep slope" or "rutting slope," and the inverse of this slope is the creep (red segmented line in Figure 3). After a large number of wheel passes, the sample begins to deform at a faster rate due to moisture damage on the aggregate structure and the rutting curve becomes much steeper. The slope of this section of the curve is called "stripping slope" (blue segmented line in Figure 3). This last portion of the curve may include a contribution to permanent deformation from tertiary viscous flow, but it is not possible to separate the viscous flow component from the moisture damage deformation from the data of this test. The number of wheel passes corresponding to the intersection of the creep slope and stripping slope lines is called "stripping inflection point" (SIP) or "stripping point."

Generally, agencies specify a maximum rut depth for a given number of wheel passes and test temperature to define sample failure; however, other approaches to use or specify the test results are also used as it will be described later. The data frequently reported include the number of wheel passes, maximum impression on the sample (or rut depth), test temperature, sample(s) air voids, creep (or rutting) slope, stripping slope, and stripping inflection point (SIP). In addition to rut depth, the agencies may also require or use the SIP, stripping and creep slopes, and slope ratio as metrics in their specifications or research.

Data Reporting Criteria

A concern about AASHTO T 324 discussed in the literature (12) is that the document does not standardize the analysis and reporting of the test results. This issue has led some of the state DOTs that adopted the HWTD test to specify their own reporting criteria for selection of the rut depth measurements that are considered and averaged, whereas other agencies do not specify how the rut depth at failure is to be obtained or simply rely on the results reported by the software provided by the equipment manufacturer (12).

Another concern is that the requirements of results reporting set by the state DOTs that have adopted the HWTD test are not uniform and, therefore, the HWTD manufacturers provide software that applies different result processing and reporting depending on which agencies they serve. A recent research sponsored by the Iowa DOT (12) addressed these concerns and studied the bias introduced by the difference in data processing and reporting on the HWTD test.

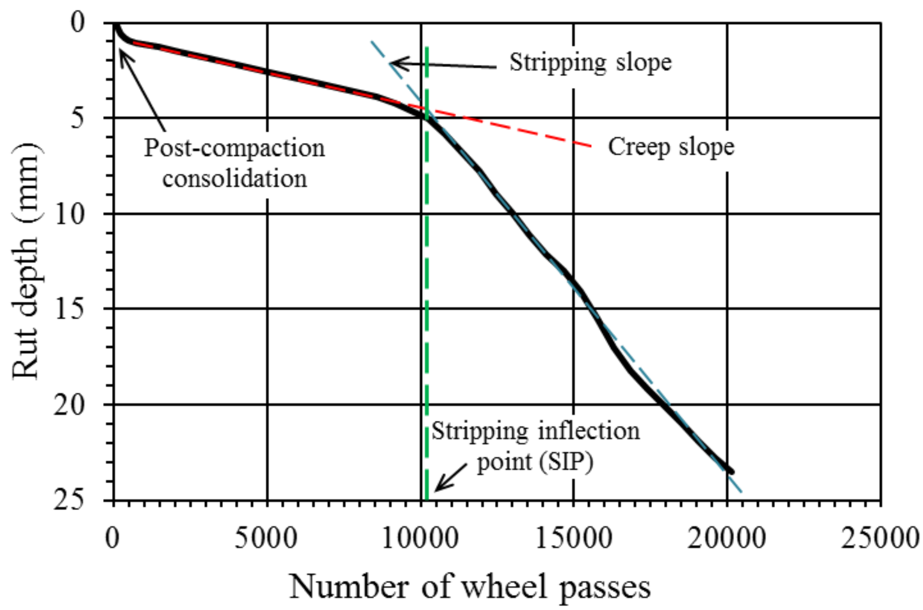

FIGURE 3 Example of typical HWTD test data

TEST REPEATABILITY, BIAS, AND VARIABILITY OF RESULTS

Recent research documented in the literature has focused on assessing whether the current HWTD test and sample preparation procedures can produce repeatable (or consistent) results. Evaluating the quality and variability of the HWTD test results is extremely important when they are used to approve mix designs and for construction QA/QC. The variability of the HWTD test results due to human errors and improper specimen preparation and handling could affect the consistency and adequacy of mix designs.

Some of the laboratory factors that can introduce variability in the test results include the following (13):

- the procedure of laboratory compaction of the specimens because it could produce specimens with non-uniform density;
- time from heating the material to compaction in the mold (related to the distance from oven to compaction equipment);
- time that the specimen is in the warm water bath before loading.

Cox et al. (13) found that the HWTD test produced consistent results when the specimen compaction procedure was done properly. For example, compaction of the mixture to the top rim of the mold was necessary to produce a specimen with uniform density. The test variability was also reduced when the calculations and weighting of the materials during the specimen preparation were done with care and according to the standard test procedures. It was found that the specimen density should be within ±0.25% throughout the specimen and ±0.5% between laboratories to achieve accurate results (13). For precision and bias statements of the HWTD test, it was proposed a coefficient of variation of 24% for a single lab and 67% for multiple labs (13). (The coefficient of variation shows the extent of the variability in relation to the mean of the data.) In summary, proper technician training and laboratory certification program are crucial so that there is consistency in the application of the procedures within a laboratory and across laboratories.

Another recent study sponsored by the Iowa DOT (12) aimed at evaluating the bias in the HWTD test. The study considered results of 150 HWTD tests, four PG binders (PG 58-28, PG 64-22, PG 64-28, PG 70-22), and four levels of design gyrations (76, 86, 96, 109). It found that the measurement location and the wheel side (in multi-wheel equipment) were possible sources of significant variation and bias in the results. From statistical analysis, the report recommended considering combinations of certain measurement locations depending on the average rut depth at the final pass, which relates to the performance of the given specimen or core in this test.

There is no agreement on how many and which measurements of rut depth should be used in the HWTD test. Reporting the largest rut depth measured instead of average values has also been recommended when limited number of data is available to perform statistical correlations (14). Other research has recommended not considering the rut depth measured at the midpoint (i.e., along the sawn joint between the two cylindrical specimens) but rather averaging either the highest five measurements or the remaining ten measurements (15).

