LOUISIANA TRANSPORTATION RESEARCH CENTER

# Technical Summary

**LTRC Report 712**

SIO No. DOTLT1000275
LTRC Project No. 19-2B

# Development of a Moisture Sensitivity Test for Asphalt Mixtures

## Introduction

Infiltrated moisture significantly affects asphalt pavement performance, resulting in stripping and durability issues that compromise long-term mechanical performance and user safety. Despite being a persistent problem, understanding and reliably assessing moisture susceptibility in asphalt pavements remains a challenge. Current characterization methods often fall short, highlighting the need for improved mixture design, pavement design, and construction practices.

A 2002 survey revealed that 87% of North American highway agencies used the Modified Lottman (ML) and Hamburg Wheel-Tracking (HWT) Tests for evaluating moisture susceptibility. However, moisture damage has worsened due to the use of unconventional asphalt modifiers, recycled materials, and alternative production techniques like warm-mix asphalt, as well as the occurrence more frequent extreme weather events.

Over the years, researchers have introduced laboratory moisture conditioning protocols to better simulate field conditions, such as the freeze-thaw conditioning procedure (AASHTO T 283) and the Moisture-induced Stress Tester (MiST) (ASTM D 7870). Although these have improved predictions, issues persist. Louisiana DOTD and other state agencies historically used the ML test (AASHTO T 283), but its tensile strength ratio (TSR) is often deemed inconsistent due to sensitivity to air void distribution and saturation levels. The conditioning proctocol use in the ML test is also criticized for impracticality and inaccurate field simulation. Although AASHTO T 324 was recently to added Louisiana's specifications to address these shortcomings, the HWT test's "pass/fail" criteria still offer limited accuracy for typical Louisiana asphalt mixtures. This study aims to evaluate current moisture damage tests comprehensively and develop a reliable procedure combining advanced moisture conditioning protocols with a suitable mechanical test.

## Objective

The objective of this study was to develop a reliable test procedure to consistently assess the resistance of asphalt mixtures to moisture-induced damage. Specific objectives included:

- Identifying candidate laboratory test methods that can be used for asphalt mixtures' moisture susceptibility evaluation;
- Identifying available moisture conditioning procedures for asphalt mixtures;
- Evaluating current and candidate moisture susceptibility test methods with typical Louisiana asphalt mixtures;
- Establishing a laboratory test protocol that combines a state-of-the-art moisture conditioning method and an advanced mechanical test method; and
- Validating the proposed moisture conditioning protocols and test methods using asphalt mixtures containing antistrip additives.

## Scope

In this study, 13 asphalt mixtures were prepared (one plant-produced and lab-compacted, 12 lab-produced and lab-compacted) using two binders (PG 67-22, PG 70-22) and three aggregates (limestone, crushed gravel, semi-crushed gravel with varying absorption).

To evaluate moisture damage mitigation, two anti-strip additives were used in the selected mixtures. The asphalt binders and mixtures were subjected to five moisture conditioning levels (control, single freeze-thaw (FT-1), triple freeze-thaw (FT-3), 3500 MiST cycles, and 7000 MiST cycles), then evaluated through frequency sweep, Multiple Stress Creep Recovery, binder bond strength, boil test, Asphalt Compatibility Tester, Modified Lottman, HWT, and SCB tests to assess the impact of moisture and material properties.

**Principal Investigator**
Louay N. Mohammad,
Ph.D., P.E. (WY), F.ASCE
225-767-9126

**LTRC Contact**
Samuel B. Cooper III, Ph.D., P.E.
225-767-9124

**Funding**
SPR: TT-Fed/TT-Reg - 6

**Read final report online:**
*www.ltrc.lsu.edu/publications.html*

## Methodology

Two asphalt binder types were selected for evaluation: unmodified PG 67-22 and SBS-modified PG 70-22, both meeting Louisiana DOTD specifications. Further, three aggregates types with 12.5 mm nominal maximum aggregate size were selected: limestone (absorption < 2%), crushed gravel (absorption > 2%, natural sand content > 15%), and semi-crushed gravel (absorption > 2%, natural sand content > 15%). The semi-crushed gravel was specifically chosen to have crushed particles passing the No. 4 sieve (4.75 mm) and smooth, round particles retained on it (50%). Additionally, two approved anti-strip additives, Evotherm and an amine-based product, were selected to assess their effectiveness in mitigating moisture damage.

The study involved two primary experiments: one for asphalt binders and one for asphalt mixtures. The goal was to validate moisture conditioning and testing protocols using the anti-stripping additives (chemical WMA and amine-based) through Modified Lottman and Hamburg Wheel-Tracking tests, assessing the impact of single freeze-thaw (FT-1), triple freeze-thaw (FT-3), as well as 3500 and 7000 Moisture-induced Stress Tester (MiST and 3500 and MiST 7000) cycles. In the asphalt binder experiment, Rolling Thin Film Oven (RTFO)-aged asphalt binders were subjected to five moisture conditioning levels. The control group remained unconditioned, while the others underwent single and triple freeze-thaw cycles (freezing at -18°C for 16 hrs., then immersion in a 60°C water bath for 24 hrs.), or 3500 and 7000 MiST cycles (hydrostatic pore pressure cycles at 60°C). After conditioning, binders were characterized using rheological tests. Frequency sweep tests at multiple temperatures were performed to construct master curves for dynamic shear modulus (G)* and phase angle (δ). Multiple stress creep recovery (MSCR) tests evaluated high-temperature performance, yielding non-recoverable creep compliance (Jnr) and percent recovery. The adhesive bond strength between conditioned binders and different aggregate substrates was also assessed using the binder bond strength (BBS) test under dry and wet conditions. The pull-off tensile strength (POTS) ratio was used to indicate moisture susceptibility.

