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FINAL REPORT

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

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16. Abstract 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.			
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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

Background	6
Research Objective	8
Mixture Testing Program.....	8
Testing Program.....	9
Dynamic Modulus.....	9
Rutting Evaluations.....	10
Resistance to Moisture Damage.....	12
Fatigue Cracking Resistance	12
Project Location and Materials Information.....	13
Test Results.....	15
AMPT Flow Number – Rutting Resistance	15
Asphalt Pavement Analyzer – Rutting Resistance	15
Dynamic Modulus	19
Overlay Tester – Fatigue Cracking	26
Tensile Strength Ratio (TSR) Test	28
Hamburg Wheel Tracking Test	28
References.....	31

List of Figures

Figure 1 – Change in Permanent Deformation (Flow Number) Properties of Various WMA Technologies Due to Change in Production (Mixing) Temperature (Bennert et al., 2011)	7
Figure 2 – Photo of the Asphalt Mixture Performance Tester (AMPT)	9
Figure 3 – a) Asphalt Pavement Analyzer (APA) at Rutgers University; b) Inside the Asphalt Pavement Analyzer Device	11
Figure 4 – Picture of the Overlay Tester (Chamber Door Open)	13
Figure 5 – Master Stiffness Curves for 0 Hr Aging Condition – Region 3 Specimen Set #3	20
Figure 6 – Master Stiffness Curves for 2 Hr Aging Condition – Region 3 Specimen Set #4	20
Figure 7 – Master Stiffness Curves for 4 Hr Aging Condition – Region 3 Specimen Set #5	21
Figure 8 – Dynamic Modulus Master Stiffness Curves for Region 3 (Rt 491) Specimen Set #2	21
Figure 9 – Master Stiffness Curves for Region 4 (Rt 5/20), Specimen Set #6	22
Figure 10 – Master Stiffness Curves for Region 4 (Rt 104), Specimen Set #7	22
Figure 11 – Master Stiffness Curves for Region 4 (Rt 20A), Specimen Set #8	23
Figure 12 – Master Stiffness Curves for 12.5mm Region 5 (I-86), Specimen Set #9	23
Figure 13 – Master Stiffness Curves for 19mm Region 5 (I-86), Specimen Set #10	24
Figure 14 – Master Stiffness Curves for Region 8 (Rt 9W), Specimen Set #11	24
Figure 15 – Master Stiffness Curves for Region 8 (Rt 9), Specimen Set #12	25
Figure 16 – Master Stiffness Curves for Region 9 (I-81), Specimen Set #13	25
Figure 17 – Master Stiffness Curves for Region 10 (NY-27A), Specimen Set #14	26

List of Tables

Table 1 – Tensile Strength Ratio (TSR) Results of Asphalt Mixtures with Varying Mixing Temperatures and Initial Moisture Contents (Bennert et al., 2011)	7
Table 2 – NYSDOT Mixture Rut Performance Tests and Criteria Tests	8
Table 3 – Minimum Flow Number Requirements for Various Traffic (ESAL) Levels (after Bonaquist, 2011)	10
Table 4 - Recommended Maximum APA Rutting Requirements for Various Traffic (ESAL) Levels (after Advanced Asphalt Technologies, 2011)	11
Table 5 – Information of WMA and HMA Projects Evaluated in Study	14
Table 6 – Summary of Flow Number Test Results	17
Table 7 – Summary of Asphalt Pavement Analyzer Test Results	18
Table 8 – Summary of Overlay Tester Results	27
Table 9 – Summary of Tensile Strength Ratio (TSR) Test Results	29
Table 10 – Summary of Hamburg Wheel Tracking Test Results	30

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.

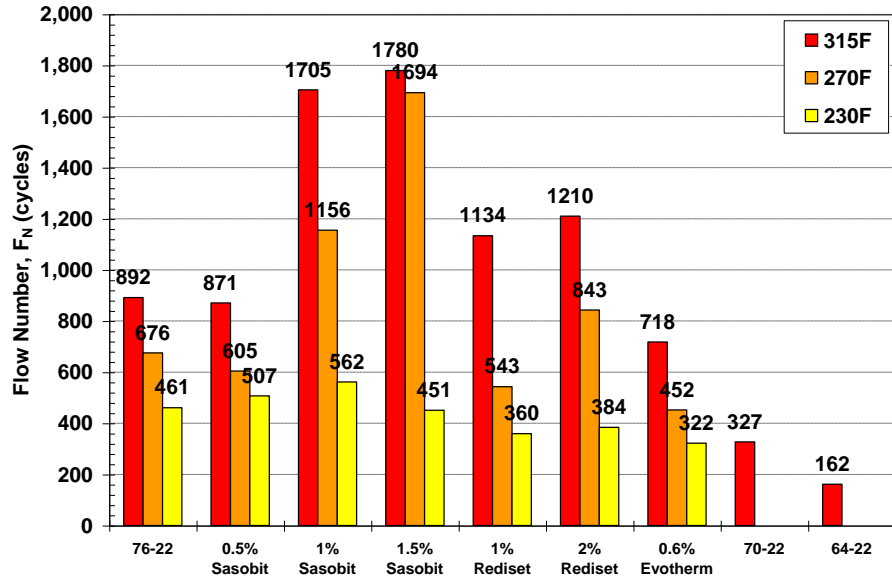


Figure 1 – Change in Permanent Deformation (Flow Number) Properties of Various WMA Technologies Due to Change in Production (Mixing) Temperature (Bennert et al., 2011)

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% 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% 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°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°C.