REVIEW OF HAMBURG WHEEL TRACKING TEST FOR PREDICTING RUTTING AND STRIPPING POTENTIAL

The HWTD test is used to evaluate and predict the rutting and moisture damage susceptibility potential of a HMA mixture. The test has been also applied to warm mix asphalt (WMA). In the HWTD, *rutting* is given by the depth of the depression (i.e., permanent deformation) caused by the repeated passes of the steel wheel over the specimen surface. *Moisture damage* is also referred to as *stripping* and is described as the progressive deterioration of the asphalt mixture by the separation of the asphalt binder from the surface of the aggregate particles and/or loss of cohesion within the binder due to the presence of water. Stripping is a complex phenomenon and is affected by the material properties and mix design, pavement drainage and traffic loading, and environmental conditions. The major contributing factors to moisture damage in the field, the appropriateness of available laboratory tests, and the effectiveness of field treatments are not fully understood (16).

MOISTURE DAMAGE MECHANISMS

The main condition needed for moisture damage in pavements is the penetration of moisture into the asphalt concrete structure. The infiltration of water into the asphalt concrete is unavoidable because asphalt pavements are not impervious. Dense-graded mixtures are generally designed to have about 4% air-void content but often end up having greater air-void contents (6 to 12%) in the field (16), in the range in which the water penetrates into the interconnected voids but do not drain out easily. In addition, dense-graded mixtures are designed to have voids to control permanent deformation and prevent the distress of bleeding of asphalt binder. Moisture can also be left in the voids and/or the surface of aggregate particles caused by incomplete drying during construction.

The mechanisms by which moisture in asphalt concrete can lead to damage of the material and eventually to structural damage are: loss of cohesion, loss of adhesion, pore water pressure, and hydraulic scouring (17). *Loss of cohesion* refers to the change in the rheology of the asphalt binder through spontaneous emulsification caused by moisture. This change may be reversible. *Loss of adhesion* can occur because of detachment and/or displacement. Loss of adhesion due to detachment is the separation of the asphalt binder from the aggregate surfaces by a thin film of water without a break of the asphalt coating. Loss of adhesion due to displacement of the binder from the aggregate surface caused by the water, because the latter is better able to reduce the interfacial free energy of the system to form a thermodynamically stable condition. Incomplete aggregate drying is frequently a major factor causing loss of adhesion.

Finally, *pore water pressure* caused by traffic loads and/or vapor in the pores created by environmental heat can induce breakage of the binder film especially at the aggregate corners (where the stresses may be higher and the binder film tends to be thinner). *Hydraulic scouring* is the detrimental effect of repetitive positive and negative (suction) pressure cycles under the wheel passes in the water of surface pores. This may be associated with "pumping" and leads to loose aggregates in the pavement surface or at the interface between lifts in the asphalt concrete (where the water may remain for longer time). These mechanisms can occur simultaneously. Observed moisture damage is often the result of the combined action of two or more of these mechanisms.

WHY A MIXTURE FAILS THE HWTD TEST?

According to AASHTO T 324 standard document, the HWTD test is used to evaluate the susceptibility (or potential for) premature failure of the "HMA due to weakness in the aggregate structure, inadequate binder stiffness, or moisture damage." This is not a binder test and, in fact, two HMA specimens with the same binder content, PG and source could perform differently under the HWTD test (18). Non uniform compaction of the mixture (13), angularity (or roundness) of the fine or coarse aggregates (18), and fines coating the aggregates (19) have been found to affect negatively the mixture performance in the HWTD test.

A mixture performance in the HWTD test could be improved making one or more of these changes in the mix design:

- add anti-stripping additive (the beneficial effect, if any, would need to be proven and quantified);
- use a different (higher temperature) PG binder or binder source;
- add higher RAP (reclaimed asphalt pavement) percentages (agency's specifications or practice often limit the RAP content and use);
- reduce the binder content (this will produce a "drier" and stiffer mix design);
- use a better quality aggregate to produce a stronger aggregate structure.

The effectiveness of these changes on a mix performance can vary greatly depending on the fundamental cause of the performance failure. There are indications from the practice that using more angular fine aggregates improved the HWTD test performance of the mixture (18).

RAP CONTENT

Considering that a large percentage of mix designs in New Mexico contain 15% or more of reclaimed asphalt pavement (RAP), it was important to review the literature regarding the effect of RAP content on the HWTD test performance of the mixtures. A recent study compiled and analyzed the HWTD test data for Kansas DOT HMA mixtures done at Kansas State University since 2000 (20). It found that the RAP content affects considerably the results of the HWTD test on Superpave mix designs. Rutting performance in the HWTD test is also highly influenced by voids in mineral aggregate (VMA) and RAP asphalt content.

HWTD TEST VERSUS FIELD PERFORMANCE

The effectiveness of the HWTD test to predict or determine the moisture susceptibility of an AC mixture has been evaluated and documented by some studies. Two comprehensive long-term projects that aimed at comparing test and field performance are summarized in this section.

IH-20 in Harrison County, Texas - Project 0-4185

The test section was located in Interstate 20 (eastbound and westbound lanes), in Harrison County, Texas (21). The test section consisted of nine HMA mixture types using three different mix designs. Each mix design was prepared with three different coarse aggregates (siliceous gravel, quartzite, sandstone). All mixtures used PG 76-22 binder. The base course was the same throughout the test section. This study included monitoring of the construction of the test section, collection of construction data and 5-year performance data, and HWTD testing on the nine mix designs.

Field performance was based on annual visual distress surveys conducted regularly during 5 years, international roughness index (IRI) values, and final rutting data measured using a dipstick® profilometer. The mixtures passed the HWTD test and did not reach the SIP. This correlated well with the field performance as no stripping was observed in the test section in 5 years of monitoring (2001 through 2004). The field-observed rutting was very minor compared to the rut depth measured in the HWTD tests. The researchers pointed out that the testing was done on a limited number of specimens and recommended performing a larger number of tests for each mixture (21).

