University Transportation Research Center - Region 2

# Final Report


## Early Age Rutting Potential of Warm Mix Asphalt (WMA)

Performing Organization: Rutgers University

December 2012

Sponsor:
New York State Department of Transportation (NYSDOT

## University Transportation Research Center - Region 2

The Region 2 University Transportation Research Center (UTRC) is one of ten original University Transportation Centers established in 1987 by the U.S. Congress. These Centers were established with the recognition that transportation plays a key role in the nation's economy and the quality of life of its citizens. University faculty members provide a critical link in resolving our national and regional transportation problems while training the professionals who address our transportation systems and their customers on a daily basis.

The UTRC was established in order to support research, education and the transfer of technology in the field of transportation. The theme of the Center is "Planning and Managing Regional Transportation Systems in a Changing World." Presently, under the direction of Dr. Camille Kamga, the UTRC represents USDOT Region II, including New York, New Jersey, Puerto Rico and the U.S. Virgin Islands. Functioning as a consortium of twelve major Universities throughout the region, UTRC is located at the CUNY Institute for Transportation Systems at The City College of New York, the lead institution of the consortium. The Center, through its consortium, an Agency-Industry Council and its Director and Staff, supports research, education, and technology transfer under its theme. UTRC's three main goals are:

### Research

The research program objectives are (1) to develop a theme based transportation research program that is responsive to the needs of regional transportation organizations and stakeholders, and (2) to conduct that program in cooperation with the partners. The program includes both studies that are identified with research partners of projects targeted to the theme, and targeted, short-term projects. The program develops competitive proposals, which are evaluated to insure the mostresponsive UTRC team conducts the work. The research program is responsive to the UTRC theme: "Planning and Managing Regional Transportation Systems in a Changing World." The complex transportation system of transit and infrastructure, and the rapidly changing environment impacts the nation's largest city and metropolitan area. The New York/New Jersey Metropolitan has over 19 million people, 600,000 businesses and 9 million workers. The Region's intermodal and multimodal systems must serve all customers and stakeholders within the region and globally.Under the current grant, the new research projects and the ongoing research projects concentrate the program efforts on the categories of Transportation Systems Performance and Information Infrastructure to provide needed services to the New Jersey Department of Transportation, New York City Department of Transportation, New York Metropolitan Transportation Council , New York State Department of Transportation, and the New York State Energy and Research Development Authorityand others, all while enhancing the center's theme.

### Education and Workforce Development

The modern professional must combine the technical skills of engineering and planning with knowledge of economics, environmental science, management, finance, and law as well as negotiation skills, psychology and sociology. And, she/he must be computer literate, wired to the web, and knowledgeable about advances in information technology. UTRC's education and training efforts provide a multidisciplinary program of course work and experiential learning to train students and provide advanced training or retraining of practitioners to plan and manage regional transportation systems. UTRC must meet the need to educate the undergraduate and graduate student with a foundation of transportation fundamentals that allows for solving complex problems in a world much more dynamic than even a decade ago. Simultaneously, the demand for continuing education is growing – either because of professional license requirements or because the workplace demands it – and provides the opportunity to combine State of Practice education with tailored ways of delivering content.

### Technology Transfer

UTRC's Technology Transfer Program goes beyond what might be considered "traditional" technology transfer activities. Its main objectives are (1) to increase the awareness and level of information concerning transportation issues facing Region 2; (2) to improve the knowledge base and approach to problem solving of the region's transportation workforce, from those operating the systems to those at the most senior level of managing the system; and by doing so, to improve the overall professional capability of the transportation workforce; (3) to stimulate discussion and debate concerning the integration of new technologies into our culture, our work and our transportation systems; (4) to provide the more traditional but extremely important job of disseminating research and project reports, studies, analysis and use of tools to the education, research and practicing community both nationally and internationally; and (5) to provide unbiased information and testimony to decision-makers concerning regional transportation issues consistent with the UTRC theme.

**Project No:** 55505-09-03

**Project Date:** December 2012

**Project Title:** Early Age Rutting Potential of Warm Mix Asphalt (WMA)

**Principal Investigator:**

**Dr. Thomas Bennert**
Senior Research Engineer
Center for Advanced Infrastructure and Transportation (CAIT)
Rutgers University
100 Brett Road
Piscataway, NJ 08854
Email: bennert@rci.rutgers.edu.

**Performing Organization:** Rutgers University

**Sponsor:**
New York State Department of Transportation (NYSDOT)

To request a hard copy of our final reports, please send us an email at utrc@utrc2.org

**Mailing Address:**

University Transportation Reserch Center
The City College of New York
Marshak Hall, Suite 910
160 Convent Avenue
New York, NY 10031
Tel: 212-650-8051
Fax: 212-650-8374
Web: www.utrc2.org

## Board of Directors

The UTRC Board of Directors consists of one or two members from each Consortium school (each school receives two votes regardless of the number of representatives on the board). The Center Director is an ex-officio member of the Board and The Center management team serves as staff to the Board.

**City University of New York**
*Dr. Hongmian Gong - Geography*
*Dr. Claire McKnight - Civil Engineering*
*Dr. Neville A. Parker - Civil Engineering*

**Clarkson University**
*Dr. Kerop D. Janoyan - Civil Engineering*

**Columbia University**
*Dr. Raimondo Betti - Civil Engineering*
*Dr. Elliott Sclar - Urban and Regional Planning*

**Cornell University**
*Dr. Huaizhu (Oliver) Gao - Civil Engineering*
*Dr. Mark A. Turnquist - Civil Engineering*

**Hofstra University**
*Dr. Jean-Paul Rodrigue - Global Studies and Geography*

**New Jersey Institute of Technology**
*Dr. Steven Chien, Civil Engineering*
*Dr. Priscilla P. Nelson - Geotechnical Engineering*

**New York University**
*Dr. Mitchell L. Moss - Urban Policy and Planning*
*Dr. Rae Zimmerman - Planning and Public Administration*

**Polytechnic Institute of NYU**
*Dr. John C. Falcocchio - Civil Engineering*
*Dr. Elena Prassas - Civil Engineering*

**Rensselaer Polytechnic Institute**
*Dr. José Holguín-Veras - Civil Engineering*
*Dr. William "Al" Wallace - Systems Engineering*

**Rochester Institute of Technology**
*Dr. James Winebrake -Science, Technology, & Society/Public Policy*

**Rowan University**
*Dr. Yusuf Mehta - Civil Engineering*
*Dr. Beena Sukumaran - Civil Engineering*

**Rutgers University**
*Dr. Robert Noland - Planning and Public Policy*
*Dr. Kaan Ozbay - Civil Engineering*

**State University of New York**
*Michael M. Fancher - Nanoscience*
*Dr. Catherine T. Lawson - City & Regional Planning*
*Dr. Adel W. Sadek - Transportation Systems Engineering*
*Dr. Shmuel Yahalom - Economics*

**Stevens Institute of Technology**
*Dr. Sophia Hassiotis - Civil Engineering*
*Dr. Thomas H. Wakeman III - Civil Engineering*

**Syracuse University**
*Dr. Riyad S. Aboutaha - Civil Engineering*
*Dr. O. Sam Salem - Construction Engineering and Management*

**The College of New Jersey**
*Dr. Michael Shenoda - Civil Engineering*

**University of Puerto Rico - Mayagüez**
*Dr. Ismael Pagán-Trinidad - Civil Engineering*
*Dr. Didier M. Valdés-Díaz - Civil Engineering*

## UTRC Consortium Universities

The following universities/colleges are members of the UTRC consortium.

City University of New York (CUNY)
Clarkson University (Clarkson)
Columbia University (Columbia)
Cornell University (Cornell)
Hofstra University (Hofstra)
New Jersey Institute of Technology (NJIT)
New York University (NYU)
Polytechnic Institute of NYU (Poly)
Rensselaer Polytechnic Institute (RPI)
Rochester Institute of Technology (RIT)
Rowan University (Rowan)
Rutgers University (Rutgers)
State University of New York (SUNY)
Stevens Institute of Technology (Stevens)
Syracuse University (SU)
The College of New Jersey (TCNJ)
University of Puerto Rico - Mayagüez (UPRM)

## UTRC Key Staff

**Dr. Camille Kamga:** *Director, Assistant Professor of Civil Engineering*

**Dr. Robert E. Paaswell:** *Director Emeritus of UTRC and Distin*guished Professor of Civil Engineering, The City College of New York

**Dr. Claire McKnight:** *Assistant Director for Education and Training; Associate Professor of Civil Engineering, City College of New York*

**Herbert Levinson:** *UTRC Icon Mentor, Transportation Consultant and Professor Emeritus of Transportation*

**Dr. Ellen Thorson:** *Senior Research Fellow, University Transportation Research Center*

**Penny Eickemeyer:** *Associate Director for Research, UTRC*

**Dr. Alison Conway:** *Associate Director for New Initiatives and Assistant Professor of Civil Engineering*

**Nadia Aslam:** *Assistant Director for Technology Transfer*

**Dr. Anil Yazici:** *Post-doc/ Senior Researcher*

**Nathalie Martinez:** *Research Associate*

ROBERT E. PAASWELL, DIRECTOR

The City College of New York
Marshak Hall, MR-910
138th Street and Convent Avenue
New York, NY 10031
212-650-8050

*U.S. DOT REGION II*
New Jersey
New York
Puerto Rico
U.S. Virgin Islands

*CONSORTIUM MEMBERS*
City University of New York
Columbia University
Cornell University
New Jersey Institute of Technology
New York University
Polytechnic Institute of NYU
Rensselaer Polytechnic Institute
Rowan University
Rutgers University
State University of New York
Stevens Institute of Technology
University of Puerto Rico

*Center Theme:*
*Planning and Managing Regional Transportation Systems in a Changing World*

*REGION II*
*UNIVERSITY TRANSPORTATION RESEARCH CENTER*

# FINAL REPORT

## *Early Age Rutting Potential of Warm Mix Asphalt (WMA)*
## *RFP Number: C-10-08*


**PRINCIPAL INVESTIGATOR:**
Thomas Bennert, Ph.D.
Senior Research Engineer
Center for Advanced Infrastructure and Transportation (CAIT)
Rutgers University
100 Brett Road
Piscataway, NJ 08854
Tel: 732-445-5376; Fax: 732-445-0577;
Email: bennert@rci.rutgers.edu.



**SPONSOR:**
New York State Department of Transportation



**RESEARCH PROJECT MANAGER:**
Nick Shaarbafan
Materials Bureau, 5th Floor
New York State Department of Transportation
50 Wolf Road
Albany, New York 12232



**DATE RESUBMITTED:**
December 13th, 2012

## DISCLAIMER

This report was funded in part through grant(s) from the Federal Highway Administration, United States Department of Transportation, under the State Planning and Research Program, Section 505 of Title 23, U.S. Code. The contents of this report do not necessarily reflect the official views or policy of the United States Department of Transportation, the Federal Highway Administration or the New York State Department of Transportation. This report does not constitute a standard, specification, regulation, product endorsement, or an endorsement of manufacturers.

<table>
<tr><td colspan="2">1. Report No. C-10-08</td><td>2. Government Accession No.</td><td colspan="2">3. Recipient's Catalog No.</td></tr>
<tr><td colspan="3" rowspan="2">4. Title and Subtitle<br><br>Early Age Rutting Potential of Warm Mix Asphalt (WMA)</td><td colspan="2">5. Report Date<br><br>December 12, 2012</td></tr>
<tr><td colspan="2">6. Performing Organization Code</td></tr>
<tr><td colspan="3">7. Author(s)<br><br>Thomas Bennert, Ph.D.</td><td colspan="2">8. Performing Organization Report No.</td></tr>
<tr><td colspan="3" rowspan="2">9. Performing Organization Name and Address<br><br>Center for Advanced Infrastructure and Transportation (CAIT), Rutgers University</td><td colspan="2">10. Work Unit No.</td></tr>
<tr><td colspan="2">11. Contract or Grant No.<br>55505-09-03</td></tr>
<tr><td colspan="3" rowspan="2">12. Sponsoring Agency Name and Address<br><br>NYS Department of Transportation<br>50 Wolf Road<br>Albany, New York 12232</td><td colspan="2">13. Type of Report and Period Covered<br><br>Final Report</td></tr>
<tr><td colspan="2">14. Sponsoring Agency Code</td></tr>
<tr><td colspan="5">15. Supplementary Notes<br><br>Project funded in part with funds from the Federal Highway Administration</td></tr>
<tr><td colspan="5">16. Abstract<br><br>Various plant produced Warm Mix Asphalt (WMA) mixtures were evaluated and compared to identical plant produced Hot Mix Asphalt to assess their early life rutting potential. Along with laboratory permanent deformation testing, fatigue and moisture damage potential testing was also included. The test results indicated that the performance of the WMA was very similar to that of the companion HMA with differences in performance a function of mix type, RAP content, and production temperature.</td></tr>
<tr><td>17. Key Words<br><br>Warm Mix Asphalt, rutting, fatigue cracking, stiffness, moisture damage</td><td colspan="4">18. Distribution Statement<br><br>No Restrictions</td></tr>
<tr><td>19. Security Classif. (of this report)<br><br>Unclassified</td><td colspan="2">20. Security Classif. (of this page)<br><br>Unclassified</td><td>21. No. of Pages<br><br>32</td><td>22. Price</td></tr>
</table>

# EXECUTIVE SUMMARY

The term warm mix asphalt (WMA) refers to technologies and systems that allow for the substantial reduction in production and compaction temperatures of hot mix asphalt. The original intent of utilizing WMA was to provide better workability and compaction of asphalt mixtures. In turn, a better compacted asphalt pavement should also enhance its general performance. It is well known that asphalt pavements compacted to better densities often have better fatigue and rutting performance.