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

where:

- |E*| = dynamic modulus, psi
- ω_r = reduced frequency, Hz
- Max = limiting maximum modulus, psi
- δ , β , and γ = fitting parameters

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

where:

a(T) = shift factor at temperature T

T_r = reference temperature, °K

T = test temperature, °K

ΔE_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°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.

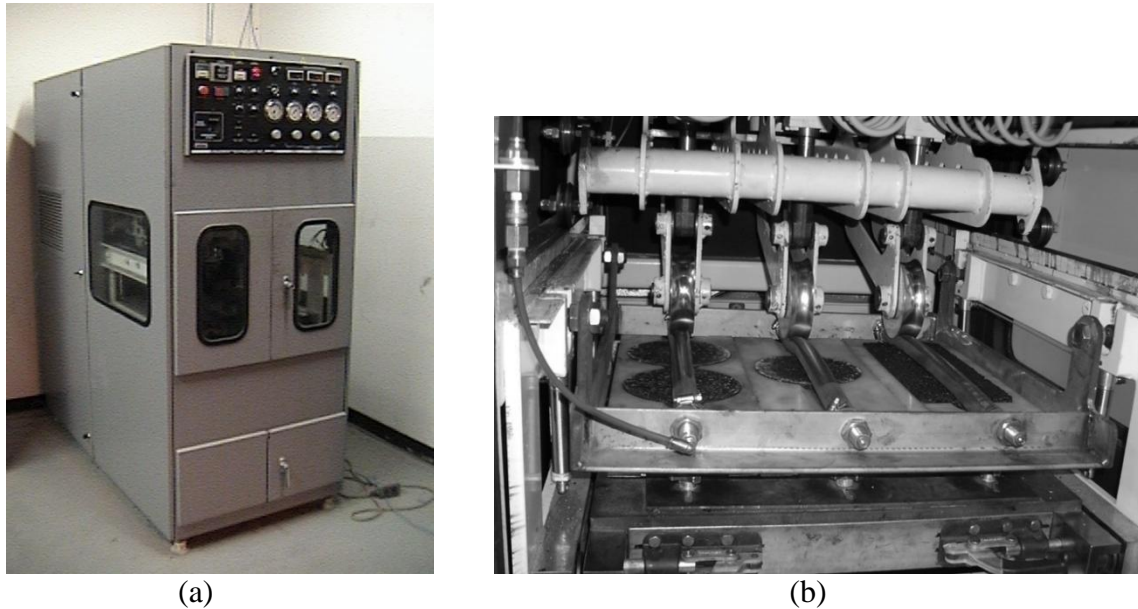


Figure 3 – a) Asphalt Pavement Analyzer (APA) at Rutgers University; b) Inside the Asphalt Pavement Analyzer Device

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.

Tensile Strength Ratio, TSR (AASHTO T283)

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%.

Wet Hamburg Wheel Track Test (AASHTO T324)

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°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

Overlay Tester (TxDOT Tex-248-F)

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°C (77°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.

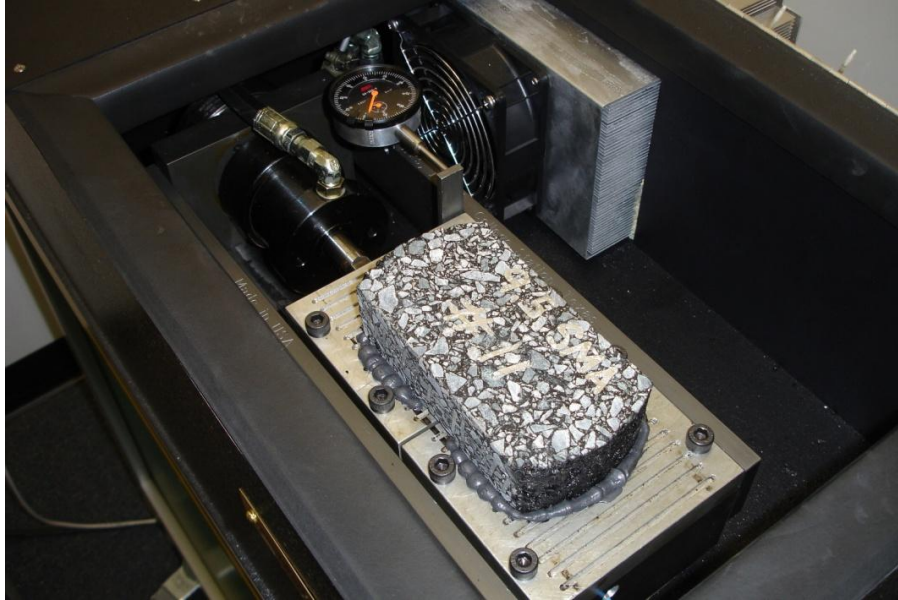


Figure 4 – Picture of the Overlay Tester (Chamber Door Open)

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 >30 Million ESAL's traffic level;
- Asphalt content: 5.2% to 6.7%;
- WMA Technologies: Terex Foaming, LEA-Lite, and Evotherm; and
- WMA Mixing Temperatures: 240°F to 300°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.