Evaluation of Hot Mix Pavement Performance in Northeast Texas

The original evaluation study dated from 1998 and included 35 HMA pavement sections in Northeast Texas, Atlanta District, to study the effects of some changes in the specifications to address moisture sensitivity problems in the HMA mixtures. In general, the 1998 project validated that the original recommendations improved the HMA pavement performance. However, the sections were very young by the time of the first evaluation. A follow-up study of these sections was started in 2001 including a detailed visual inspection of the pavement surface and testing of field cores. Table 1 presents an extract of the data from the 2001 long-term evaluation of HMA sections (22) showing the effects of mineralogy of coarse aggregate and anti-stripping additive type on the test and field performance. In Table 1, higher visual performance rating relates to better field performance. Mixtures with gravel aggregate performed much better when containing liquid additive than without any anti-stripping agent. Mixtures with limestone aggregate showed less surface distresses and less rut depth when containing liquid additive than without any anti-stripping agent. The TSR did not correlate well with the field performance rating or with the HWTD test results from the study of the Northeast Texas sections (22), whereas the rut depth from the HWTD test correlated well with the field performance.

Table 1. Comparison of HWTD Test Results, TSR and Visual Performance Rating (22)

Aggregate type	Anti-stripping additive type	Tensile strength ratio, TSR	HWTD rut depth (mm) at 20,000 passes	Visual performance rating	Pavement age (years)
Gravel	Lime	0.91	2.9	90	4.7
Gravel	Liquid	0.82	29.3	76	6.5
Gravel	None	0.99	18.2	58	8.7
Limestone	Liquid	0.86	7.9	90	5.5
Limestone	None	0.98	27.7	70	7.3

HWTD TEST PERFORMANCE OF MIX DESIGNS

One of the objectives of this report was to summarize the documented HWTD test performance of mix designs in New Mexico and experience of other states using the HWTD with similar climatic and/or traffic conditions. The section describes first the main features and components of the NMDOT-approved mix designs. It follows describing the relevant information and findings of the only two documented projects found in the literature that have tested New Mexico's mix designs using the HWTD. The experience of Colorado and Texas DOTs using the HWTD test on their mixtures is also summarized. Finally, the search for relevant information in the LTPP database on the application of HWTD testing is described.

NEW MEXICO DOT-APPROVED MIX DESIGNS

The HMA mix designs in New Mexico are SP-III and SP-IV (as per May 2014) and contain an anti-stripping additive. The designed air-void content is 4% for all mixtures. In 2013, 133 new mix designs were approved (including NMDOT district and commercial mix designs), of which 62.4% were SP-III and 38.6% were SP-IV, and 23 job mix formula (JMF) adjustments were approved. Thirty five mix designs (26.3%) used WMA technologies: 27 projects used foaming, 6 projects used Evotherm®, and 2 projects used water.

In 2013, 28.6% of the approved mix designs used 1% lime and 71.4% used 1% Versabind® as anti-stripping additive. The asphalt binder content varied from 4.1% to 5.8%. The aggregate types varied widely based on local availability and were reported as limestone, volcanic rock, basalt, rhyolite, monzonite, quartzite, sand and gravel, and river deposits. The content of RAP in the approved mix designs ranged between 0% and 35%. In 2013, 32% contained 0% RAP, 21% contained 15% RAP, 3% contained 18 to 21% RAP, 13% contained 25% RAP, 13% contained 28 to 34% RAP, and 18% contained 35% RAP. These statistics vary yearly but illustrate the characteristics of the most common mix designs in New Mexico.

At the time of completion of this report, the New Mexico DOT-approved Performance Graded binders (PG grades) available from suppliers in New Mexico are (Parveez Anwar, NMDOT State Asphalt Engineer, personal communication, May 2014):

- PG 58-28
- PG 64-22
- PG 64-28
- PG 70-22
- PG 70-28
- PG 76-22
- PG 76-28
- PG 70-28+ (for open graded friction course only)
- PG 70-28R+ (for open graded friction course only)

The following PG grades are also approved but are not available in New Mexico so they require a special order and are rarely used in the state: PG 58-22, PG 58-34, PG 64-34, PG 70-16, PG 76-16, PG 82-16, and PG 82-22.

PERFORMANCE OF NEW MEXICO MIX DESIGNS

The HWTD test is not used routinely in New Mexico. Thus the performance of the New Mexico Superpave (SP) mix designs under this laboratory test in terms of rutting and stripping is unknown. Available HWTD test results on New Mexico mixtures are very limited. This section summarizes and evaluates relevant information and findings from two recent research projects that included HWTD testing on core specimens from New Mexico pavements. One of the projects focused on HMA permeability and the other focused on WMA pavements.

Permeability Study – Project NM11MSC-04

A recent permeability study (2011-2013) included HWTD testing on core specimens from 16 sites on in-service pavements in New Mexico (23). Four specimens were tested for each site (4 test replicates). The rut depth at 20,000 passes and the SIP were reported. The main goal of the project was to determine the permeability of New Mexico HMA mixtures to make a permeability database and compare these permeability values with specification values set by other DOTs (23).

Half of the sections in the study were described as "good performing" pavements and the other half as "bad performing" pavements and were selected based on the responses of a survey to district personnel. The "bad performing" pavements were chosen from those reported in the survey as "pavements with high permeability or showing visual stripping." The "good performing" pavement sections were pavements "with low permeability or no visual stripping."

The study concluded that "pavements with higher moisture damage have higher permeability" and that "moisture damage increases with the increase of permeability." The report concluded that the HWTD test "does not give a good prediction of a pavement's moisture susceptibility" based on the limited number and type of samples and tests performed.