However, the implementation and use of WMA may create potential issues as well. The reduced oxidative aging of the asphalt binder during production may increase the asphalt's susceptibility to rutting. Another issue that will need to be addressed is the potential for moisture damage. Although moisture damage potential is also possible in some hot mix asphalt (HMA) mixtures, due to its method of production, it may be more likely in WMA. Inadequately dried aggregates at lower production temperatures, and even the possible introduction of additional moisture to the WMA from the various WMA foaming technologies, may affect the binder to aggregate adhesion, moisture susceptibility and general mixture performance. The magnitude to which the different WMA technologies/additives affect the moisture sensitivity will vary and will depend on many regional (climate, aggregate type and asphalt binder source) and pavement specific conditions (traffic loading and general pavement integrity).

To help address New York State's concerns with the implementation of WMA, fourteen (14) sets of WMA and companion HMA plant produced mixtures were evaluated in the laboratory for their respective rutting, fatigue cracking, and moisture damage resistance. WMA technologies mainly revolved around foamed asphalt and surfactant technologies (Evotherm). To avoid issues with reheating the loose mix in the laboratory, all test specimens were produced at the asphalt plant's Quality Control laboratory after 2 hours of oven conditioning. On average, the test results indicated that the WMA specimens were slightly more prone to laboratory permanent deformation testing, slightly more prone to moisture damage, but achieved a greater resistance to fatigue cracking. However, when comparing the test data to established performance criteria for rutting and moisture damage potential, both the WMA and HMA mixtures were found to perform equally in most cases.

# Table of Contents

## List of Figures



## List of Tables

## BACKGROUND

The term warm mix asphalt (WMA) refers to technologies and systems that allow for the substantial reduction in production and compaction temperatures of hot mix asphalt. The original intent of utilizing WMA was to provide better workability and compaction of asphalt mixtures at significantly lower temperatures. In addition, WMA was developed to reduce emissions and energy production usage and their associated production energy costs. Furthermore, the production and compaction at substantially lower temperatures can allow for longer mixture hauling distances/times and may prolong the paving season particularly in colder regions of the US and Canada. Ideally, an asphalt pavement that is easier to compact should also experience an extension in its in-service performance life in terms of all major asphalt distresses: rutting, fatigue, low temperature damage, thermal cracking, and moisture damage. It is well known that asphalt pavements compacted to proper densities often have superior fatigue and rutting performance. A thorough analysis of this can be found in detail in NCHRP Report 567, *Volumetric Requirements for Superpave Mix Design* (Christensen and Bonaquist, 2006).

Since its initial demonstration project at the annual World of Asphalt Trade Show and Conference in 2004, the use of WMA in the United States has ranged from 200 ton pilot projects to specifying 20,000 ton interstate projects. To date, the reported performance on these projects has been generally good with premature failures often being classified as construction issues or plant malfunctions. However, it has been consistently reported on a number of documented WMA projects that; 1) WMA often shows greater potential for rutting than conventional HMA when evaluated using conventional laboratory procedures and 2) WMA often shows greater potential for moisture damage than conventional HMA when evaluated using conventional laboratory procedures. These differences in performance may be explained by the lower production temperatures not oxidizing the asphalt binder resulting in a mixture with lower stiffness and lesser aggregate drying and possible creating a mixture more sensitive to stripping and rutting. Figure 1 and Table 1 provides an example of how the relative change in production temperature and initial aggregate moisture content can create these potential issues in a laboratory setting (Bennert et al., 2011).

A compounding issue to the influence of production temperature reduction and the possibility of residual aggregate moisture is the number of WMA technologies/processes currently on the market. According to the Federal Highway Administration (FHWA), there exists over twenty different WMA technologies/processes in North America, although they can generally be broken down into three distinct categories; 1) Organic/wax additives, 2) Chemical additives, and 3) Water-based foaming processes. Each one of these technologies/processes results in a slightly different modification to the final asphalt mixture. For example, the Sasobit wax will have a tendency to increase the high temperature PG grade, thus aid in rutting resistance. While the Rediset WMX and Evotherm 3G additives are surfactants containing anti-stripping agents to aid in reducing moisture damage potential. Therefore, for WMA to be successfully and faithfully implemented by federal, state, and local agencies, it is extremely important that a thorough and comprehensive acceptance testing program be evaluated and implemented to ensure WMA performs in similar manner to HMA with respect to rutting and moisture susceptibility properties.

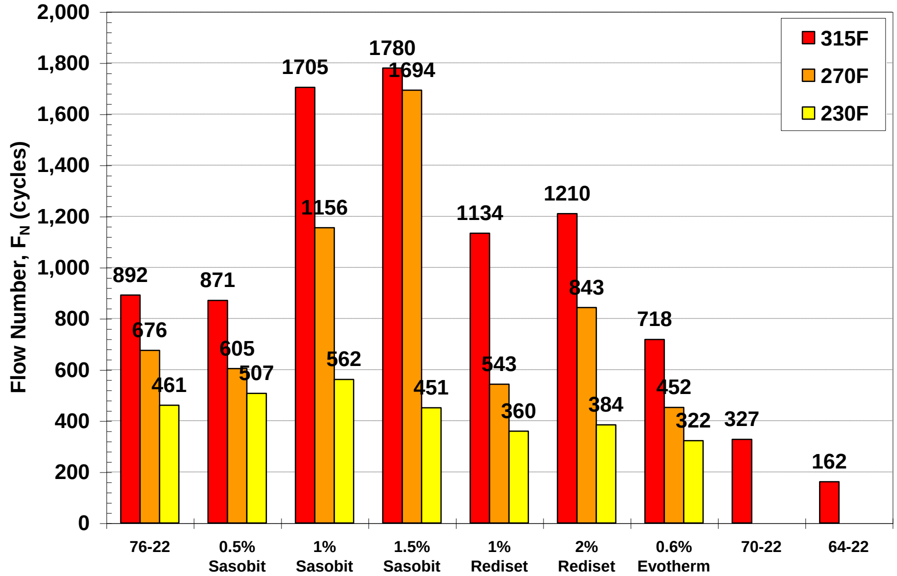



Figure 1 – Change in Permanent Deformation (Flow Number) Properties of Various WMA Technologies Due to Change in Production (Mixing) Temperature (Bennert et al., 2011)

Table 1 – Tensile Strength Ratio (TSR) Results of Asphalt Mixtures with Varying Mixing Temperatures and Initial Moisture Contents (Bennert et al., 2011)

| Moisture Content of Aggregate Blend = 0.61%<br>Trap Rock Aggregate | | | | |
|---|---|---|---|---|
| Mixing Temp (F) | Moisture Content (%) | TSR | Tensile Strength (U) | Tensile Strength (C) |
| 270 | 0 | 62.6 | 224.7 | 140.7 |
| | 3 | 52.0 | 195.8 | 123.3 |
| | 6 | 63.0 | 184.6 | 96.1 |
| 315 | 0 | 88.2 | 240.7 | 212.2 |
| | 3 | 64.0 | 217.7 | 139.3 |
| | 6 | 65.8 | 236.4 | 155.5 |

| Moisture Content of Aggregate Blend = 1.47%<br>Gravel Gravel | | | | |
|---|---|---|---|---|
| Mixing Temp (F) | Moisture Content (%) | TSR | Tensile Strength (U) | Tensile Strength (C) |
| 270 | 0 | 63.0 | 247.3 | 155.9 |
| | 3 | 38.7 | 157.2 | 90.4 |
| | 6 | 57.5 | 220.7 | 85.3 |
| 315 | 0 | 93.9 | 195.6 | 183.6 |
| | 3 | 63.2 | 227.3 | 143.5 |
| | 6 | 71.5 | 219.3 | 156.9 |

## RESEARCH OBJECTIVE

The purpose of this research will be to evaluate the early age rutting potential of various New York State Department of Transportation (NYSDOT) WMA mixtures. Current specifications for selecting the appropriate PG Binder grade to use in the asphalt mixture rely on the knowledge that the binders experience aging due to the asphalt mixture production temperatures near 325°F. Since WMA uses lower mixture production temperatures, the PG binder is not aged to the same extent. The effect of not aging the PG binder is of a concern with regard to the permanent deformation (rutting) of the mixture.

## MIXTURE TESTING PROGRAM

During the 2010 and 2011 construction seasons, NYSDOT proposed and placed several trial sections of WMA under an experimental work plan. These trial sections were placed across the state with many variables (traffic levels, aggregate types, WMA technology types, etc.). NYSDOT fabricated samples from the various projects, which in turn were sent to the Research Team for testing and analysis. In accordance with the NYSDOT RFP C-10-08, Flow Number obtained from the Asphalt Mixture Performance Tester (AASHTO TP79-09) and rut depths measured from the Asphalt Pavement Analyzer (AASHTO TP 63-09, see Table 2 AASHTO test Method for APA) were conducted to evaluate the rutting potential of the WMA when compared with companion HMA sections. The permanent deformation testing was conducted in accordance with to NYSDOT Item 404.XXYZQ191 – Warm Mix Asphalt. The test parameters for these tests are shown in Table 2.

Table 2 – NYSDOT Mixture Rut Performance Tests and Criteria

| Type of Test | AASHTO Test Method | Test Specimen Air Voids[1] | Test Temperature | |
|---|---|---|---|---|
| | | | Upstate | Downstate |
| Asphalt Pavement Analyzer (APA) | TP 63-09 | 7.0 ± 1.0% | 136°F (58°C) | 147°F (64°C) |
| Hamburg Wheel Track (HWT) | T 324-04 | 7.0 ± 1.0% | 122°F (50°C) | 122°F (50°C) |
| Asphalt Mixture Performance Tester (AMPT) | TP 79-09 | 7.0 ± 1.0% | 122°F (50°C) | 127°F (53°C) |

Note 1: Condition the mixture for 4 hours ± 5 minutes at the desired field compaction temperature

Along with the Asphalt Mixture Performance Tester Flow Number (AASHTO TP79-09) and the Asphalt Pavement Analyzer (AASHTO T340) tests proposed and agreed upon by the NYSDOT, Rutgers University also conducted the following tests to help further characterize the early life performance of the WMA and HMA mixtures;

- Mixture Stiffness
  - Dynamic Modulus (E*) Using the Asphalt Mixture Performance Tester – AASHTO TP79
- Moisture Damage
  - Tensile Strength Ratio (TSR) – AASHTO T283
  - Wet Hamburg Wheel Tracking (HWT) – AASHTO T324
- Fatigue Cracking
  - Overlay Tester – TxDOT Tex-248F

The test results will be used by  NYSDOT to better understand the initial performance of plant produced WMA and help to provide further guidance as to its  adoption in the state of New York.

## TESTING PROGRAM

### ***Dynamic Modulus (AASHTO TP79)***

Dynamic modulus and phase angle data were measured and collected in uniaxial compression using the Simple Performance Tester (SPT) following the method outlined in AASHTO TP79, *Determining the Dynamic Modulus and Flow Number for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)* (Figure 2).  The data was collected at three temperatures; 4, 20, and 35$^{o}$C using loading frequencies of 25, 10, 5, 1, 0.5, 0.1, and 0.01 Hz.

Figure 2 – Photo of the Asphalt Mixture Performance Tester (AMPT)

The collected modulus values of the varying temperatures and loading frequencies were used to develop Dynamic Modulus master stiffness curves and temperature shift factors using numerical optimization of Equations 1 and 2.  The reference temperature used for the generation of the master curves and the shift factors was 20$^{o}$C.

$$\log|E^*| = \delta + \frac{(Max - \delta)}{1 + e^{\beta + \gamma\left\{\log\omega + \frac{\Delta E_a}{19.14714}\left[\left(\frac{1}{T}\right) - \left(\frac{1}{T_r}\right)\right]\right\}}} \quad (1)$$

where:

$|E^*|$ = dynamic modulus, psi
$\omega_r$ = reduced frequency, Hz
*Max* = limiting maximum modulus, psi
$\delta$, $\beta$, and $\gamma$ = fitting parameters

$$\log\left[a(T)\right] = \frac{\Delta E_a}{19.14714}\left(\frac{1}{T} - \frac{1}{T_r}\right) \quad (2)$$

where:

$a(T)$ = shift factor at temperature T
$T_r$ = reference temperature, °K
T = test temperature, °K
$\Delta E_a$ = activation energy (treated as a fitting parameter)

***Rutting Evaluation***

The rutting potential of the asphalt mixtures were evaluated using two different test procedures; 1) Asphalt Mixture Performance Tester (AMPT) Flow Number and 2) the Asphalt Pavement Analyzer.