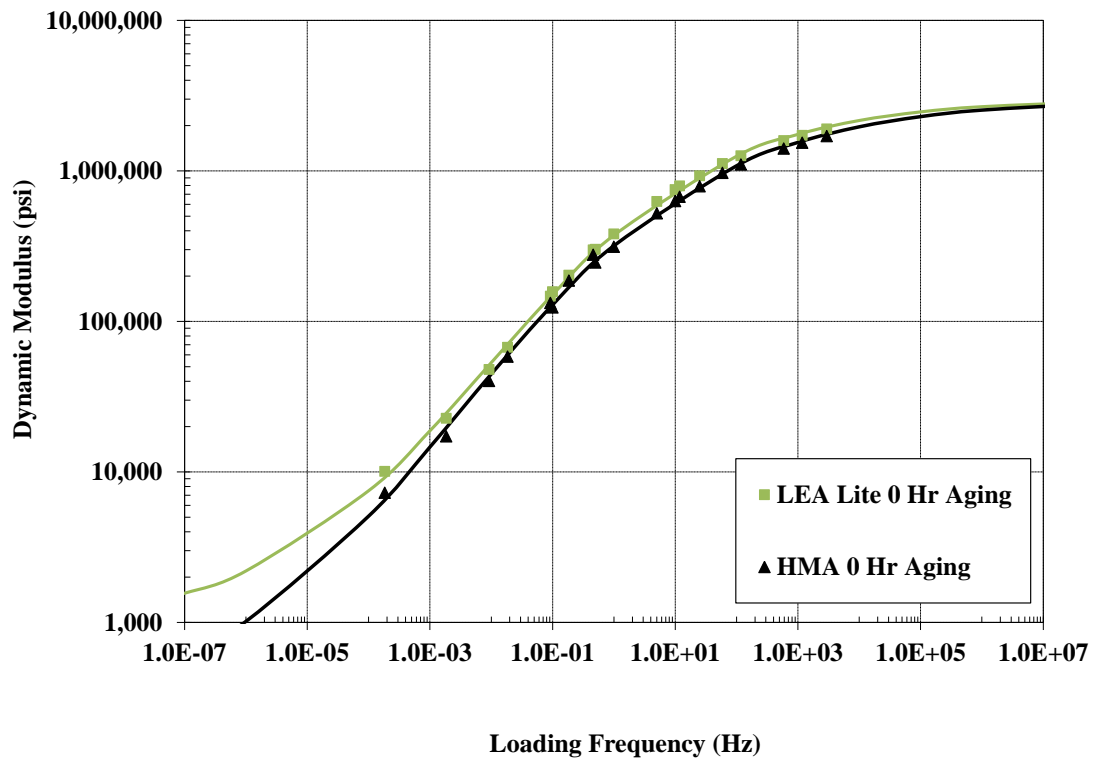


Figure 5 – Master Stiffness Curves for 0 Hr Aging Condition – Region 3, Specimen Set # 3

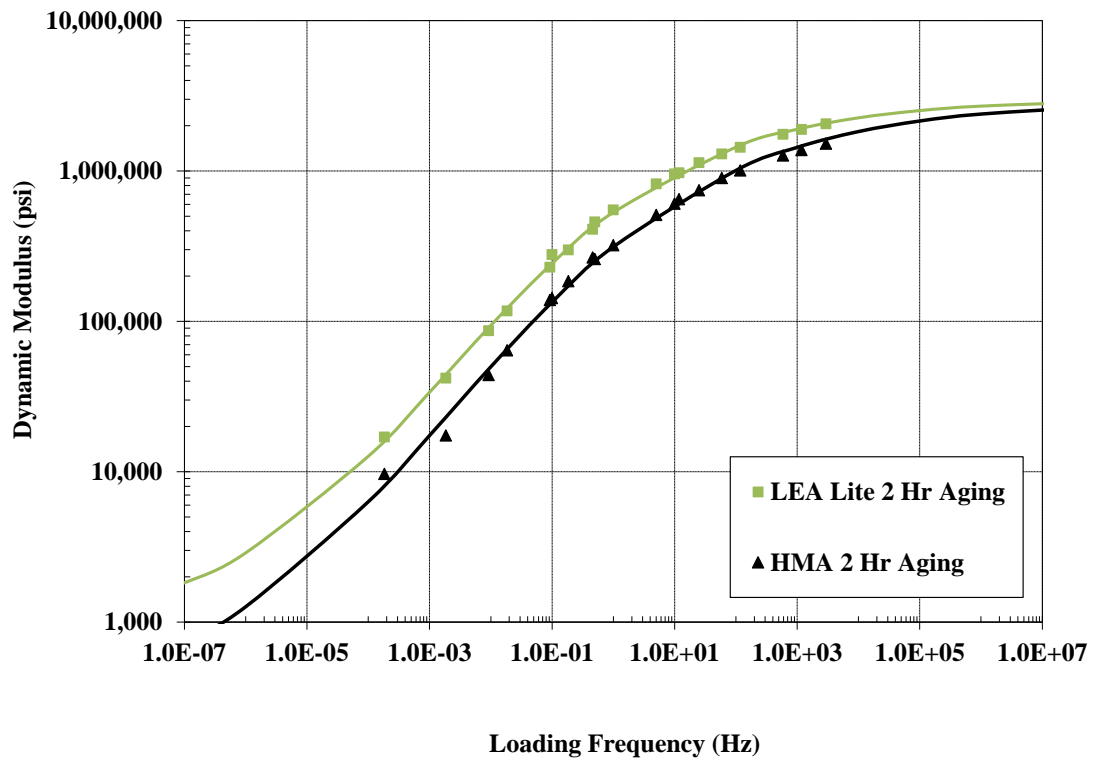


Figure 6 – Master Stiffness Curves for 2 Hr Aging Condition – Region 3, Specimen Set # 4