It is well known that high permeability in the pavement allows water to enter and drain out quickly, decreasing the detrimental effects of water. Some of the pavements classified in this study as "bad performing" could have been high permeability asphalt concrete, not allowing accumulation of moisture inside the voids for considerable time. This could explain why three of the four specimens in the "bad performing" category actually performed very well in the HWTD test.

It is also important to note that most of the field permeability measurements and all cores were taken from the pavement shoulders (without open graded friction course, OGFC) because all the driving lanes had an OGFC overlay or inlay. In contrast, the test sections were selected and categorized as "good" or "bad" performing based on observations of the surface driving lanes by district personnel, which did include the effects of the more permeable OGFC surface. The report did not consider available information on pavement distresses of these sections for selecting "good" and "bad" performing test sections and for interpreting test results in terms of rutting and moisture damage susceptibility; however, these data could be the focus of future studies.

Moisture Susceptibility of WMA Study – NCHRP Report 763

The NCHRP Report 763 *Evaluation of the Moisture Susceptibility of WMA Technologies* (24) was published in February 2014. The goal of the project was to provide guidelines for identifying and limiting moisture susceptibility of WMA mixtures. The project evaluated three types of specimens: 1) laboratory-mixed laboratory-compacted (LMLC) specimens, plant-mixed laboratory-compacted (PMLC) specimens, and plant-mixed field-compacted (PMFC) cores. Four field WMA projects were included in the study located in Iowa, New Mexico, Montana, and Texas.

The study was motivated by the lack of standard laboratory conditioning and aging protocols to be used for WMA mix design to simulate better the early-life performance of WMA. In addition, WMA may be more susceptible to rutting during early life due to the reduced aging (because of lower placement temperatures) and an increase in moisture susceptibility resulting from the incomplete drying of aggregate and differences in aggregate absorption of binder compared to HMA.

The New Mexico project was on Interstate 25 near the city of Truth or Consequences. Its construction was completed in October 2012. The cores were taken immediately after construction. Base on the NCHRP report (24), the asphalt binder was a polymer-modified PG 64-28 and the aggregates were described as siliceous gravel. The mix designs included 35% RAP and 1% of Versabind® as anti-stripping additive. The mixtures were:

- HMA with RAP (285 °F to 290 °F);
- WMA with Evotherm 3G® plus RAP (255 °F to 260 °F);
- WMA with Foaming technology plus RAP (265 °F to 270 °F).

The field compaction temperature ranges for the three projects are shown in parenthesis above. Indirect tensile (IDT) tests, resilient modulus (M_R) test, and HWTD test (SIP and stripping slope) were performed on the specimens. The IDT tests were done on dry and wet (conditioned) specimens and the tensile strength ratio (TSR) was calculated as the ratio of the wet to the dry tensile strengths. Similarly, the resilient modulus ratio ($M_{R\text{-ratio}}$) was calculated as the ratio of the wet to the dry M_R values. (The project used M_R as a performance test in part because it was suitable for testing field cores unlike the dynamic modulus test.) The following laboratory aging conditions were considered for specimens and cores from the New Mexico sections:

- long-term oven aging (LTOA) consisting of 2 weeks at 60 °C (for specimens);
- long-term oven aging (LTOA) consisting of 5 days at 85 °C (for specimens);
- no long-term oven aging (for specimens);
- field aging (for cores).

In regard to the New Mexico test sections, the NCHRP report (24) found that:

- in general, the initial test performance (and stiffness) of HMA cores (PMFC) and LMLC specimens without field or laboratory aging was better than the performance of the WMA mixtures; the difference in test performance was reduced with field aging (cores) and LTOA (specimens);
- better or equivalent test performance of WMA mixtures versus HMA mixtures was achieved with the several field and laboratory aging conditions;
- all cores and specimens and
- the test section on Interstate 25 did not exhibit distress related to moisture susceptibility to the time of publication of the NCHRP 763 report (winter 2013-spring 2014), despite construction completion in October 2012 without experiencing a summer of aging prior to winter conditions, having heavy traffic, and climatic conditions that favor moisture susceptibility (dry, cold winters and hot summers).

The results of the study indicated that WMA is more likely to be moisture susceptible in its early life (prior to the first summer aging) as compared to HMA, but equivalent test performance is expected after a summer of aging. The use of anti-stripping agents (compatible with the corresponding WMA technologies and component materials) may reduce this early moisture susceptibility. Ensuring summer aging of WMA before the first wet and cold winter to prevent moisture-related pavement distresses was recommended.

The NCHRP 9-52 is an ongoing project that continues to monitor the field test section in New Mexico. This project deals with the short-term laboratory conditioning of asphalt mixtures to simulate the effects of plant aging and 1 to 2 years in the field.

PERFORMANCE OF COLORADO MIX DESIGNS

Even though Colorado DOT has not included the HWTD testing into the standard specifications for mix design and construction QA/QC, this agency has performed the test on its HMA mixtures since the 1990s creating a large database. Recently, Colorado's HWTD test data from 2007 through 2010 and 2012 were reviewed to determine how well the HWTD results correlated to field performance (19). Of particular interest were the specimens that failed the HWTD test while in creep slope without hitting the SIP.

The main problems with pavement distresses in Colorado are associated to fatigue cracking, other types of cracking, and raveling. It was found that most of the sections were performing well based on cracking data even though the specimens had failed the HWTD test while in creep slope without hitting the SIP. However, the report could not reach a definite conclusion because of several factors, including that i) the project files for some of the samples could not be found; ii) it was not possible to absolutely confirm that the materials tested were the same as those placed in the field; iii) there could be stripping at the bottom of the HMA layer and/or fatigue cracking that had not shown on the pavement surface yet; and iv) poor field compaction of the HMA could be the cause of the surface distresses (19).

All but one of the Colorado's aggregate sources used in mix designs performed well in the HWTD test for the 2007-2012 data. From the Colorado DOT experience (19), several conditions were found to affect the performance of a HMA mixture under the HWTD test, such as:

- the lime is not properly added to the mixture in the production phase;
- the aggregate is coated in fines;
- the binder used does not have sufficient adhesion with the aggregate chosen.