Repeated Load Flow Number (AASHTO TP79)

Repeated Load permanent deformation testing was measured and collected in uniaxial compression using the Simple Performance Tester (SPT) following the method outlined in AASHTO TP79, *Determining the Dynamic Modulus and Flow Number for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)*. The unconfined repeated load tests were conducted with a deviatoric stress of 600 kPa and a test temperature of 50$^{o}$C, as per the recommendations of the NYSDOT WMA Technology Approval Process.

Minimum recommended Flow Number values, based on ESAL level, has been established under NCHRP Project 9-43 and are proposed for implementation in AASHTO R35. Table 3 provides the minimum recommended values as proposed in the Appendix to AASHTO R35, *Appendix: Special Mixture Design Considerations and Methods for Warm Mix Asphalt (WMA)*.

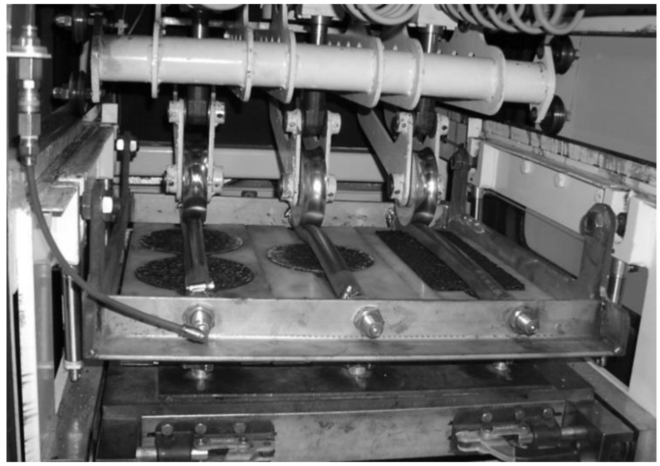
Table 3 – Recommended Minimum Flow Number Requirements for Warm Mix Asphalt (WMA) Levels (after Bonaquist, 2011)

| Traffic Level, Million ESAL's | Minimum Flow Number (cycles) | |
|---|---|---|
| | HMA | WMA |
| < 3 | --- | --- |
| 3 to < 10 | 53 | 30 |
| 10 to < 30 | 190 | 105 |
| > 30 | 740 | 415 |

Asphalt Pavement Analyzer (AASHTO TP 63-09)

The Asphalt Pavement Analyzer (APA) was conducted in accordance with AASHTO TP 63-09 (see Table 2 AASHTO test Method for APA), *Determining Rutting Susceptibility of Asphalt Paving Mixtures Using the Asphalt Pavement Analyzer (APA).* A hose pressure of 100 psi and a wheel load of 100 lb were used in the testing. Testing was continued until 8,000 loading cycles and APA rutting deformation was recorded at each cycle. The APA device used for testing at Rutgers University is shown in Figures 3a and 3b.

(a)



(b)

Figure 3 – a) Asphalt Pavement Analyzer (APA) at Rutgers University; b) Inside the Asphalt Pavement Analyzer Device

Prior to testing, each sample was heated for 6 hours (+/- 15 minutes) at the testing temperature to ensure temperature equilibrium within the test specimen was achieved. Testing started with 25 cycles used as a seating load to eliminate any sample movement during testing. After the 25 seating cycles completed, the data acquisition began sampling test information until a final 8,000 loading cycles was reached. Table 4 includes the recommended APA rutting requirements from NCHRP 9-33 (Advanced Asphalt Technologies., 2011).

Table 4 – Recommended Maximum APA Rutting Requirements for Various Traffic (ESAL) Levels (after Advanced Asphalt Technologies, 2011)

| Traffic Level, Million ESAL's | Maximum APA Rutting (mm) |
|---|---|
| < 3 | --- |
| 3 to < 10 | 5 |
| 10 to < 30 | 4 |
| > 30 | 3 |

### *Resistance to Moisture-Induced Damage*

The resistance to moisture damage was evaluated using both the tensile strength ratio (TSR) test procedure and the wet Hamburg Wheel Tracking Test (AASHTO T324). The test procedures and results are discussed below.

<u>Tensile Strength Ratio, TSR (AASHTO T283)</u>

Tensile strengths of dry and conditioned asphalt samples were measured in accordance with AASHTO T283, *Resistance of Compacted Asphalt Mixtures to Moisture Induced Damage*. Specimens were prepared at the asphalt plant's QC laboratory directly from plant produced material. The test specimens were compacted to 95 mm in height and within a target air void range of 6.5 to 7.5%.

<u>Wet Hamburg Wheel Track Test (AASHTO T324)</u>

Hamburg Wheel Track tests were conducted in accordance with AASHTO T324, *Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA)*. Test specimens were tested at a test temperature (water) of 50$^{o}$C. For comparison purposes, the NYSDOT uses the number of cycles to reach 0.5 inches (12.5 mm) of rutting. For a PG64-22 asphalt binder, the mixtures must achieve a minimum of 10,000 cycles before achieving 0.5 inches of rutting. For a PG70-22 asphalt binder, the mixtures must achieve a minimum of 15,000 cycles before achieving 0.5 inches of rutting. For a PG76-22 asphalt binder, the mixtures must achieve a minimum of 20,000 cycles before achieving 0.5 inches of rutting.

### *Fatigue Cracking Resistance*

<u>Overlay Tester (TxDOT Tex-248-F)</u>

The Overlay Tester, described by Zhou and Scullion (2005), has shown to provide an excellent correlation to field cracking for both composite pavements (Zhou and Scullion, 2005; Bennert et al., 2009) as well as flexible pavements (Zhou et al., 2007). Figure 4 shows a picture of the Overlay Tester used in this study. Sample preparation and test parameters used in this study followed that of TxDOT Tex-248-F testing specifications. These include:

- 25$^{o}$C (77$^{o}$F) test temperature;
- Opening width of 0.025 inches;
- Cycle time of 10 seconds (5 seconds loading, 5 seconds unloading); and
- Specimen failure defined as 93% reduction in Initial Load.

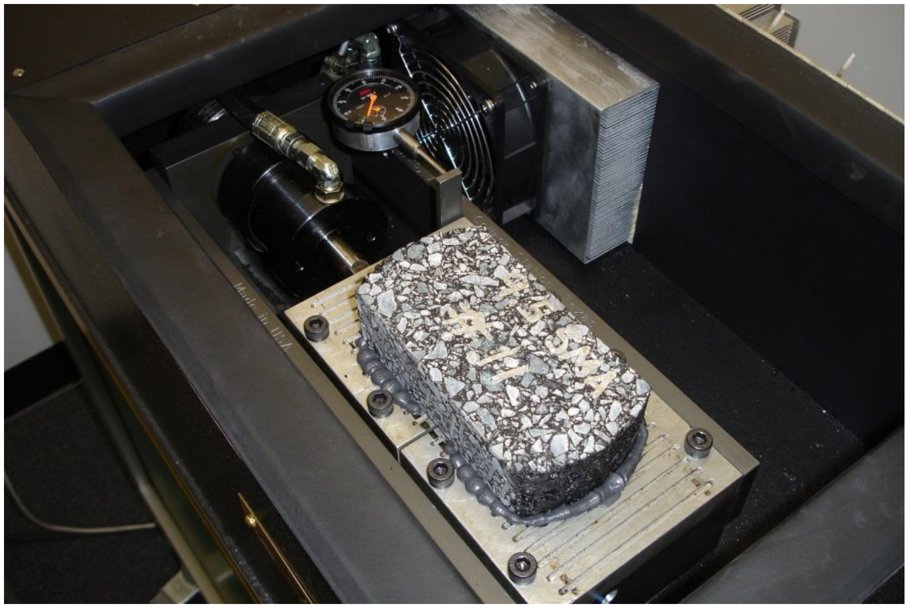


Figure 4 – Picture of the Overlay Tester (Chamber Door Open)

**PROJECTS LOCATION AND MATERIALS INFORMATION**

For this research project, a total of Eleven (11) different projects that consisted of 14 WMA specimen sets and their companion 14 HMA Specimen sets, were evaluated. In each project, both a warm mix asphalt (WMA) and hot mix asphalt (HMA) mixtures were produced using the identical job mix formula, aggregates, and asphalt binder. A summary of the different characteristics from each of the specimens can be found in Table 5. Overall, the project list encompassed the following:

- 0% to 20% RAP;
- < 3 to >30Million ESAL's traffic level;
- Asphalt content: 5.2% to 6.7%;
- WMA Technologies: Terex Foaming, LEA-Lite, and Evotherm; and
- WMA Mixing Temperatures: 240$^{o}$F to 300$^{o}$F

Table 5 – Information of WMA and HMA Projects Evaluated in Study

| WMA PROJECTS LIST | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **REGION** | **SPECIMEN SET NUMBER** | **PROJECT LOCATION** | **WMA TECHNOLOGY USED** | **PAVING DATE** | **MIX INFORMATION** | **WMA TEMP.** | **HMA TEMP.** | **PG-BINDER** | **RAP AMOUNT** | **ASPHALT CONTENT (%)** | **DESIGN ESAL's** |
| 1 | Specimen Set #1 | I87 | LEA-LITE | 2011 | 12.5 mm | 270°F | 310-325°F | 64-22 | 20.0% | 5.2% | < 30.0 |
| 3 | Specimen Set #2 | RT 481 | TEREX FOAMING | 2010 | 9.5 mm | 300°F | ------ | 64-22 | 20.0% | 5.9% | <3.0 |
| 3 | Specimen Set #3 | RT 96 | LEA-LITE | 2010 | 9.5 mm 0 Hour Aging | 270°F | 310°F | 64-22 | 15.0% | 6.7% | < 3.0 |
| 3 | Specimen Set #4 | RT 96 | LEA-LITE | 2010 | 9.5 mm 2 Hours Aging | 270°F | 310°F | 64-22 | 15.0% | 6.7% | < 3.0 |
| 3 | Specimen Set #5 | RT 96 | LEA-LITE | 2010 | 9.5 mm 4 Hours Aging | 270°F | 310°F | 64-22 | 15.0% | 6.7% | < 3.0 |
| 4 | Specimen Set #6 | Rte 5/20 and Rte 15A | LEA-LITE | 2010 | 9.5 mm | 260-262°F | ------ | 64-22 | 20.0% | 6.3% | < 30.0 |
| 4 | Specimen Set #7 | Rte 104 | LEA-LITE | 2011 | 12.5 mm | 275°F | 325°F | 64-22 | 20.0% | 5.4% | < 30.0 |
| 4 | Specimen Set #8 | Rte 20A | LEA-LITE | 2011 | 12.5 mm | 285°F | 290°F | 64-22 | 10.0% | 5.3% | < 10.0 |
| 5 | Specimen Set #9 | I-86 | LEA-LITE | 2011 | 12.5 mm | 270-275°F | ------ | 64-22 | 0.0% | 5.4% | < 10.0 |
| 5 | Specimen Set #10 | I-86 | LEA-LITE | 2011 | 19.5 mm | 270-275°F | ------ | 64-22 | 0.0% | 5.8% | < 10.0 |
| 8 | Specimen Set #11 | Route 9W | EVOTHERM | 2010 | 12.5 mm | 275°F | 315°F | 64-22 W/Anti St. Agent | 20.0% | 6.1% | < 3.0 |
| 8 | Specimen Set #12 | Route 9 | EVOTHERM | 2011 | 12.5 mm | 275°F | 315°F | 70-22 | 15.0% | 6.1% | < 30.0 |
| 9 | Specimen Set #13 | I-81 | LEA-LITE | 2010 | 9.5 mm | 240-255°F | ------ | 64-22 | 0.0% | 6.2% | > 30.0 |
| 10 | Specimen Set #14 | NY27A | EVOTHERM | 2011 | 9.5 mm | 260-265°F | 310-325°F | 70-22 | 10.0% | 5.9% | < 10.0 |

## TEST RESULTS

It should be noted that all test specimens were compacted at the asphalt plant's quality control laboratory. The loose mix was sampled from the delivery trucks prior to leaving the asphalt plant, and therefore, may or may not have been placed in silo storage – this would obviously depend on the plant type where the mixtures were produced (i.e. – batch or drum plant). In addition, during the sample compaction process, the NYSDOT technical staff had aged the loose mix in an oven for 2 hours prior to compaction at the target compaction temperature.

### AMPT Flow Number – Rutting Resistance

A summary of the Flow Number testing is shown as Table 6. The table contains the project information, along with the Flow Number test results for the WMA and HMA companion mixtures. A Student T-test analysis, conducted using a 95% confidence interval, was used to indicate whether or not the test results were statistically equal or not. Along with the statistical analysis result, the NCHRP 9-43 Flow Number criteria, established for laboratory produced WMA mixtures, is provided for a general comparison.

The testing of 14 different sets of WMA specimens and 14 different sets of HMA specimens mixtures showed that:

- 7 sets of companion specimens showed that the HMA statistically performed better than the WMA;
- 3 sets of companion specimens showed that the WMA statistically performed better than the HMA;
    - 2 of the 3 sets of companion specimens had 0% RAP with the third project only having 10% RAP
- 4 sets of companion specimens showed that the WMA and HMA were statistically equal
    - 3 of the 4 sets of companion specimens had 20% RAP with the fourth project using a PG70-22 asphalt binder with 10% RAP

### Asphalt Pavement Analysis – Rutting Resistance

A summary of the Asphalt Pavement Analyzer (APA) rutting is shown in Table 7. Similar to the Flow Number, the table contains the project information, along with APA rutting results of the WMA and companion HMA mixtures. A Student T-test analysis, conducted using a 95% confidence interval, was used to indicate whether or not the test results were statistically equal or not. Along with the statistical analysis, the NCHRP 9-33 APA rutting criteria was included. However, it should be noted that these criteria was established with limited data and is based on laboratory prepared test specimens at 4% air voids.