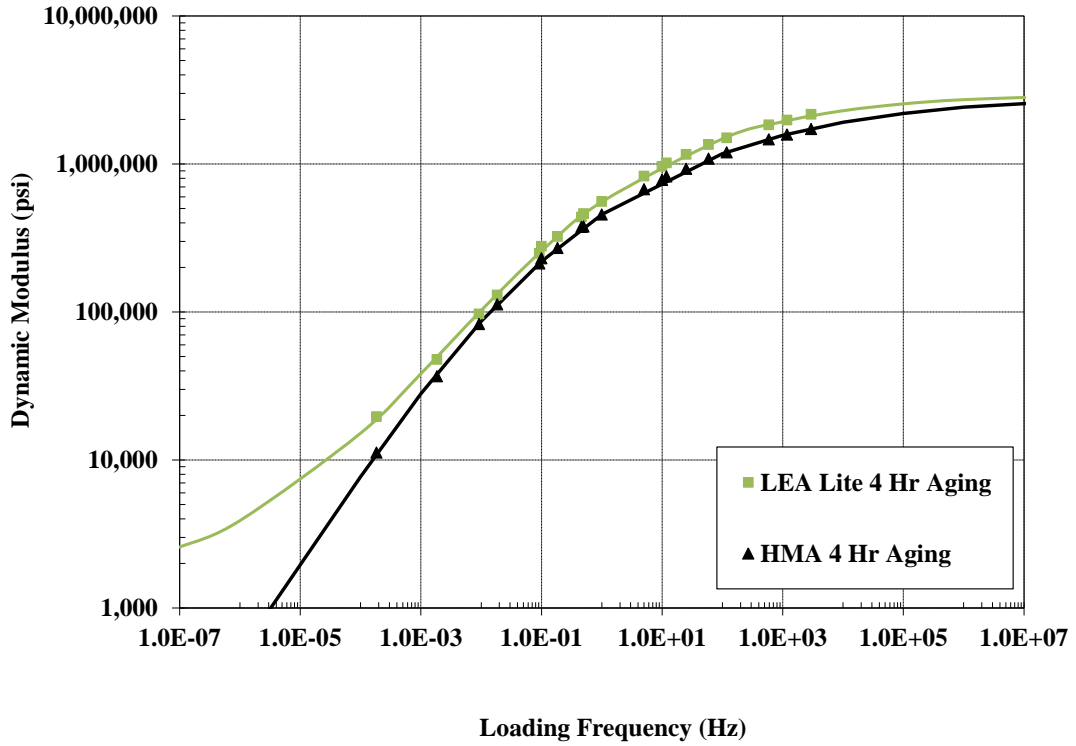


Figure 7 – Master Stiffness Curves for 4 Hr Aging Condition – Region 3, Specimen Set # 5