PERFORMANCE OF TEXAS MIX DESIGNS

The Texas DOT has reported in numerous presentations and reports that the stripping and rutting performance problems have decreased considerably with the increase in HWTD testing and specifications in the state [e.g. (25)]. The HWTD test has been described as the "best identifier of mixtures susceptible to premature failure" (25). The HWTD test has shown to be a good indicator of the effectiveness of anti-stripping additives, whereas the TSR was found not to be a good indicator of the anti-stripping effects on HMA mixtures (22).

As mentioned earlier, the TSR did not correlate well with the field performance or the HWTD test results from the study of the Northeast Texas sections (22). Similar conclusions in terms of TSR were reached in other studies on Texas sections [e.g. (26)].

Based on the Texas DOT experience on a very large number (in the range of hundreds) of test results and mixture types and mix designs (25), mixtures with igneous aggregate performed significantly better (at 50 ^{o}C) than those with limestone or gravel (for all types of mixtures). Lime additive as anti-stripping agent increased the HWTD test performance at 50 ^{o}C compared to liquid additive or no anti-stripping additive. It was also found that raising the test temperature from 40 ^{o}C to 50 ^{o}C decreased the performance in the HWTD test.

HWTD IN THE LTPP DATABASE

The FHWA's Long Term Pavement Performance (LTPP) is a large research project established to collect pavement performance data throughout the U.S. The LTPP includes two fundamental classes of study and several smaller studies with the goal of monitoring and collecting comprehensive performance data and investigating critical aspects of the pavement performance in a long-term basis. The fundamental studies are the General Pavement Studies (GPS) and the Specific Pavement Studies (SPS), which combined consist of more than 2,500 test sections on in-service highway pavements (rigid and flexible) in different geographic and climatic regions of the U.S. The LTPP Information Management System (IMS) is the central database that contains all the information and data collected under the LTPP program.

The LTPP IMS contains information on New Mexico pavements. Specific Pavement Study SPS-1 (Project 350100) is located north of Las Cruces on Interstate 25 (north bound line), Dona Ana County, New Mexico. Ten test sections are in this project, for a total length of about one mile.

The LTPP IMS was search for documents that report the application of the HWTD test to predict rutting and stripping potential (i.e., moisture susceptibility) of various HMA mixtures in New Mexico and/or in regions with similar climates as those of New Mexico. The search quickly indicated that the LTPP IMS does not contain such information. The LTPP Program uses Protocol P05 *Test Method for Moisture Susceptibility of Asphalt Concrete (AC05)* for determining the moisture susceptibility (stripping potential) of asphalt concrete specimens. The LTPP's Protocol P05 is based on AASHTO T 283 standard test method to determine the tensile strength of conditioned specimens. The LTPP Program does not use the HWTD test for evaluating rutting and moisture susceptibility; therefore, the LTPP publications were not found relevant to the objectives of this project.

MIX DESIGN AND CONSTRUCTION SPECIFICATIONS

NMDOT 2014 SPECIFICATIONS

The NMDOT *Standard Specifications for Highway and Bridge Construction 2014 Edition* (herein referred to as NMDOT Standard Specifications) do not require the HWTD test for HMA and WMA mix design and/or construction quality assurance and quality control (QA/QC) (27). The NMDOT uses the Superpave mix design method in all projects.

Section 423 *Hot Mix Asphalt – Superpave (QLA and Non-QLA)* specifies testing the HMA mix designs according to AASHTO T 283 (Modified as per NMDOT Standard Specifications, Section 423.2.8 *Mix Design*) and requires a minimum tensile stress ratio (TSR) of .85 (or 85%). Likewise, Section 424 *Warm Mix Asphalt* specifies testing the WMA mix designs according to AASHTO T 283 (Modified as per NMDOT Standard Specifications, Section 424.2.8 *Mix Design*) and requires a minimum TSR of 0.85. Currently, the NMDOT Standard Specifications do not specify minimum indirect tensile strength or TSR for construction QA/QC or plant mix samples, and do not specify maximum rut depth from testing for mix design or plant mix samples.

STATE AGENCIES THAT REQUIRE HWTD TESTING

Based on a limited online search of state DOT websites performed in this study and the 2013 Colorado DOT report (19), at the time of publication of this report, nine (9) state DOTs include requirements based on the HWTD test in their performance-based specifications for HMA and/or WMA mix design and/or for QA/QC (in alphabetic order):

- California DOT (Caltrans)
- Illinois DOT
- Iowa DOT
- Kansas DOT
- Louisiana DOT
- Montana DOT
- Oklahoma DOT
- Texas DOT
- Utah DOT

Note that this list is not comprehensive. At the time of publication of this report, Iowa DOT was the most recent state agency to incorporate the HWTD test into the design specifications in April of 2014 (28). Colorado DOT has performed extensively the HWTD test for information and research on the Colorado mixtures since the 1990s and the agency is currently considering the adoption of the test for performance-based specifications (19). Other state DOTs also own or are in the process of acquiring the HWTD equipment even though the test is not part of their asphalt mix design and construction specifications at this time. New Mexico DOT has recently acquired an HWTD for the Materials Laboratory in Santa Fe, NM and will be operational in the summer of 2014 (James Gallegos, personal communication, April 2014).

MIX DESIGN AND CONSTRUCTION SPECIFICATIONS

Passing/Not Passing Limits

State DOTs that use the HWTD have adopted mainly one of two approaches to incorporate the HWTD test conditions into their design and/or construction specifications for HMA and/or

WMA mixtures: either varying the number of wheel passes run depending on the high-temperature binder grade (PG) (for a given test temperature), or varying the test temperature depending on the high-temperature binder grade (PG) (for a given maximum number of wheel passes run). The HWTD test passing/not passing limits in terms of maximum rut depth, stripping inflection point (SIP) and stripping slope also vary among the state DOTs.