The testing of 14 different sets of WMA specimens and their companion HMA mixtures showed that:

- 3 sets of companion specimens showed that the HMA statistically performed better than the WMA;

- 5 sets of companion specimens showed that the WMA statistically performed better than the HMA; and
- 6 sets of companion specimens showed that the APA Rutting performance of the WMA and HMA were statistically equal.

Table 6 – Summary of Flow Number Test Results

## WMA PROJECTS LIST - Flow Number Results

| REGION | SPECIMEN SET NUMBER | PROJECT LOCATION | WMA TECHNOLOGY USED | PAVING DATE | MIX INFORMATION | WMA TEMP. | HMA TEMP. | PG-BINDER | RAP AMOUNT | ASPHALT CONTENT (%) | DESIGN ESAL's | Flow Number (cycles) | | | | t-Test Results |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | NCHRP 9-43 Spec | | Test Results | | |
| | | | | | | | | | | | | HMA | WMA | HMA | WMA | |
| 1 | Specimen Set #1 | I87 | LEA-LITE | 2011 | 12.5 mm | 270°F | 310-325°F | 64-22 | 20.0% | 5.2% | < 30.0 | > 190 | > 105 | 212 | 137 | EQUAL |
| 3 | Specimen Set #2 | RT 481 | TEREX FOAMING | 2010 | 9.5 mm | 300°F | ------ | 64-22 | 20.0% | 5.9% | <3.0 | --- | --- | 485 | 342 | NOT EQUAL |
| 3 | Specimen Set #3 | RT 96 | LEA-LITE | 2010 | 9.5 mm 0 Hour Aging | 270°F | 310°F | 64-22 | 15.0% | 6.7% | < 3.0 | --- | --- | 99 | 51 | NOT EQUAL |
| 3 | Specimen Set #4 | RT 96 | LEA-LITE | 2010 | 9.5 mm 2 Hours Aging | 270°F | 310°F | 64-22 | 15.0% | 6.7% | < 3.0 | --- | --- | 225 | 80 | NOT EQUAL |
| 3 | Specimen Set #5 | RT 96 | LEA-LITE | 2010 | 9.5 mm 4 Hours Aging | 270°F | 310°F | 64-22 | 15.0% | 6.7% | < 3.0 | --- | --- | 287 | 178 | NOT EQUAL |
| 4 | Specimen Set #6 | Rte 5/20 and Rte 15A | LEA-LITE | 2010 | 9.5 mm | 260-262°F | ------ | 64-22 | 20.0% | 6.3% | < 30.0 | > 190 | > 105 | 318 | 244 | EQUAL |
| 4 | Specimen Set #7 | Rte 104 | LEA-LITE | 2011 | 12.5 mm | 275°F | 325°F | 64-22 | 20.0% | 5.4% | < 30.0 | > 190 | > 105 | 641 | 596 | EQUAL |
| 4 | Specimen Set #8 | Rte 20A | LEA-LITE | 2011 | 12.5 mm | 285°F | 290°F | 64-22 | 10.0% | 5.3% | < 10.0 | > 53 | > 30 | 239 | 187 | NOT EQUAL |
| 5 | Specimen Set #9 | I-86 | LEA-LITE | 2011 | 12.5 mm | 270-275°F | ------ | 64-22 | 0.0% | 5.4% | < 10.0 | > 53 | > 30 | 488 | 795 | NOT EQUAL |
| 5 | Specimen Set #10 | I-86 | LEA-LITE | 2011 | 19.5 mm | 270-275°F | ------ | 64-22 | 0.0% | 5.8% | < 10.0 | > 53 | > 30 | 338 | 552 | NOT EQUAL |
| 8 | Specimen Set #11 | Route 9W | EVOTHERM | 2010 | 12.5 mm | 275°F | 315°F | 64-22 W/Anti St. Agent | 20.0% | 6.1% | < 3.0 | --- | --- | 615 | 299 | NOT EQUAL |
| 8 | Specimen Set #12 | Route 9 | EVOTHERM | 2011 | 12.5 mm | 275°F | 315°F | 70-22 | 15.0% | 6.1% | < 30.0 | > 190 | > 105 | 89 | 163 | NOT EQUAL |
| 9 | Specimen Set #13 | I-81 | LEA-LITE | 2010 | 9.5 mm | 240-255°F | ------ | 64-22 | 0.0% | 6.2% | > 30.0 | > 740 | > 415 | 172 | 84 | NOT EQUAL |
| 10 | Specimen Set #14 | NY27A | EVOTHERM | 2011 | 9.5 mm | 260-265°F | 310-325°F | 70-22 | 10.0% | 5.9% | < 10.0 | > 53 | > 30 | 202 | 221 | EQUAL |

Table 7 – Summary of Asphalt Pavement Analyzer Test Results

| WMA PROJECTS LIST | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| REGION | SPECIMEN SET NUMBER | PROJECT LOCATION | WMA TECHNOLOGY USED | PAVING DATE | MIX INFORMATION | WMA TEMP. | HMA TEMP. | PG-BINDER | RAP AMOUNT | ASPHALT CONTENT (%) | DESIGN ESAL's | Asphalt Pavement Analyzer Rutting (mm) | | | |
| | | | | | | | | | | | | 9-33 Spec | HMA | WMA | t-Test |
| 1 | Specimen Set #1 | I87 | LEA-LITE | 2011 | 12.5 mm | 270°F | 310-325°F | 64-22 | 20.0% | 5.2% | < 30.0 | < 4.0 | 4.21 | 4.54 | EQUAL |
| 3 | Specimen Set #2 | RT 481 | TEREX FOAMING | 2010 | 9.5 mm | 300°F | ------ | 64-22 | 20.0% | 5.9% | <3.0 | N.A. | 3.36 | 3.11 | EQUAL |
| 3 | Specimen Set #3 | RT 96 | LEA-LITE | 2010 | 9.5 mm 0 Hour Aging | 270°F | 310°F | 64-22 | 15.0% | 6.7% | < 3.0 | N.A. | 8.31 | 5.07 | NOT EQUAL |
| 3 | Specimen Set #4 | RT 96 | LEA-LITE | 2010 | 9.5 mm 2 Hours Aging | 270°F | 310°F | 64-22 | 15.0% | 6.7% | < 3.0 | N.A. | 4.76 | 3.38 | NOT EQUAL |
| 3 | Specimen Set #5 | RT 96 | LEA-LITE | 2010 | 9.5 mm 4 Hours Aging | 270°F | 310°F | 64-22 | 15.0% | 6.7% | < 3.0 | N.A. | 4.84 | 3.09 | NOT EQUAL |
| 4 | Specimen Set #6 | Rte 5/20 and Rte 15A | LEA-LITE | 2010 | 9.5 mm | 260-262°F | ------ | 64-22 | 20.0% | 6.3% | < 30.0 | < 4.0 | 4.68 | 4.63 | EQUAL |
| 4 | Specimen Set #7 | Rte 104 | LEA-LITE | 2011 | 12.5 mm | 275°F | 325°F | 64-22 | 20.0% | 5.4% | < 30.0 | < 4.0 | 3.21 | 3.61 | EQUAL |
| 4 | Specimen Set #8 | Rte 20A | LEA-LITE | 2011 | 12.5 mm | 285°F | 290°F | 64-22 | 10.0% | 5.3% | < 10.0 | < 5.0 | 4.54 | 5.76 | NOT EQUAL |
| 5 | Specimen Set #9 | I-86 | LEA-LITE | 2011 | 12.5 mm | 270-275°F | ------ | 64-22 | 0.0% | 5.4% | < 10.0 | < 5.0 | 4.08 | 2.65 | NOT EQUAL |
| 5 | Specimen Set #10 | I-86 | LEA-LITE | 2011 | 19.5 mm | 270-275°F | ------ | 64-22 | 0.0% | 5.8% | < 10.0 | < 5.0 | 2.47 | 2.49 | EQUAL |
| 8 | Specimen Set #11 | Route 9W | EVOTHERM | 2010 | 12.5 mm | 275°F | 315°F | 64-22 W/Anti St. Agent | 20.0% | 6.1% | < 3.0 | N.A. | 2.7 | 4.28 | NOT EQUAL |
| 8 | Specimen Set #12 | Route 9 | EVOTHERM | 2011 | 12.5 mm | 275°F | 315°F | 70-22 | 15.0% | 6.1% | < 30.0 | < 4.0 | 4.39 | 3.19 | NOT EQUAL |
| 9 | Specimen Set #13 | I-81 | LEA-LITE | 2010 | 9.5 mm | 240-255°F | ------ | 64-22 | 0.0% | 6.2% | > 30.0 | < 3.0 | 3.61 | 5.48 | NOT EQUAL |
| 10 | Specimen Set #14 | NY27A | EVOTHERM | 2011 | 9.5 mm | 260-265°F | 310-325°F | 70-22 | 10.0% | 5.9% | < 10.0 | < 5.0 | 5.03 | 4.76 | EQUAL |

As indicated earlier, the scope of the project was to evaluate rutting potential using only the AMPT Flow Number and Asphalt Pavement Analyzer. However, NYSDOT provided extra samples for further mixture performance evaluation that Rutgers University tested for the "sake of research". This included the following:

- Mixture Stiffness – AMPT Dynamic Modulus
- Fatigue Cracking – Overlay Tester
- Moisture Damage
    - Tensile Strength Ratio Test
    - Wet Hamburg Wheel Tracking Test

However, it should be noted that due to time constraints, the above testing was not conducted on all mixtures for each of the 14 different companion specimens. However, a majority of the 14 different companion specimens were tested and the test results provide a good overview of the general mixture properties and differences between the HMA and companion WMA sections.

**Dynamic Modulus**

The dynamic modulus of the mixtures was determined using the Asphalt Mixture Performance Tester (AMPT) and associated test procedure described earlier. Unlike the other test conducted during this study, there is no one parameter or outcome from the dynamic modulus test, as it results in a master stiffness curve over a wide range of frequencies and test temperatures. Therefore, only general observations (i.e. – more or less stiff) are able to be provided.

The resultant master stiffness curves for the 13 different companion specimens are shown in Figures 5 through 17. General observations from the dynamic modulus testing:

- 6 of the 13 sets of companion specimens evaluated show that the stiffness properties were similar to equal between the HMA and WMA mixtures;
- 4 of the 13 sets of companion specimens evaluated show that the HMA mixture was stiffer than the companion WMA mixture; and
- 3 of the 13 sets of companion specimens evaluated show that the WMA mixture was stiffer than the companion HMA mixture. It is interesting to note that all three of these sets of companion specimens were produced by the same contractor, using the same mixture but different aging times (specimen sets number 3, 4, and 5) and a PG64-22 with 15% RAP using LEA-Lite as the WMA technology.

Overall, when differences in stiffness were found, it occurred at the higher test temperatures, which corresponds to the lower testing frequencies on the master stiff curves charts. For most cases, the low temperature stiffness properties, shown as the higher or faster loading frequencies, were similar between the HMA and WMA mixtures.