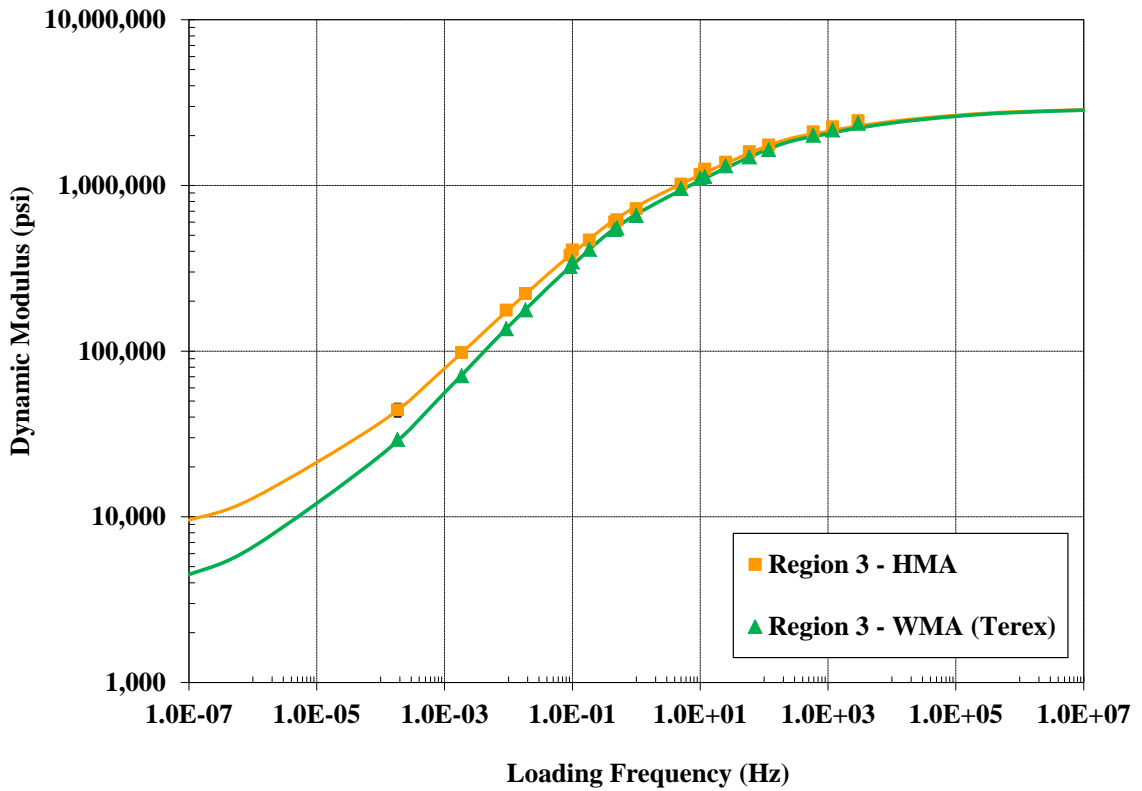


Figure 8 – Dynamic Modulus Master Stiffness Curves for Region 3 (Rt 481), Specimen Set # 2