Table 2 provides the HWTD test conditions and limits of nine state DOTs that currently require the test in their specifications or as special provisions and Colorado DOT. The latter has applied the test for research and characterization of the mix designs used in Colorado for over 25 years. Internal research at the Colorado DOT found that setting a maximum rut depth of 4 mm at 10,000 passes yielded approximately the same passing/not passing HWTD test results as setting a maximum rut depth of 10 mm at 20,000 passes (19). Based on this experience, Colorado DOT continued testing to 10,000 passes so that more specimens could be tested in the agency's laboratory using two HWTDs.

HWTD Test Requirements in the Specifications

This section summarizes some relevant information on how the HWTD test results have been incorporated into roads and highways design and construction specifications of state DOTs in the recent years. The information is organized by state DOT and indicates whether the HWTD test is used for HMA and WMA and for mix design and construction QA/QC procedures.

<u>California DOT</u>

- The AASHTO T 324 (Modified) is required in the specifications for HMA and WMA.
- Both the minimum number of passes to produce a given rut depth and the minimum number of passes to reach the SIP are specified.
- The test results are required to show the number of passes with rut depth and number of passes at the strip inflection point (SIP) for laboratory and plant-produced HMA. The test is shut off after 25,000 passes (29).
- The HWTD test is required for mix design and construction QA/QC process (i.e., engineer's acceptance and quality control) and when RAP substitution is greater than 15% in the HMA mix design. The minimum requirements are shown in Table 3.
- For QA/QC, the sampling frequency is one in the first production day and one per every 10,000 tons.
- The standard specifications also limit the minimum dry strength and the tensile strength ratio (in percent) according to the California Test 371 (30).

<u>Illinois DOT</u>

- Until late 2013, the HWTD test was specified as an acceptance test on a project and District level as revision to the special provisions. The agency continued to build the test result/performance database for the Illinois DOT's mix designs for HMA and WMA projects.
- From November 2013, all HMA mixtures are required to pass the HWTD test specifications for mix design verification and production (31). For construction QA, a 300 ton test strip at the beginning of the HMA production (for each mixture with 3,000 ton or more, for each contractor) is required to pass the HWTD test performance

Table 2. HWTD Test Conditions and Limits Used by Some State DOTs

State DOT	PG	Number of wheel passes [a]	Test temperature	Maximum rut depth [b] (mm)	Maximum rut depth [b] (inch)	Comments or other requirements
California DOT	PG58-XX	10,000	50 °C	12.7	0.5	Test temperature is 50 °C for all PGs for WMA technology
	PG64-XX		55 °C			
	PG70 and higher		60 °C			
Illinois DOT	PG58-XX	5,000	50 °C	12.5	0.5	Currently specified on a project and District level as revision of special provisions
	PG64-XX	7,500				
	PG70-XX	15,000				
	PG76-XX	20,000				
Iowa DOT	PG58-XX	20,000	50 °C	N/A	N/A	SIP specified for moisture sensitivity evaluation only. No maximum rut depth specified.
	PG64-XX					
	PG70-XX					
Kansas DOT	N/A	10,000	50 °C	12.5	0.5	Passing criteria are not changed with PG binder.
Louisiana DOTD	PG70-22 (Level 1) [c]	20,000	50 °C	10	0.39	Currently specified on a project basis as special provisions. In 2015, requirements will be incorporated into the HMA standard specifications. Values and PG shown for wearing binder.
	PG76-22 (Level 2) [c]			6	0.24	
Montana DOT	PG58-28	Plant mix: 10,000 Mix design: 15,000	44 °C	13	0.5	Specified test temperature is 14 °C below the average 7-day maximum pavement design temperature.
	PG64-22 PG64-28		50 °C			
	PG70-28		56 °C			
Oklahoma DOT	PG64-XX	10,000	50 °C	12.5	0.5	N/A
	PG70-XX	15,000				
	PG76-XX	20,000				

[a] Minimum number of passes to the specified maximum rut depth
[b] Not to exceed in given number of passes
[c] Level 1: low traffic, Average Daily Traffic (ADT) < 7000; Level 2: high traffic, ADT > 7000
[d] 20,000 passes for 75 or greater design gyrations; 10,000 passes for less than 75 design gyrations
N/A: not specified or not applicable
DOTD: Department of Transportation and Development

Table 2. HWTD Test Conditions and Limits Used by Some State DOTs (Continued)

State DOT	PG	Number of wheel passes [a]	Test temperature	Maximum rut depth [b] (mm)	Maximum rut depth [b] (inch)	Comments or other requirements
Texas DOT	PG64-XX	10,000	50 °C	12.5	0.5	N/A
	PG70-XX	15,000				
	PG76-XX	20,000				
Utah DOT	PG58-XX	20,000 [d]	46 °C	10	0.4	N/A
	PG64-XX		50 °C			
	PG70-XX		54 °C			
Colorado DOT	PG58-XX	10,000	46 °C	4	0.16	Test and limits are used for research and documentation and are not part of the specifications.
	PG64-XX		50 °C			
	PG70-XX		55 °C			
	PG76-XX		60 °C			

[a] Minimum number of passes to the specified maximum rut depth
[b] Not to exceed in given number of passes
[c] Level 1: low traffic, Average Daily Traffic (ADT) < 7000; Level 2: high traffic, ADT > 7000
[d] 20,000 passes for 75 or greater design gyrations; 10,000 passes for less than 75 design gyrations
N/A: not specified or not applicable
DOTD: Department of Transportation and Development

Table 3. HWTD Test Performance Limits in the California DOT 2010 Standard Specifications, 2014 Revised (29)

Quality characteristic	Performance graded	HMA Type [a] A	HMA Type [a] B	HMA Type [a] RHMA-G [b]
Minimum number of passes at 0.5 inch average rut depth	PG-58	10,000	10,000	15,000
	PG-64	15,000	15,000	20,000
	PG-70	20,000	20,000	25,000
	PG-76	25,000	25,000	N/A
Minimum number of passes to reach SIP	PG-58	10,000	10,000	10,000
	PG-64	10,000	10,000	12,500
	PG-70	12,500	12,500	15,000
	PG-76	15,000	15,000	N/A

[a] Gradations provided in reference 29.
[b] Rubberized HMA (gap-graded)
N/A: not specified or not applicable

specifications (Table 2); these QA tests are run by the Illinois DOT laboratory. If the specimens do not meet the specifications, the contractor can compact all previously produced material if all other mix design criteria are met, but no additional mixture should be produced until the Department's engineer receives passing HWTD test results from the contractor (31).