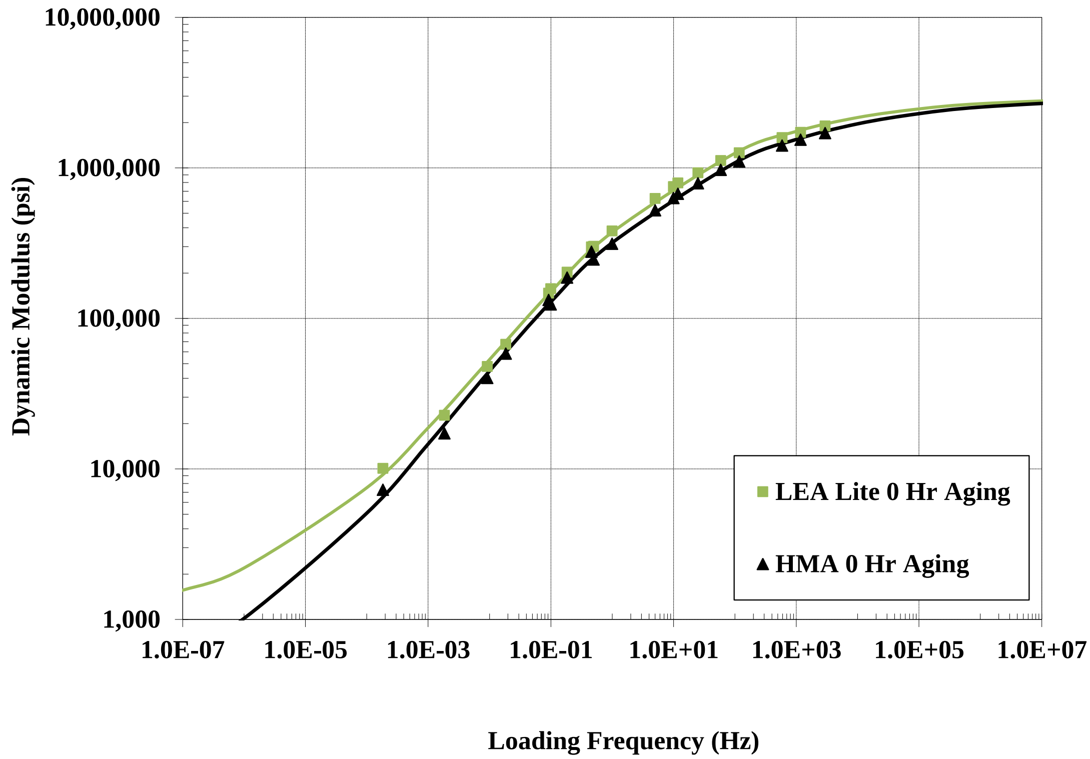



Figure 5 – Master Stiffness Curves for 0 Hr Aging Condition – Region 3, Specimen Set # 3

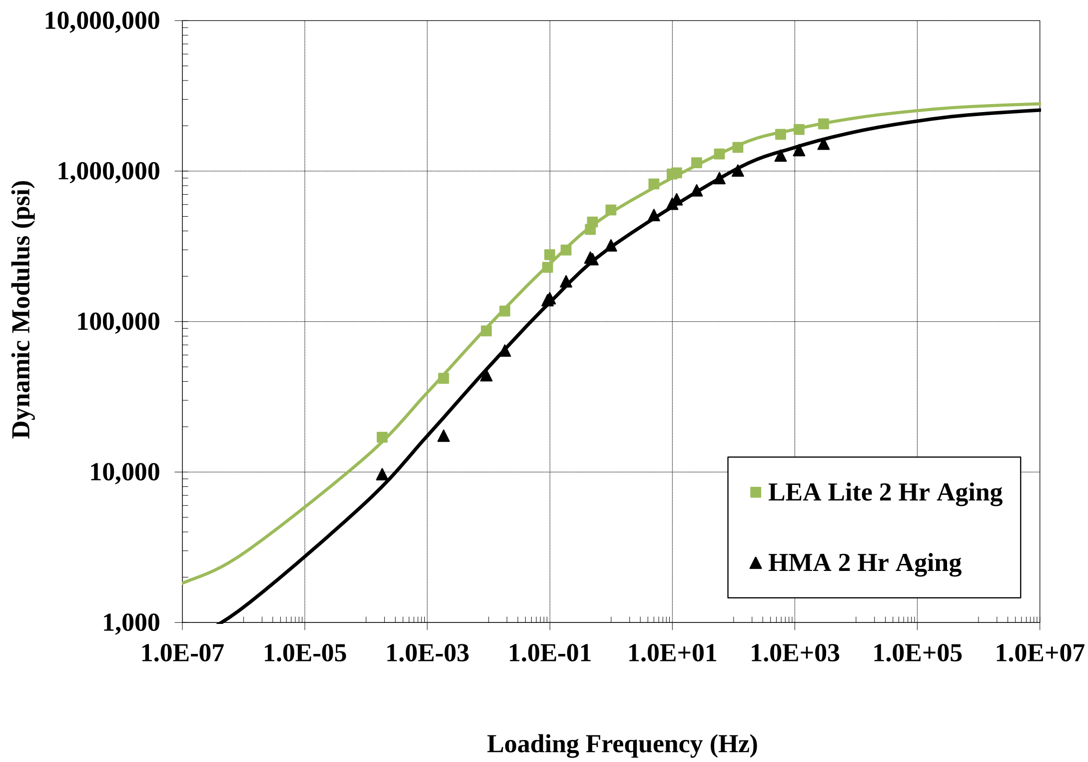



Figure 6 – Master Stiffness Curves for 2 Hr Aging Condition – Region 3, Specimen Set # 4

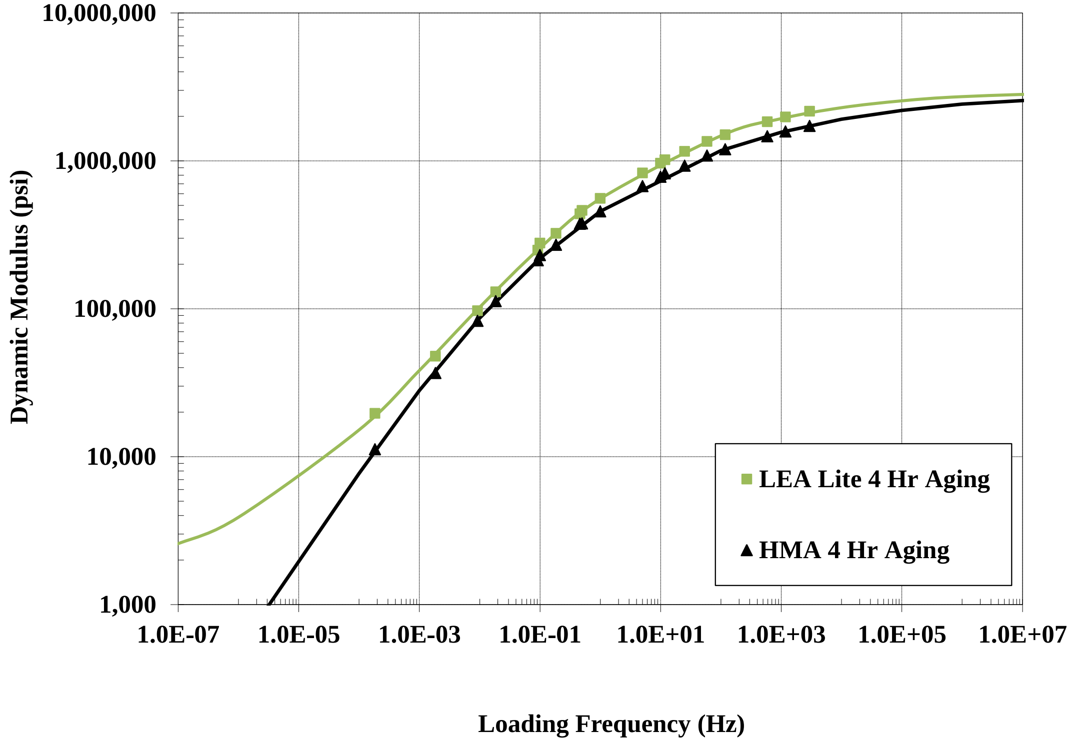



Figure 7 – Master Stiffness Curves for 4 Hr Aging Condition – Region 3, Specimen Set # 5

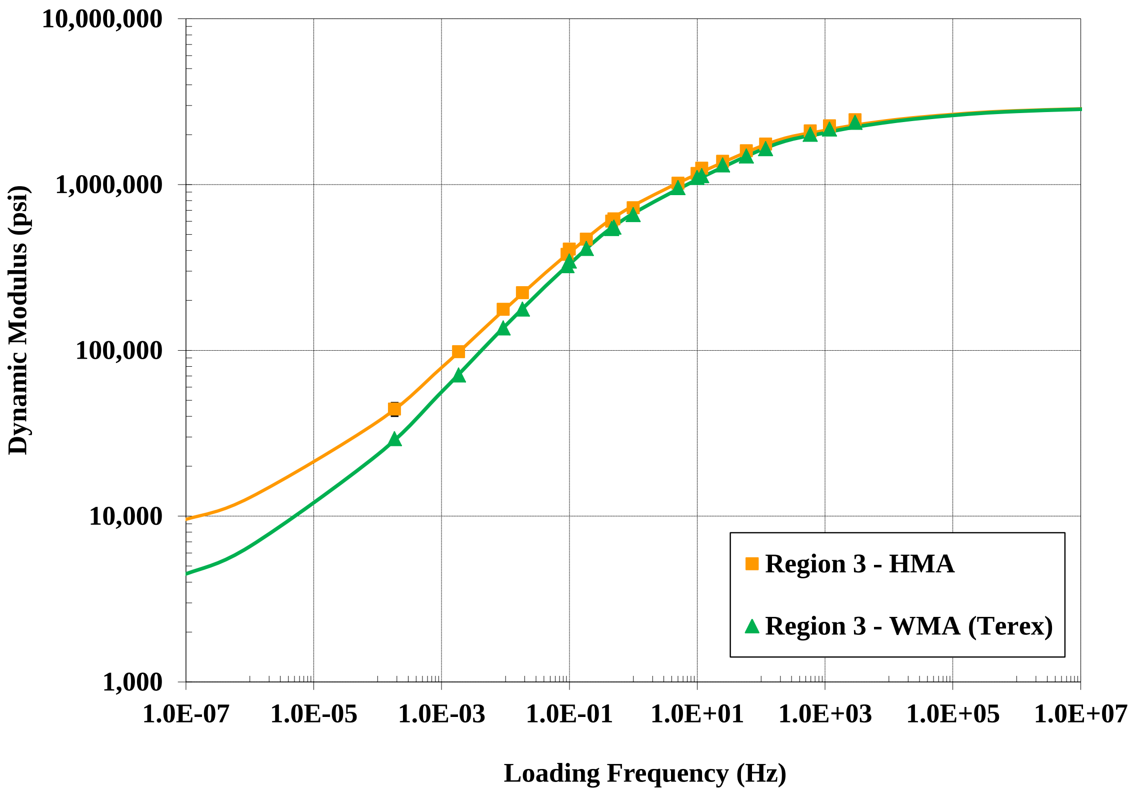



Figure 8 – Dynamic Modulus Master Stiffness Curves for Region 3 (Rt 481), Specimen Set # 2