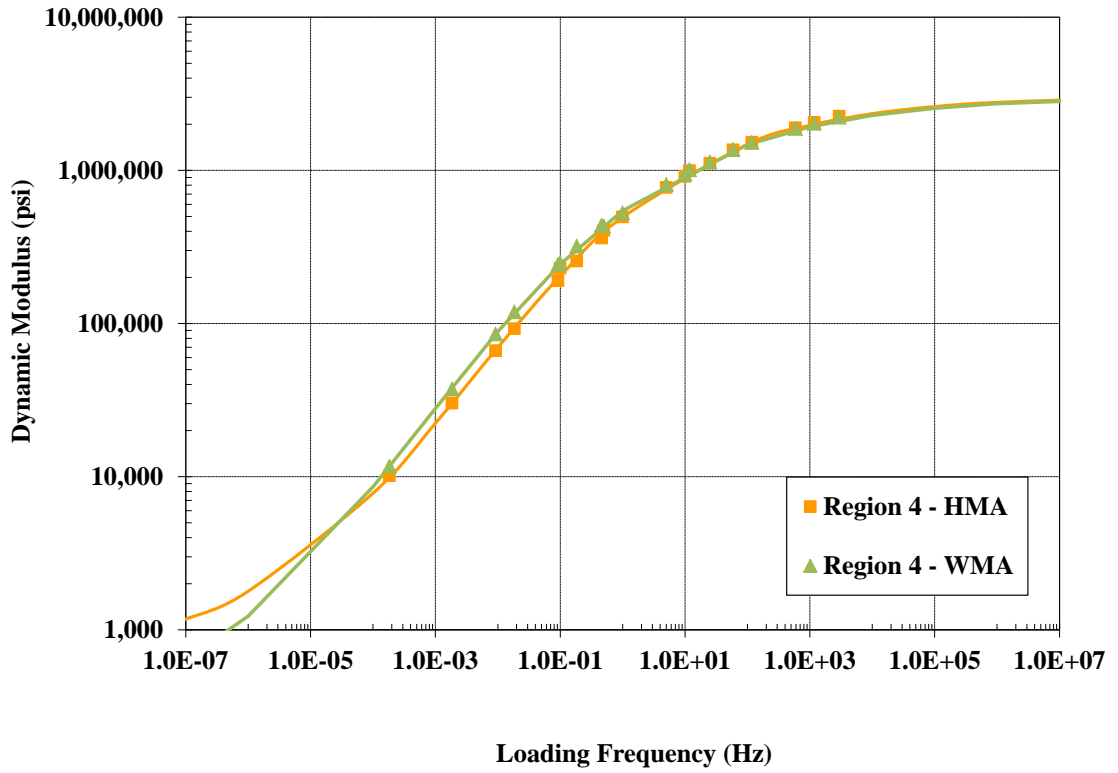


Figure 9 – Master Stiffness Curves for Region 4 (Rt 5/20), Specimen Set # 6

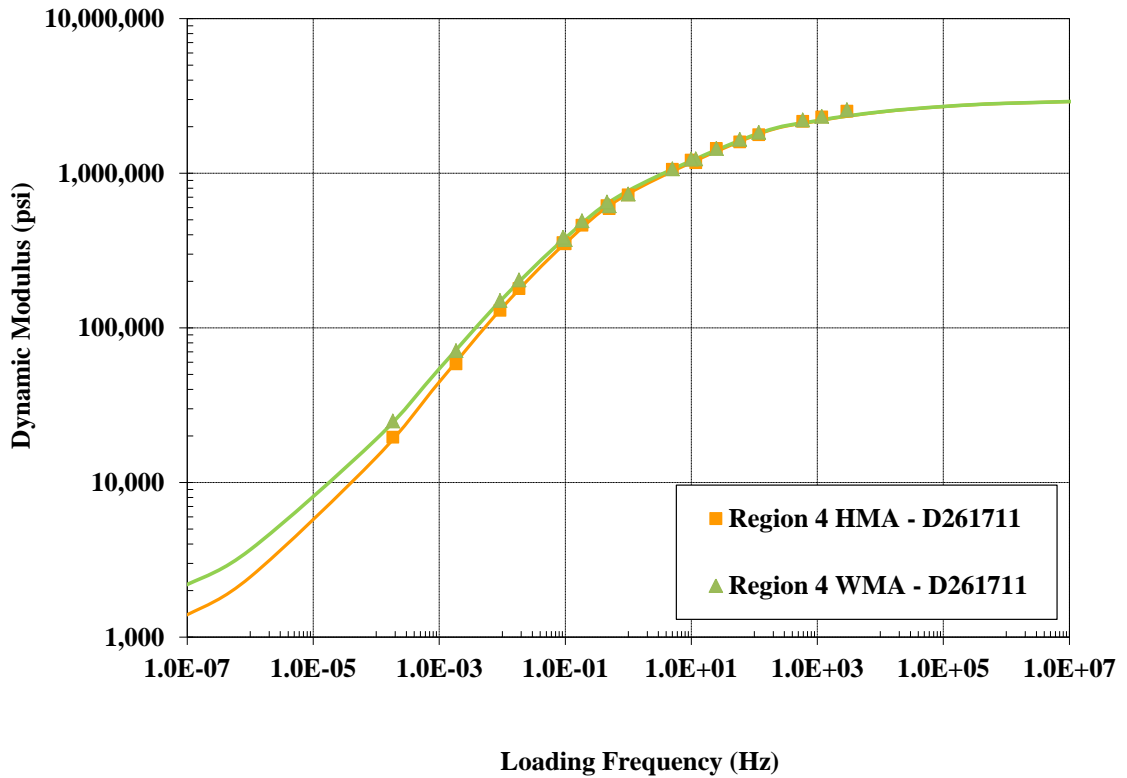


Figure 10 – Master Stiffness Curves for Region 4 (Rt 104), Specimen Set # 7

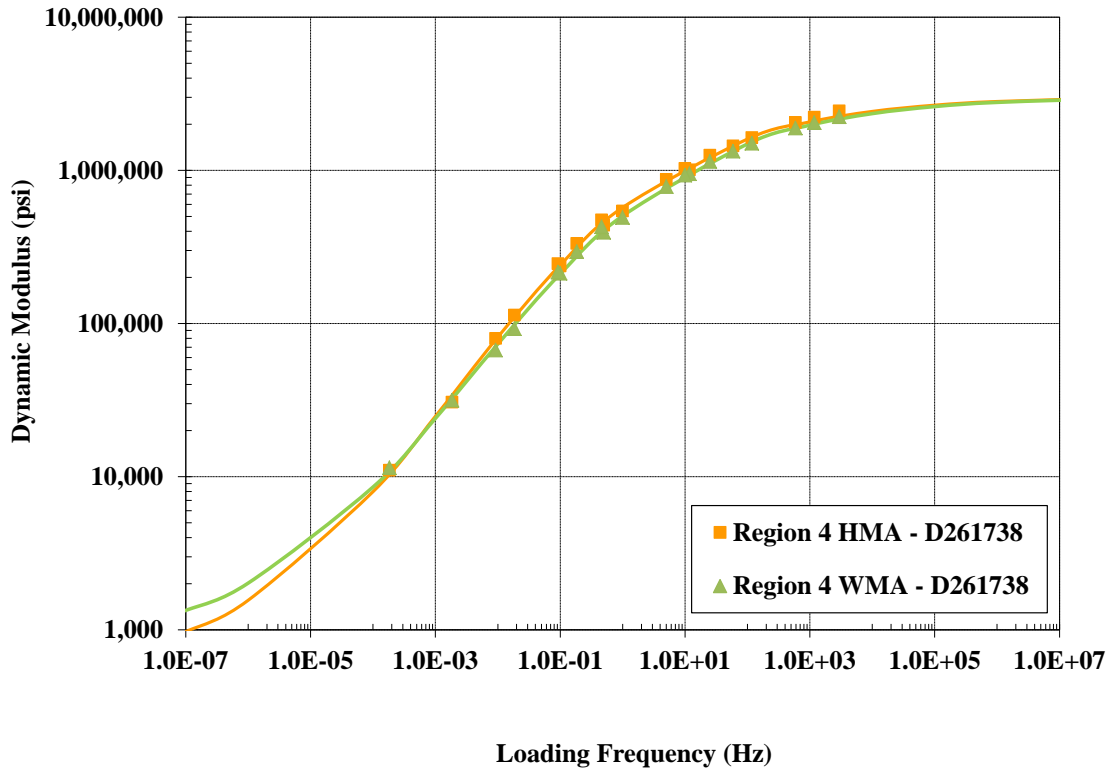