- The number of passes shown in Table 2 was adopted in 2012 (32). The minimum number of passes for PG58-XX and PG64-XX was 10,000 before the change.
- The 2010 Standard Specifications also specify a minimum tensile strength ratio (TSR) according to Illinois Modified AASHTO T 283 to determine the need for anti-stripping additive and for mix design and quality control for mixture containing anti-stripping additives.
- The WMA samples are aged two hours at 270 ^{o}F in loose condition and then compacted prior to HWTD testing (32).

Iowa DOT

- The Iowa Modified (I.M.) 319 *Moisture Sensitivity Testing of Asphalt Mixtures* (6) is applied for determining moisture susceptibility of asphalt mixtures based on the SIP. No limiting rut depth is specified.
- According to I.M. 319, for testing in the mix design phase, the specimens are aged two hours at the proposed field compaction temperature. Specimens are conditioned for 30 minutes after achieving the test temperature and at no time should be submerged longer than 35 minutes prior to test initiation.
- The HWTD test is shut off after 20,000 passes or when the maximum rut depth measured with the LVDT (Linear Variable Differential Transformer) is 20 mm (6).
- The I.M. 319 is applied for evaluation of moisture susceptibility of proposed mix designs and for plant-produced mixtures, as part of the quality assurance program.
- For plant-produced material, the maximum number of passes to reach SIP is 10,000 for interstate and primary highways designed for less than 30,000,000 ESALS and 14,000 for interstate and primary highways designed for 30,000,000 ESALS and higher. This applies to the three PG binders shown in Table 2. If the SIP (i.e., ratio of the creep slope and the stripping slope as defined in Materials I.M 319) is less than 2.00, then the SIP is invalid and the mixture is considered passing.
- The Iowa DOT Specifications (Section 2303.02.E.2.d) indicate that the engineer, when notified of non-compliant results, may suspend paving operations until an approved "significant mix change" is implemented (33).
- In Materials I.M. 510 (Appendix A) of Iowa DOT, AASHTO T 324 standard test is applied to specified limiting rut depth for performance requirements for 3/8 HMA special thin lifts (when exposed to traffic) (33).

Kansas DOT

- The HWTD tests requirements have been introduced as Special Provision to the Standard Specifications, Edition 2007 for state projects.
- The HWTD tests are performed by Kansas State University (34).
- The Special Provision requires the contractor to submit the HWTD test results with the job mix formula to the District Materials Engineer for review and approval. The test

results should include: average number of wheel passes, average rut depth, creep slope, SIP, and stripping slope.

- Kansas DOT Standard Specifications, Edition 2007 require a minimum tensile strength ratio (TSR) of 0.8 (or 80%) for mix design and construction QA/QC verifications.

<u>Montana DOT</u>

- The HWTD test requirements were introduced in the 2007 *"Supplemental Specifications to Montana Standard Specifications for Road and Bridge Construction 2006 Edition"* (35) and have remained in subsequent versions of the supplemental specifications.
- The HWTD test acceptance requirements are for mix designs and for plant mix materials.
- According to Section 401.03.02 of the supplemental specifications, when two consecutive samples do not meet the HWTD test requirements, the contractor is required to suspend production and submit a revised mix design and samples for verification and HWTD testing. The initial mix design requirements will be used for verification. Production is not allowed to resume until the revised mix design is verified and HWTD mix design requirements are met.
- The test standard (MT 330-04 *Resistance of Compacted Bituminous Mixture to Moisture Induced Damage*, Modified AASHTO T 283) has been archived. However, the current version (effective 06-12-2014) of the *Supplemental Specifications to Montana Standard Specifications for Road and Bridge Construction 2006 Edition* still specifies a minimum tensile strength ratio of 0.7 for mix designs according to MT 330.

<u>Oklahoma DOT</u>

- In 2011, the HWTD test requirements were introduced as a special provision [708-23(a) 09, effective 07-08-2011] (36) into the Oklahoma DOT *2009 Standard Specifications for Highway Construction, English and Metric* for Sections 708.04 and 708.06. The special provision replaced the maximum rut depth requirements determined by the Asphalt Pavement Analyzer (APA) method with the HWTD test requirements.
- The HWTD test acceptance requirements are for mix designs and for plant mix materials.
- According to the OHD L-55 standard test procedure, the HWTD test is shut off after 20,000 passes or when the maximum rut depth measured with the LVDT (Linear Variable Differential Transformer) is 20 mm (8).
- The *2009 Standard Specifications for Highway Construction, English and Metric* require a minimum tensile strength ratio (TSR) of 0.8 for Superpave mix design (laboratory compacted) and 0.75 for field samples (laboratory compacted), determined according to AASHTO T 283 (37).

<u>Texas DOT</u>

- The HWTD test requirements were introduced into the Texas DOT *2004 Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges*, in Item 300 of the document (38). All HMA items, except Items 292 (plant mix, asphalt treated base) and 342 (permeable friction course) include HWTD test criteria.
- The HWTD test acceptance requirements are for HMA mix designs and for plant mix materials in construction QC/QA procedures. The HWTD test is required on lab mixed specimens for mix design approval, on a trial batch (lot 1), and on a minimum of one specimen during the project. If the tested specimens during construction do not pass the

specifications for the HWTD test, the contractor is required to suspend the job and may be required to remove and replace the material that is not in compliance.