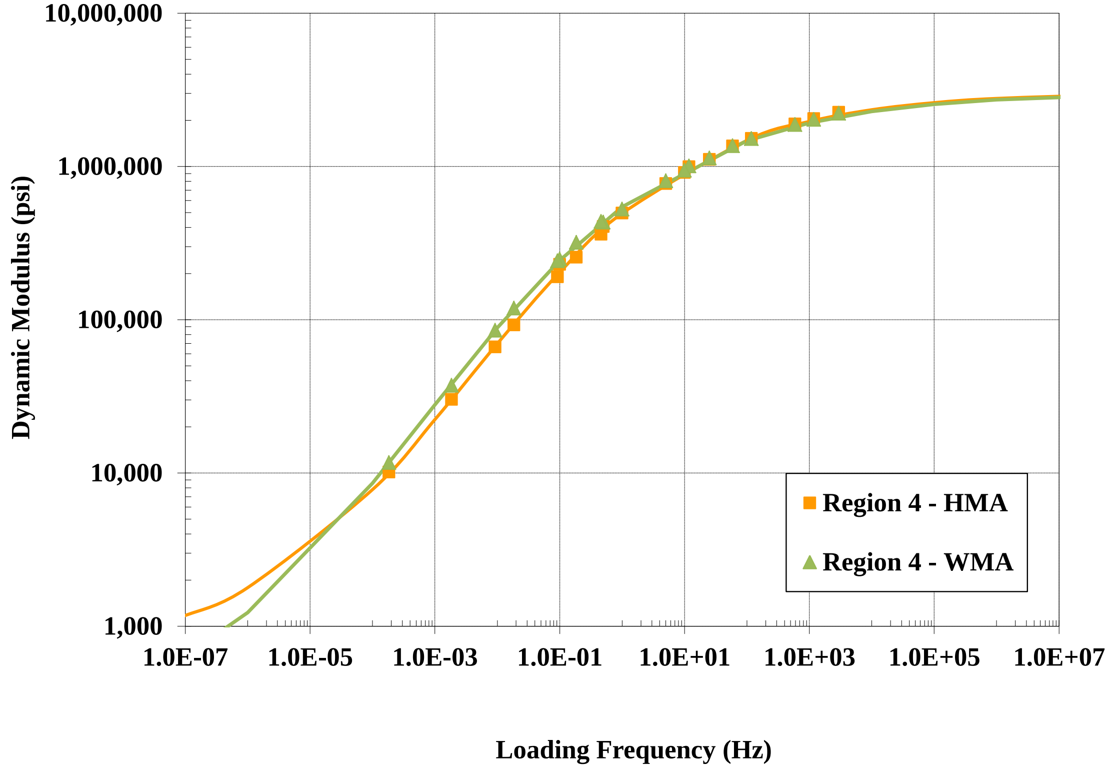



Figure 9 – Master Stiffness Curves for Region 4 (Rt 5/20), Specimen Set # 6

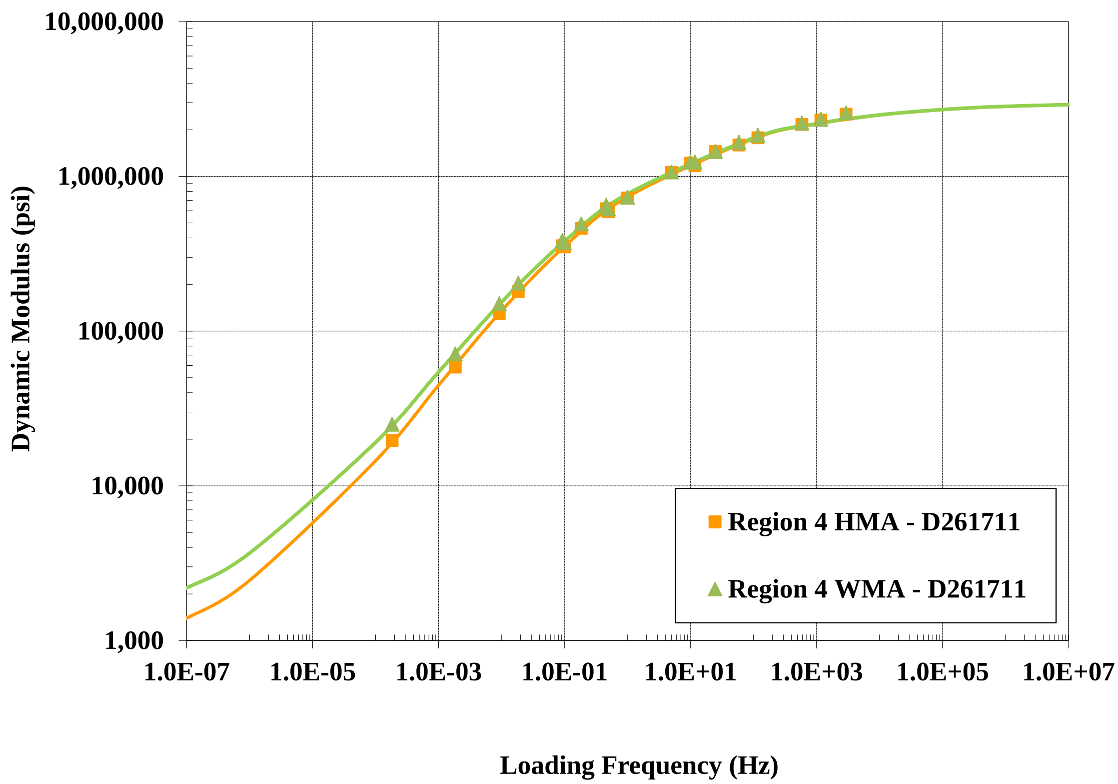



Figure 10 – Master Stiffness Curves for Region 4 (Rt 104), Specimen Set # 7

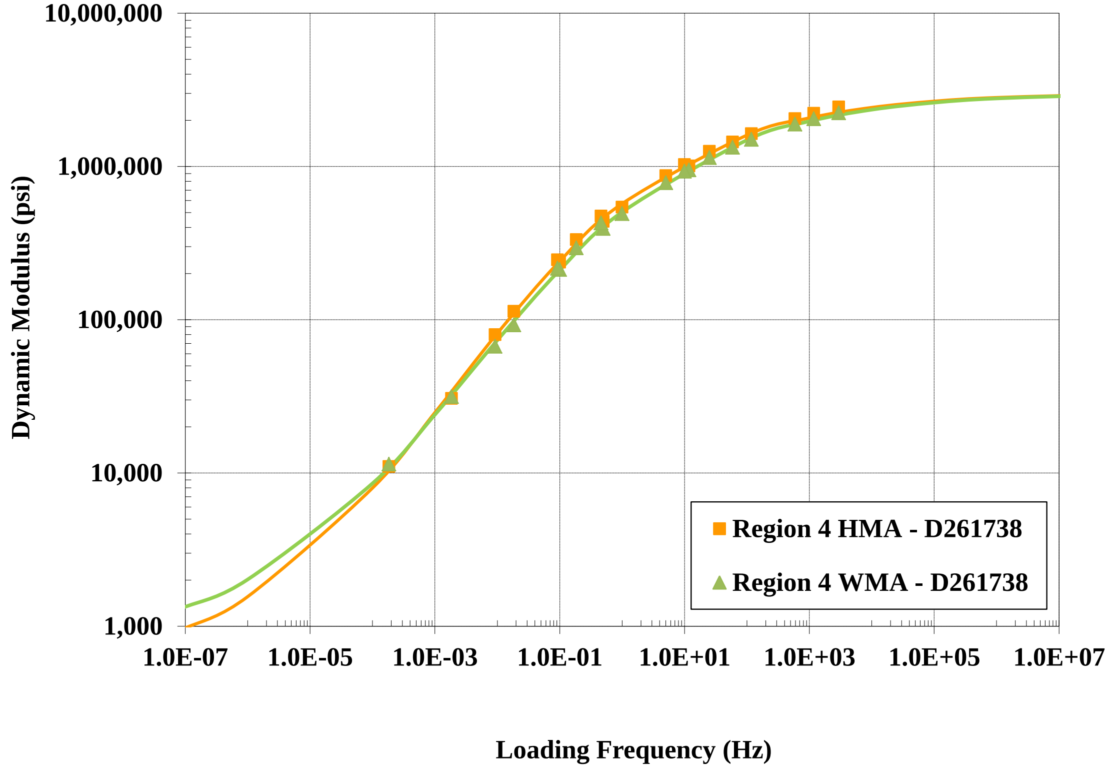



Figure 11 – Master Stiffness Curves for Region 4 (Rt 20A), Specimen Set # 8

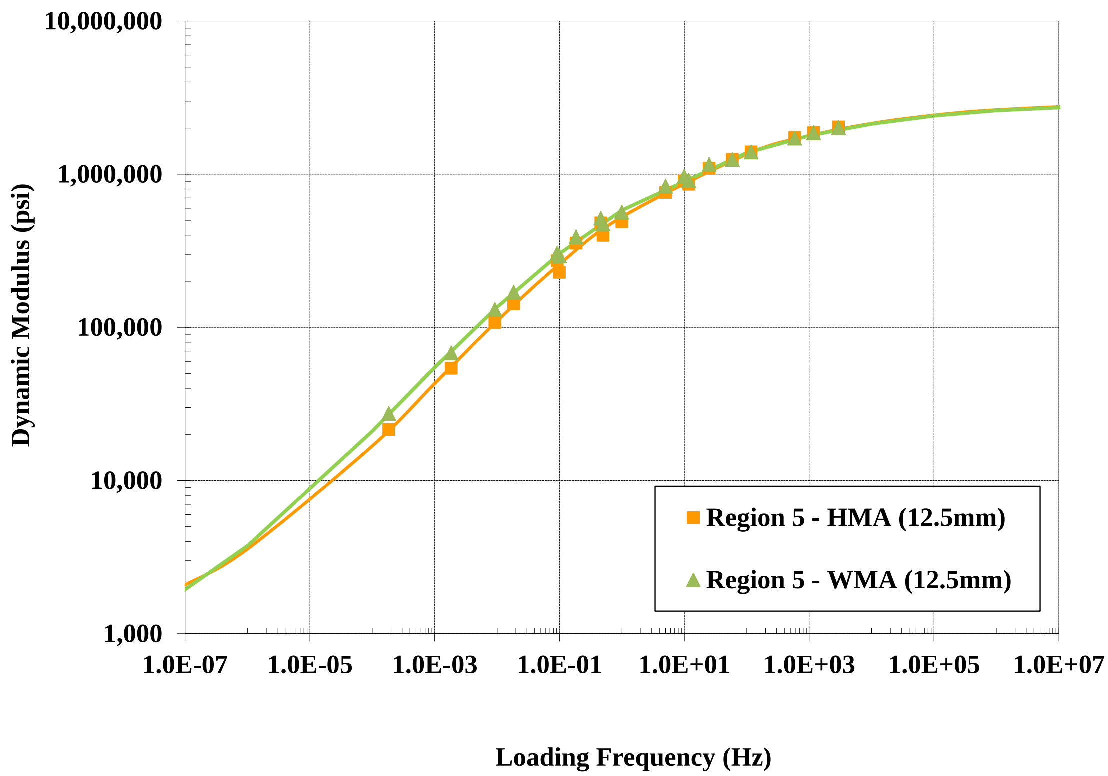



Figure 12 – Master Stiffness Curves for 12.5mm Region 5 (I-86), Specimen Set # 9

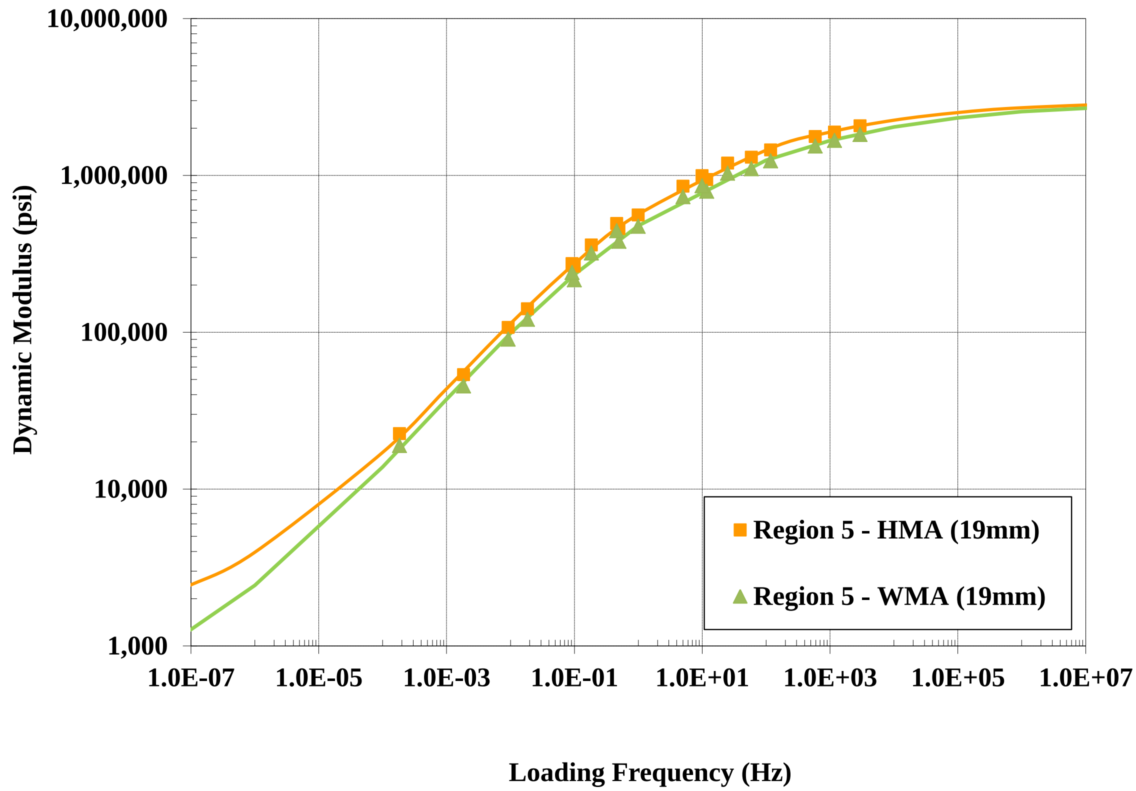



Figure 13 – Master Stiffness Curves for 19mm Region 5 (I-86), Specimen Set # 10

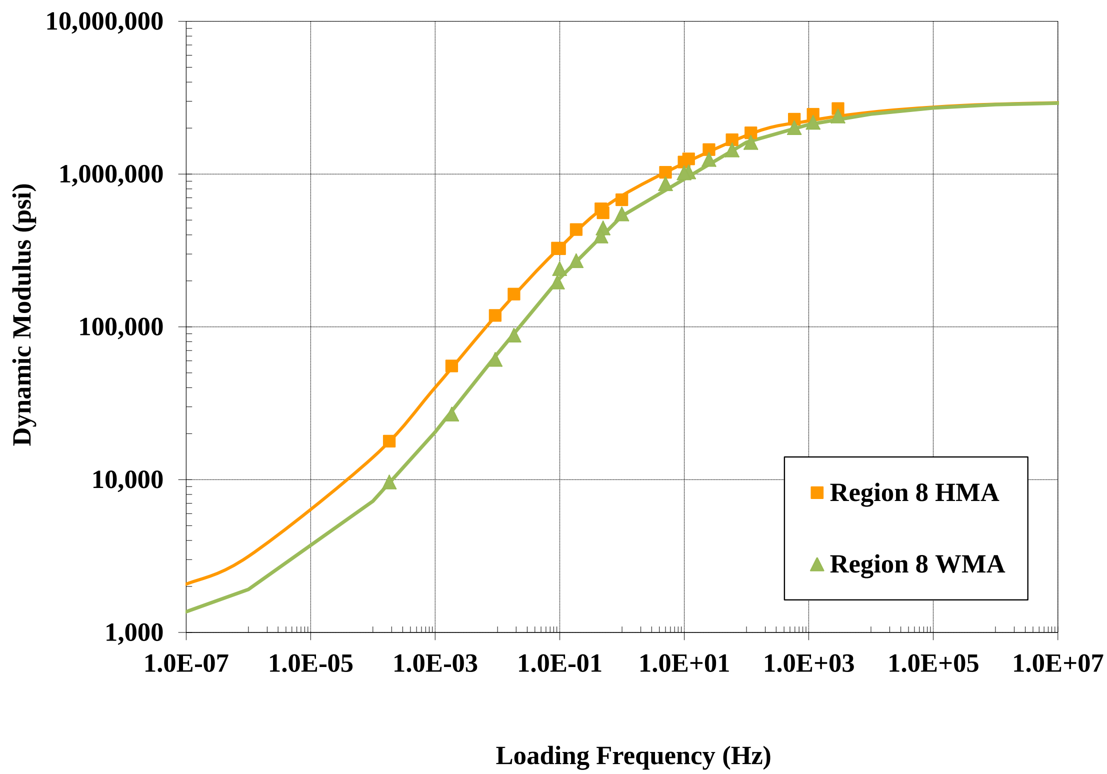



Figure 14 – Master Stiffness Curves for Region 8 (Rt 9W), Specimen Set # 11

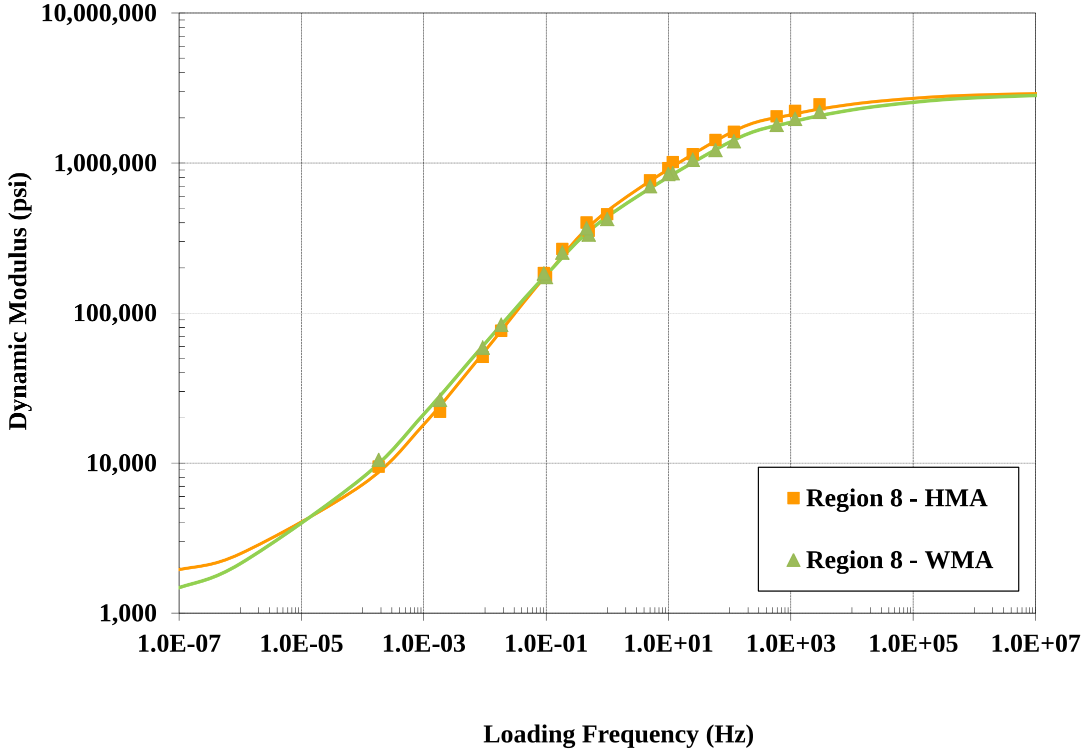



Figure 15 – Master Stiffness Curves for Region 8 (Rt 9), Specimen Set # 12

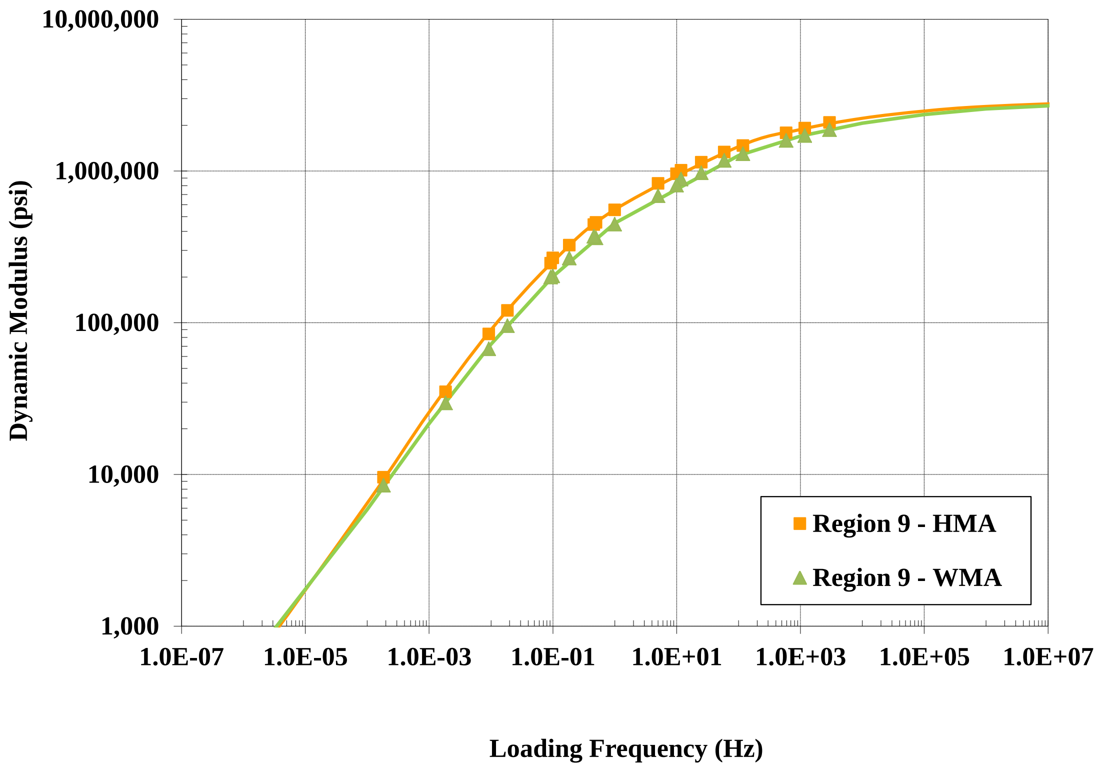



Figure 16 – Master Stiffness Curves for Region 9 (I-81), Specimen Set # 13

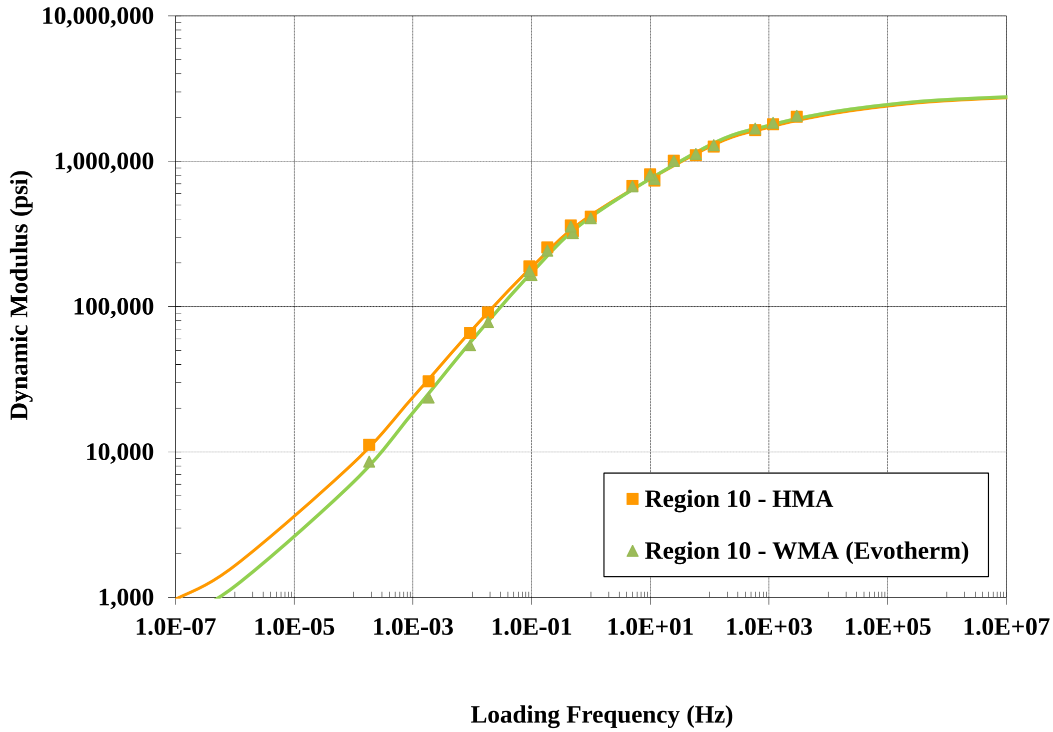



Figure 17 – Master Stiffness Curves for Region 10 (NY-27A), Specimen Set # 14

## Overlay Tester – Fatigue Cracking

The Overlay Tester was used to determine the fatigue cracking performance for 13 of the 14 sets of WMA specimens and their companion HMA included in the NYSDOT study. The Overlay Tester provides a measure of the resistance to crack propagation in asphalt mixtures and has been found to correlate well to both reflective cracking on composite pavements and load associated cracking in flexible pavements. The test results were compared statistically using the Student t-Test and a confidence interval of 95% (Table 8).

In general, the results of the fatigue cracking in the Overlay Tester showed that:

- 5 of the 13 sets of companion specimens evaluated showed that the fatigue cracking properties were statistically equal between the HMA and WMA mixtures;
- 7 of the 13 sets of companion specimens evaluated showed that the WMA mixtures achieved better cracking resistance properties when compared to the companion HMA mixtures;
- 1 of the 13 set of companion specimen evaluated showed that the HMA mixture achieved better cracking resistance properties when compared to the companion WMA mixtures.

Table 8 – Summary of Overlay Tester Results

| WMA PROJECTS LIST | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| REGION | SPECIMEN SET NUMBER | PROJECT LOCATION | WMA TECHNOLOGY USED | PAVING DATE | MIX INFORMATION | WMA TEMP. | HMA TEMP. | PG-BINDER | RAP AMOUNT | ASPHALT CONTENT (%) | DESIGN ESAL's | Overlay Tester (cycles) | | |