Figure 11 – Master Stiffness Curves for Region 4 (Rt 20A), Specimen Set # 8

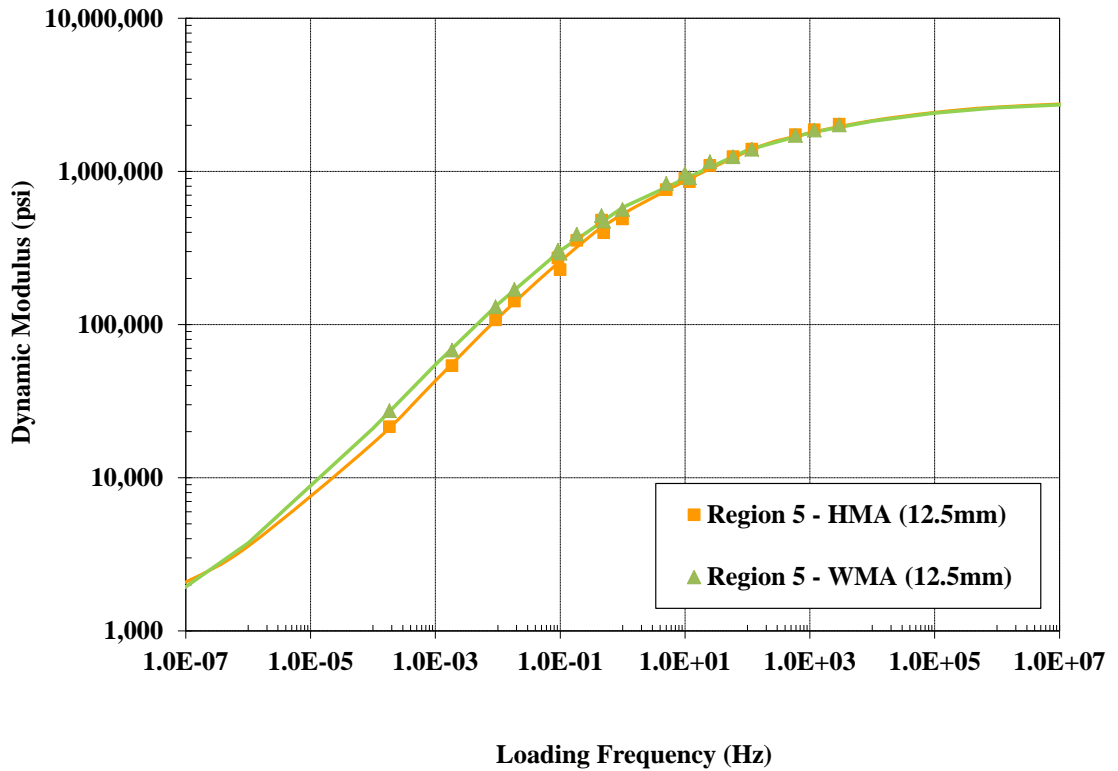


Figure 12 – Master Stiffness Curves for 12.5mm Region 5 (I-86), Specimen Set # 9

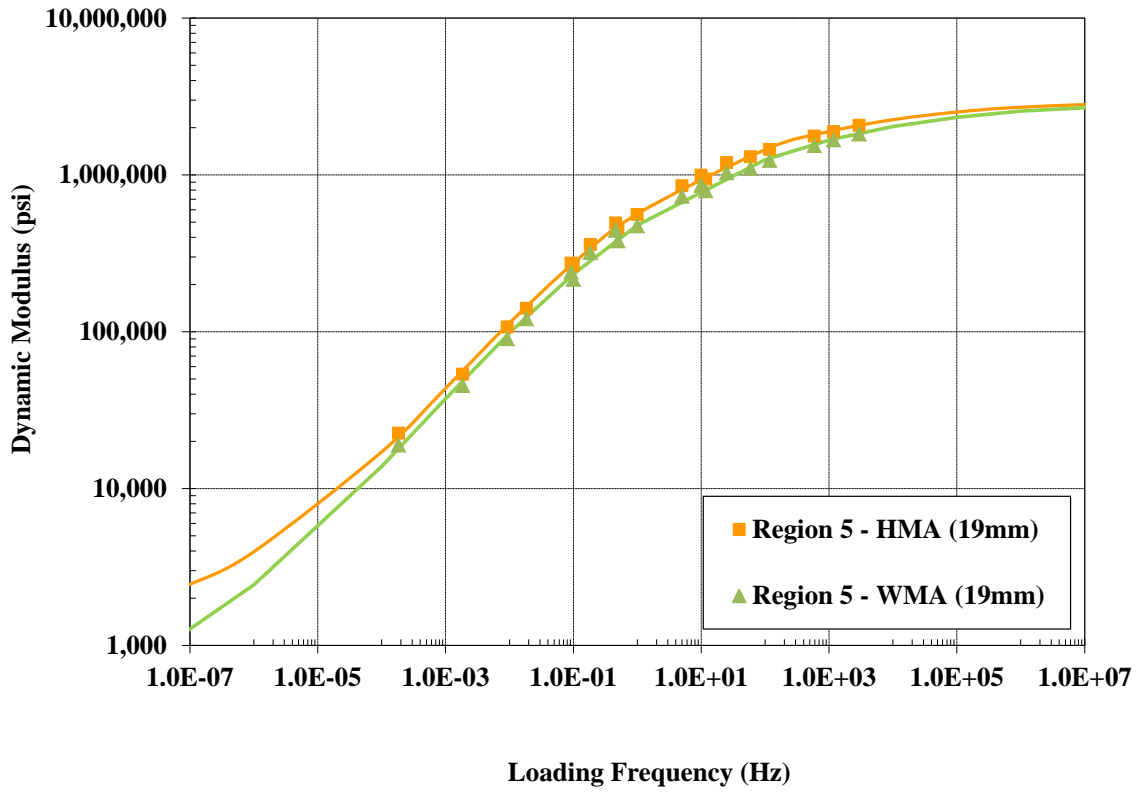