- The Texas DOT *2004 Standard Specifications for Construction and Maintenance of Highways, Streets, and Bridges* provide specifications for minimum tensile strength (dry condition) determined according to Text-226-F *Indirect Tensile Strength Test*.

Utah DOT

- The HWTD test requirements were introduced into the Utah DOT *2012 Standard Specifications for Road and Bridge Construction* (39) and apply to HMA and WMA.
- The HWTD test requirements were also included in Part 8 Section 960 (MOI 8-960) of the Utah's Materials Manual of Instruction (*Guidelines for Superpave Volumetric Mix Design and Verifications*), effective 04-2014 (40).
- The HWTD test acceptance requirements and procedure apply to contractor's Superpave mix design and Utah DOT verifications of the mix design and field mix materials.
- According to Part 8 Section 990 of the Utah's Materials Manual of Instruction (10), the HWTD is shut off after 20,000 passes or when the maximum rut depth measured with the LVDT is 20 mm.
- The HWTD testing according to Utah DOT MOI 8-990 replaced the tensile strength ratio determined according to the Lottman test.

NEEDS ASSESSMENT AND RECOMMENDATIONS

Based on the findings of the literature review and the state of practice at the state and national levels, several research needs were identified for NMDOT. The following proposed recommendations are provided.

Research need 1 – Determine the performance of New Mexico mix designs under the HWTD test conditions.

The NMDOT is considering the implementation of the HWTD test into the Standard Specifications for Highway and Bridge Construction as a performance-based test in the mix design phase and the construction QA/QC phase. If adopted, the HWTD test will be used in the specifications as a means to control the rutting and moisture susceptibility of the New Mexico mixtures. However, the performance of the New Mexico mix designs under the HWTD test conditions is unknown. Very limited HWTD test data is available for New Mexico materials. This performance has to be determined before the HWTD test is incorporated into the specifications and modifications are made.

The laboratory data is also needed for determining appropriate passing/non passing criteria for the HWTD test and for the long-term evaluation of the effectiveness of the modifications to the standard specifications in the state.

The test matrix will need to consider important factors that may affect the mixture performance in the HWTD test, including:

- local districts preferences and material availability (aggregate types)
- NMDOT-approved PG binders (and possible binder sources)
- aggregate types and characteristics
- anti-stripping additive (currently lime and Versabind®)
- RAP content (currently varies from 0% to 35%)
- WMA technology (water, foaming, others) based on availability of projects

The following research tasks are proposed:

Task 1 **–** Design testing program for HWTD test.

Task 1a: Prepare the test matrix considering the most important variables for the local conditions and set priorities based on available resources and timeframe.
Task 1b: Write or adopt standard testing method for the HWTD test to be used in New Mexico.
Task 1c: Determine appropriate sample conditioning, if any, before tests are performed for HMA and WMA.

Task 2 **–** Testing phase using the HWTD.

Task 3 **–** Analyze data applying statistical methods. Determine if correlations or trends exist in the data for the variables considered.

Task 4 **–** Assess data quality and determine data variability (in single lab).

Task 5 **–**Establish or confirm passing/non passing criteria for the HWTD testing and write draft specifications.

Tasks 2 through 4 can be performed concurrently.

<u>Research need 2</u> – Determine the most effective companion test to the HWTD test (for fatigue cracking).

In general, stiffer and harder mixtures perform better in the HWTD test than softer mixtures. Mixtures with hard aggregate (igneous) perform better than mixtures with weaker aggregate (such as limestone) in this test. Reducing the binder content in the mix design may also improve the mixture performance in this test. However, stiffer mixtures with lower binder content may be more susceptible to fatigue cracking. To prevent mix designs that pass the HWTD test but are prone to fatigue failures, several of the state DOTs that have implemented the HWTD test into their specifications have also adopted (and required) a companion test that provides the fracture energy.

Fracture energy-type tests for HMA include the indirect tensile (IDT) test, the disk-shape compact tension (DCT) test, and the semi-circle bend (SCB) test. The latter seems to be more attractive because two tests can be performed from a single sample or core. All of these can be performed in laboratory-compacted specimens and field cores.

The following research tasks are proposed:

Task 1 **–** Design testing program for SCB test.

- Task 1a: Prepare the test matrix considering the most important variables for the local conditions and set priorities based on available resources and timeframe. The test matrix should be in agreement with the HWTD testing plan and objective.
- Task 1b: Write or adopt standard testing method for the SCB test to be use in New Mexico.
- Task 1c: Determine appropriate sample conditioning, if any, before the test is performed for HMA and WMA.

Task 2 **–** Testing phase for the SCB test.

Task 3 **–** Analyze data applying statistical methods. Determine if correlations or trends exist in the data for the variables considered and correlate with HWTD test results.

Task 4 **–** Assess data quality and determine data variability (in single lab)

Task 5 **–**Establish or confirm passing/non passing criteria for the SCB testing and write draft specifications.

Tasks 2 through 4 can be performed concurrently.

FINAL REMARKS

The review of the recent literature (last decade) indicated that the Hamburg Wheel Tracking Device (HWTD) test can be used as a performance test in the mix design and production phases. The test results have been correlated well with field performance documented in few long-term pavement monitoring and evaluation projects in the U.S. The

In general, stiffer and harder mixtures perform better in the HWTD test than softer mixtures. Mixtures with hard aggregate (igneous) perform better than mixtures with weaker aggregate (such as limestone) in this test. The HWTD test cannot be used to predict susceptibility to fatigue cracking.

The HWTD test has been suggested by some as a forensic investigation tool in combination with other methods, such as distress surveys, rutting measurements, sampling and destructive and non-destructive testing, and even as a pavement evaluation tool before deciding on a rehabilitation or resurfacing strategy especially in sections with indication of distresses caused by moisture (41).

The state DOTs that have adopted the HWTD test into their HMA specifications have also applied it to WMA specifications with no or very small modifications to the procedure or limits. This may change in the future as more experience and new data on WMA test and field performance becomes available.

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