| | | | | | | | | | | | | HMA | WMA | t-Test |
| 1 | Specimen Set #1 | I87 | LEA-LITE | 2011 | 12.5 mm | 270°F | 310-325°F | 64-22 | 20.0% | 5.2% | < 30.0 | --- | --- | N.A. |
| 3 | Specimen Set #2 | RT 481 | TEREX FOAMING | 2010 | 9.5 mm | 300°F | ------ | 64-22 | 20.0% | 5.9% | <3.0 | 39 | 152 | NOT EQUAL |
| 3 | Specimen Set #3 | RT 96 | LEA-LITE | 2010 | 9.5 mm 0 Hour Aging | 270°F | 310°F | 64-22 | 15.0% | 6.7% | < 3.0 | 3030 | 3087 | EQUAL |
| 3 | Specimen Set #4 | RT 96 | LEA-LITE | 2010 | 9.5 mm 2 Hours Aging | 270°F | 310°F | 64-22 | 15.0% | 6.7% | < 3.0 | 537 | 897 | NOT EQUAL |
| 3 | Specimen Set #5 | RT 96 | LEA-LITE | 2010 | 9.5 mm 4 Hours Aging | 270°F | 310°F | 64-22 | 15.0% | 6.7% | < 3.0 | 166 | 353 | NOT EQUAL |
| 4 | Specimen Set #6 | Rte 5/20 and Rte 15A | LEA-LITE | 2010 | 9.5 mm | 260-262°F | ------ | 64-22 | 20.0% | 6.3% | < 30.0 | 155 | 44 | NOT EQUAL |
| 4 | Specimen Set #7 | Rte 104 | LEA-LITE | 2011 | 12.5 mm | 275°F | 325°F | 64-22 | 20.0% | 5.4% | < 30.0 | 114 | 179 | NOT EQUAL |
| 4 | Specimen Set #8 | Rte 20A | LEA-LITE | 2011 | 12.5 mm | 285°F | 290°F | 64-22 | 10.0% | 5.3% | < 10.0 | 73 | 242 | NOT EQUAL |
| 5 | Specimen Set #9 | I-86 | LEA-LITE | 2011 | 12.5 mm | 270-275°F | ------ | 64-22 | 0.0% | 5.4% | < 10.0 | 355 | 302 | EQUAL |
| 5 | Specimen Set #10 | I-86 | LEA-LITE | 2011 | 19.5 mm | 270-275°F | ------ | 64-22 | 0.0% | 5.8% | < 10.0 | 104 | 378 | NOT EQUAL |
| 8 | Specimen Set #11 | Route 9W | EVOTHERM | 2010 | 12.5 mm | 275°F | 315°F | 64-22 W/Anti St. Agent | 20.0% | 6.1% | < 3.0 | 71 | 148 | EQUAL |
| 8 | Specimen Set #12 | Route 9 | EVOTHERM | 2011 | 12.5 mm | 275°F | 315°F | 70-22 | 15.0% | 6.1% | < 30.0 | 365 | 432 | EQUAL |
| 9 | Specimen Set #13 | I-81 | LEA-LITE | 2010 | 9.5 mm | 240-255°F | ------ | 64-22 | 0.0% | 6.2% | > 30.0 | 135 | 167 | EQUAL |
| 10 | Specimen Set #14 | NY27A | EVOTHERM | 2011 | 9.5 mm | 260-265°F | 310-325°F | 70-22 | 10.0% | 5.9% | < 10.0 | 497 | 670 | NOT EQUAL |

### Tensile Strength Ratio (TSR) Test

The moisture damage potential of the HMA and WMA mixtures were assessed using AASHTO T283, Tensile Strength Ratio (TSR) test. To compare the respective TSR performance of the HMA and WMA, the TSR results were compared with the acceptable range (d2s) recently determined during an AMRL Inter-Laboratory Study (ILS) from NCHRP Project 9-26A (Azari, et al., 2010). According to the data generated by Azari et al., (2010), the acceptable Single Operator range of TSR values is 9.3%. This essentially means that if the WMA and HMA TSR values differ by less than 9.3%, the TSR values are statistically equal.