The asphalt mixture experiment involved designing 13 12.5 mm Superpave asphalt mixtures using the two binder types and three aggregate types. Mixture designs followed AASHTO M 323, R 35, and Louisiana DOTD specifications, focusing on achieving optimum asphalt cement content based on volumetric properties (air voids, VMA, VFA) and densification. Seven mixtures were used for developing and validating moisture damage tests and conditioning protocols, and six were used to assess the effectiveness of anti-strip additives. Moisture susceptibility was evaluated in both loose and compacted mixtures. For loose mixtures, the boil test (ASTM D 3625) was performed with varying durations to visually assess asphalt film stripping, and the Asphalt Compatibility Tester (ACT) was used to quantify color change indicating binder loss. Compacted asphalt mixtures were subjected to five moisture conditioning levels, mirroring the binder experiment: control (short-term aging), single and triple freeze-thaw cycles (AASHTO T 283), and 3500 and 7000 MiST cycles (ASTM 7870). Mechanical performance of conditioned mixtures was then evaluated using the Modified Lottman (ML) test for tensile strength ratio (TSR), the Hamburg Wheel-Tracking (HWT) test for rutting and stripping potential, and the Semi-Circular Bending (SCB) test to characterize fracture resistance at intermediate temperatures. A new parameter, *Jd*, and its ratio, was introduced to quantify moisture damage's effect on cracking resistance based on SCB results. Finally, data from both experiments were subjected statistical analysis using ANOVA in SAS 9.4. The statistical significance of difference in moisture damage resistance among various asphalt binder types and mixtures under different conditioning levels was determined by this analysis. A Tukey's multiple comparison test with a 95% confidence level was performed to create statistical groupings, which allowed for a clear ranking of performance.

## Conclusions

Moisture conditioning significantly influenced asphalt binder rheology. Freeze-thaw and MiST conditioning increased binder stiffness, particularly in unmodified PG 67-22 binders. Both PG 67-22 and PG 70-22 binders showed slightly reduced stress sensitivity due to this stiffness increase. Binder Bond Strength (BBS) tests revealed that aggregate type, binder grade, and conditioning significantly influenced failure mode. Limestone showed higher BBS with cohesive failure, indicating better moisture resistance, while gravel had lower BBS and mixed failure types. Polymer-modified binders had higher BBS, but conditioning reduced BBS in all binders, increasing adhesive failure susceptibility.

Hamburg Wheel-Tracking (HWT) tests on asphalt mixtures showed increased rutting after freeze-thaw and MiST conditioning, effectively identifying moisture-sensitive mixtures. This suggests integrating moisture conditioning into HWT protocols. SBS-modified PG 70-22 mixtures demonstrated improved moisture damage resistance, with lower rut depths and higher indirect tensile strength (ITS) compared to unmodified PG 67-22. The HWT rut depth and the new SCB *Jd*-ratio effectively tracked moisture damage and distinguished enhanced resistance from SBS-modified binders and anti-strip additives.

This study highlights the impact of moisture conditioning on asphalt properties and the effectiveness of various testing protocols. MiST conditioning effectively simulated field moisture-damage, unlike the inconsistent freeze-thaw conditioning from the Modified Lottman test. The HWT rut depth and SCB *Jd*-ratio better captured moisture-induced damage. An amine-based anti-strip additive improved moisture resistance, while a WMA additive performed similarly to the control. MiST 7000 conditioning caused more severe damage than FT3, emphasizing the need for appropriate conditioning methods for accurate assessment.

## Recommendations

For accurate moisture susceptibility evaluation, transportation agencies should prioritize direct moisture conditioning of both asphalt binders and mixtures. While increased binder stiffness from conditioning did not always improve mixture resistance, applying protocols such as three freeze-thaw cycles (FT-3), 3500 MiST cycles, or 7000 MiST cycles is crucial. Integrating a suitable conditioning protocol into the Hamburg Wheel-Tracking (HWT) test is specifically recommended to better identify moisture-prone mixtures.

The study suggests the Semi-Circular Bend (SCB) Jd-ratio parameter as a viable alternative or supplement to HWT rut depth for evaluating moisture-induced damage, as it demonstrated sensitivity and provided fracture behavior insights. Future research could utilize Atomic Force Microscopy on mixture samples for deeper understanding of cohesive/adhesive failure mechanisms.

Concerns exist regarding increased HWT rut depth with both amine-based (AM) and warm mix asphalt (WMA) anti-strip additives, suggesting a potential negative impact on rutting resistance. Agencies should carefully assess trade-offs between moisture damage mitigation and rutting susceptibility during mixture design. Comprehensive field studies are strongly recommended to validate the long-term impacts of anti-strip additives, especially given their prevalence in regions like Louisiana.