The TSR test results for 11 of the 14 sets of WMA specimens and their companion HMA projects are shown in Table 9. In general, the results of TSR comparisons were as follows:

- Only 6 of the 11 HMA specimens mixtures passed the 80% TSR criteria;
- Only 7 of the 11 WMA specimens mixtures passed the 80% TSR criteria;
- Comparing the HMA and WMA using the d2s developed by Azari et al. (2010)
    - 4 of the 11 sets of companion specimens showed that the HMA had a better TSR performance than the WMA;
    - 1 of the 11 set of companion specimen showed that the WMA had a better TSR performance than the HMA;
    - 6 of the 11 sets of companion specimens showed that the TSR performance of the HMA and WMA were statistically equal.

### Hamburg Wheel Tracking Test

The moisture damage potential was also evaluated using the Hamburg Wheel Tracking test in accordance with AASHTO T324 and the test parameters described earlier. Although no current test criteria have been established by NYSDOT regarding the Hamburg Wheel Tracking test results, many states are adopting the criteria established by TxDOT. The criteria is based on achieving a minimum number of loading cycles before reaching 12.5 mm of vertical deformation. TxDOT recommends the following minimum number of cycles:

- HMA with a PG64-22 asphalt binder: > 10,000 cycles
- HMA with a PG70-22 asphalt binder: > 15,000 cycles
- HMA with a PG76-22 asphalt binder: > 20,000 cycles

Based on the 10 sets of specimens and their companion evaluated, the following Hamburg Wheel Tracking results were found (Table 10):

- In 7 of the 10 sets of companion specimens evaluated, the HMA mixture performed better than the WMA;
- In 3 of the 10 sets of companion specimens evaluated, the WMA mixture performed better than the HMA;
- When comparing the performance of the mixtures to the TxDOT criteria;
    - Only 3 of the 10 HMA specimens passed the Hamburg Wheel Tracking criteria;
    - Only 3 of the 10 WMA specimens passed the Hamburg Wheel Tracking criteria;

Table 9 – Summary of Tensile Strength Ratio (TSR) Test Results

| WMA PROJECTS LIST | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| REGION | SPECIMEN SET NUMBER | PROJECT LOCATION | WMA TECHNOLOGY USED | PAVING DATE | MIX INFORMATION | WMA TEMP. | HMA TEMP. | PG-BINDER | RAP AMOUNT | ASPHALT CONTENT (%) | DESIGN ESAL's | Tensile Strength Ratio, TSR (%) | | | |
| | | | | | | | | | | | | NYSDOT | HMA | WMA | d2S |
| 1 | Specimen Set #1 | I87 | LEA-LITE | 2011 | 12.5 mm | 270°F | 310-325°F | 64-22 | 20.0% | 5.2% | < 30.0 | > 80% | --- | --- | N.A. |
| 3 | Specimen Set #2 | RT 481 | TEREX FOAMING | 2010 | 9.5 mm | 300°F | ------ | 64-22 | 20.0% | 5.9% | <3.0 | > 80% | 122.3 | 98.7 | NOT EQUAL |
| 3 | Specimen Set #3 | RT 96 | LEA-LITE | 2010 | 9.5 mm 0 Hour Aging | 270°F | 310°F | 64-22 | 15.0% | 6.7% | < 3.0 | > 80% | --- | --- | N.A. |
| 3 | Specimen Set #4 | RT 96 | LEA-LITE | 2010 | 9.5 mm 2 Hours Aging | 270°F | 310°F | 64-22 | 15.0% | 6.7% | < 3.0 | > 80% | 92.8 | 97.5 | EQUAL |
| 3 | Specimen Set #5 | RT 96 | LEA-LITE | 2010 | 9.5 mm 4 Hours Aging | 270°F | 310°F | 64-22 | 15.0% | 6.7% | < 3.0 | > 80% | --- | --- | N.A. |
| 4 | Specimen Set #6 | Rte 5/20 and Rte 15A | LEA-LITE | 2010 | 9.5 mm | 260-262°F | ------ | 64-22 | 20.0% | 6.3% | < 30.0 | > 80% | 102.8 | 99.3 | EQUAL |
| 4 | Specimen Set #7 | Rte 104 | LEA-LITE | 2011 | 12.5 mm | 275°F | 325°F | 64-22 | 20.0% | 5.4% | < 30.0 | > 80% | 51.1 | 42.2 | EQUAL |
| 4 | Specimen Set #8 | Rte 20A | LEA-LITE | 2011 | 12.5 mm | 285°F | 290°F | 64-22 | 10.0% | 5.3% | < 10.0 | > 80% | 59.6 | 83.8 | NOT EQUAL |
| 5 | Specimen Set #9 | I-86 | LEA-LITE | 2011 | 12.5 mm | 270-275°F | ------ | 64-22 | 0.0% | 5.4% | < 10.0 | > 80% | 68.2 | 49.6 | NOT EQUAL |
| 5 | Specimen Set #10 | I-86 | LEA-LITE | 2011 | 19.5 mm | 270-275°F | ------ | 64-22 | 0.0% | 5.8% | < 10.0 | > 80% | 57.1 | 64.7 | EQUAL |
| 8 | Specimen Set #11 | Route 9W | EVOTHERM | 2010 | 12.5 mm | 275°F | 315°F | 64-22 W/Anti St. Agent | 20.0% | 6.1% | < 3.0 | > 80% | 117.5 | 109.4 | EQUAL |
| 8 | Specimen Set #12 | Route 9 | EVOTHERM | 2011 | 12.5 mm | 275°F | 315°F | 70-22 | 15.0% | 6.1% | < 30.0 | > 80% | 93.4 | 90.1 | EQUAL |
| 9 | Specimen Set #13 | I-81 | LEA-LITE | 2010 | 9.5 mm | 240-255°F | ------ | 64-22 | 0.0% | 6.2% | > 30.0 | > 80% | 111.5 | 91 | NOT EQUAL |
| 10 | Specimen Set #14 | NY27A | EVOTHERM | 2011 | 9.5 mm | 260-265°F | 310-325°F | 70-22 | 10.0% | 5.9% | < 10.0 | > 80% | 61.3 | 50.6 | NOT EQUAL |

Table 10 – Summary of Hamburg Wheel Tracking Test Results

| WMA PROJECTS LIST | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **REGION** | **SPECIMEN SET NUMBER** | **PROJECT LOCATION** | **WMA TECHNOLOGY USED** | **PAVING DATE** | **MIX INFORMATION** | **WMA TEMP.** | **HMA TEMP.** | **PG-BINDER** | **RAP AMOUNT** | **ASPHALT CONTENT (%)** | **DESIGN ESAL's** | **Number of Cycles to Achieve 12.5mm Hamburg Rutting** | | |
| | | | | | | | | | | | | **TxDOT** | **HMA** | **WMA** |
| 1 | Specimen Set #1 | I87 | LEA-LITE | 2011 | 12.5 mm | 270°F | 310-325°F | 64-22 | 20.0% | 5.2% | < 30.0 | > 10,000 | N.A. | N.A. |
| 3 | Specimen Set #2 | RT 481 | TEREX FOAMING | 2010 | 9.5 mm | 300°F | ------ | 64-22 | 20.0% | 5.9% | <3.0 | > 10,000 | 9,865 | 7,855 |
| 3 | Specimen Set #3 | RT 96 | LEA-LITE | 2010 | 9.5 mm 0 Hour Aging | 270°F | 310°F | 64-22 | 15.0% | 6.7% | < 3.0 | > 10,000 | 5,629 | 1,324 |
| 3 | Specimen Set #4 | RT 96 | LEA-LITE | 2010 | 9.5 mm 2 Hours Aging | 270°F | 310°F | 64-22 | 15.0% | 6.7% | < 3.0 | > 10,000 | N.A. | 5,774 |
| 3 | Specimen Set #5 | RT 96 | LEA-LITE | 2010 | 9.5 mm 4 Hours Aging | 270°F | 310°F | 64-22 | 15.0% | 6.7% | < 3.0 | > 10,000 | 8,210 | 5,745 |
| 4 | Specimen Set #6 | Rte 5/20 and Rte 15A | LEA-LITE | 2010 | 9.5 mm | 260-262°F | ------ | 64-22 | 20.0% | 6.3% | < 30.0 | > 10,000 | N.A. | N.A. |
| 4 | Specimen Set #7 | Rte 104 | LEA-LITE | 2011 | 12.5 mm | 275°F | 325°F | 64-22 | 20.0% | 5.4% | < 30.0 | > 10,000 | > 20,000 | 11,546 |
| 4 | Specimen Set #8 | Rte 20A | LEA-LITE | 2011 | 12.5 mm | 285°F | 290°F | 64-22 | 10.0% | 5.3% | < 10.0 | > 10,000 | 10,690 | 5,155 |
| 5 | Specimen Set #9 | I-86 | LEA-LITE | 2011 | 12.5 mm | 270-275°F | ------ | 64-22 | 0.0% | 5.4% | < 10.0 | > 10,000 | 9,935 | 4,640 |
| 5 | Specimen Set #10 | I-86 | LEA-LITE | 2011 | 19.5 mm | 270-275°F | ------ | 64-22 | 0.0% | 5.8% | < 10.0 | > 10,000 | 14,550 | > 20,000 |
| 8 | Specimen Set #11 | Route 9W | EVOTHERM | 2010 | 12.5 mm | 275°F | 315°F | 64-22 W/Anti St. Agent | 20.0% | 6.1% | < 3.0 | > 10,000 | 7,850 | 15,358 |
| 8 | Specimen Set #12 | Route 9 | EVOTHERM | 2011 | 12.5 mm | 275°F | 315°F | 70-22 | 15.0% | 6.1% | < 30.0 | > 15,000 | 6,810 | 9,485 |
| 9 | Specimen Set #13 | I-81 | LEA-LITE | 2010 | 9.5 mm | 240-255°F | ------ | 64-22 | 0.0% | 6.2% | > 30.0 | > 10,000 | N.A. | N.A. |
| 10 | Specimen Set #14 | NY27A | EVOTHERM | 2011 | 9.5 mm | 260-265°F | 310-325°F | 70-22 | 10.0% | 5.9% | < 10.0 | > 15,000 | 8,402 | 7,869 |

## REFERENCES


Advanced Asphalt Technologists, 2011, *A Manual for Design of Hot Mix Asphalt with Commentary, NCHRP Report 673*, National Cooperative Highway Research Program (NCHRP), Transportation Research Board, Washington, D.C., 285 pp.

Azari, H., N. Kringos, and T. Scarpas, 2010, *NCHRP Web-Only Document 166: Precisions Estimates of AASHTO T283: Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage*, TRB, The National Academy of Sciences, Washington, D.C. (http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w166.pdf)

Bennert, T., W. Worden, and M. Turo, 2009, "Field and Laboratory Forensic Analysis of Reflective Cracking on Massachusetts Interstate 495", *Transportation Research Record: Journal of the Transportation Research Board, No. 2126*, Transportation Research Board of the National Academies, Washington, D.C., pp. 27 – 38.

Bennert, T., A. Maher, and R. Sauber, 2011, "Influence of Production Temperature and Aggregate Moisture Content on Performance of Warm Mix Asphalt", T*ransportation Research Record: Journal of the Transportation Research Board, No. 2208*, Transportation Research Board of the National Academies, Washington, D.C., pp. 97 - 107.

Bonaquist, R., 2011, *Mix Design Practices for Warm Mix Asphalt, NCHRP Report 691*, National Cooperative Highway Research Program (NCHRP), Transportation Research Board, Washington, D.C., 111 pp.

Christensen, D. and R. Bonaquist, 2006, *Volumetric Requirements for Superpave Mix Design, NCHRP Report 567,* Transportation Research Board, Washington D.C., 57 pp.

Zhou, F. and Tom Scullion, 2005, "Overlay Tester: A Simple Performance Test for Thermal Reflective Cracking", *Journal of the Association of Asphalt Paving Technologists*, Vol. 74, pp. 443 – 484.

Zhou, F., S. Hu, and T. Scullion, 2007, *Development and Verification of the Overlay Tester Based Fatigue Cracking Prediction Approach*, FHWA/TX-07/9-1502-01-8, 90 pp.

University Transportation Research Center - Region 2

Funded by the U.S. Department of Transportation

**Region 2 - University Transportation Research Center**
**The City College of New York**
**Marshak Hall, Suite 910**
**160 Convent Avenue**
**New York, NY 10031**
**Tel: (212) 650-8050**
**Fax: (212) 650-8374**
**Website: www.utrc2.org**