Figure 13 – Master Stiffness Curves for 19mm Region 5 (I-86), Specimen Set # 10

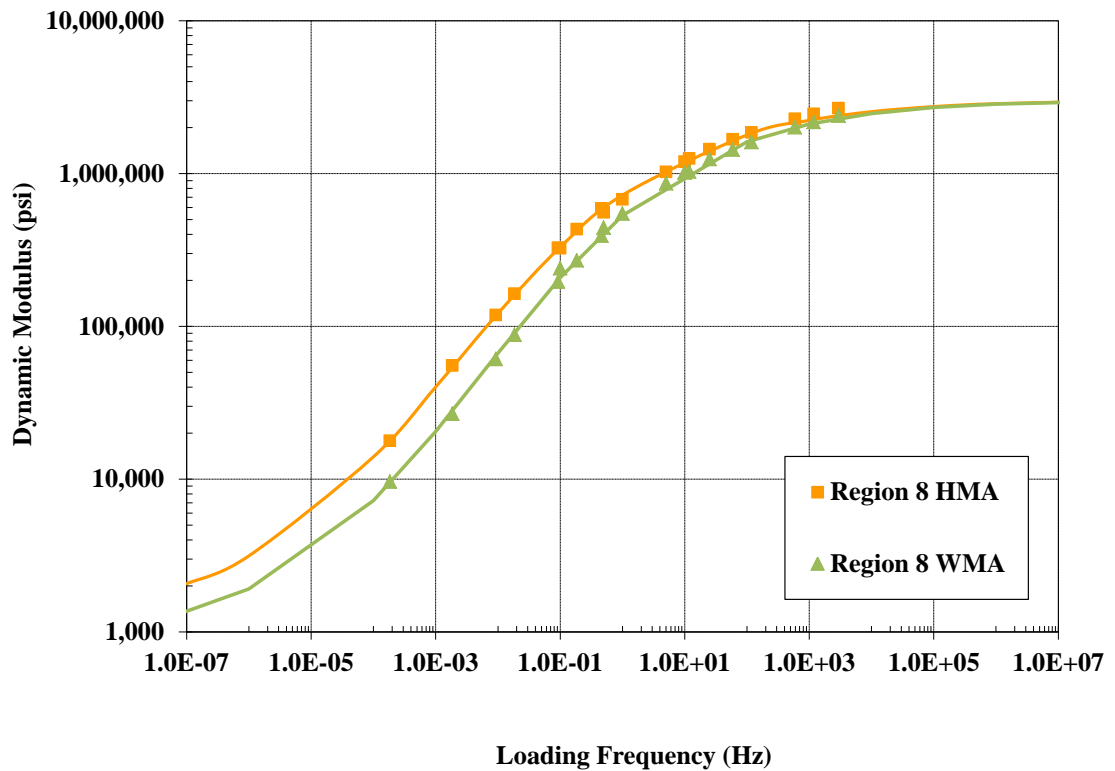


Figure 14 – Master Stiffness Curves for Region 8 (Rt 9W), Specimen Set # 11

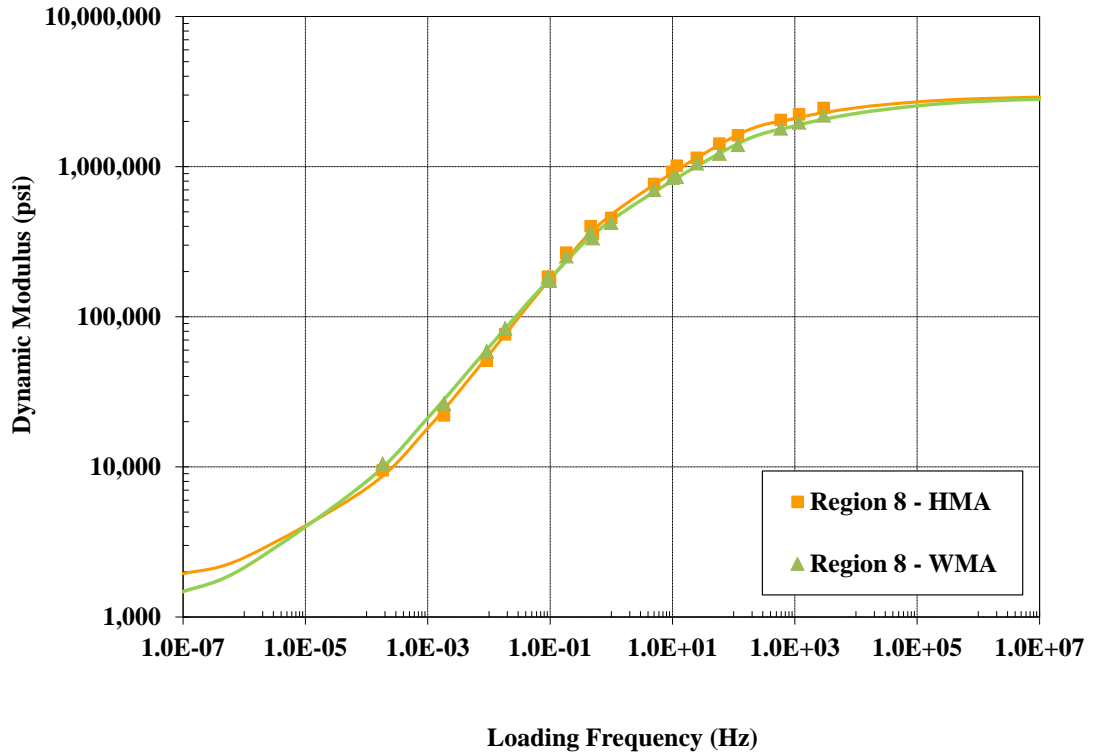


Figure 15 – Master Stiffness Curves for Region 8 (Rt 9), Specimen Set # 12

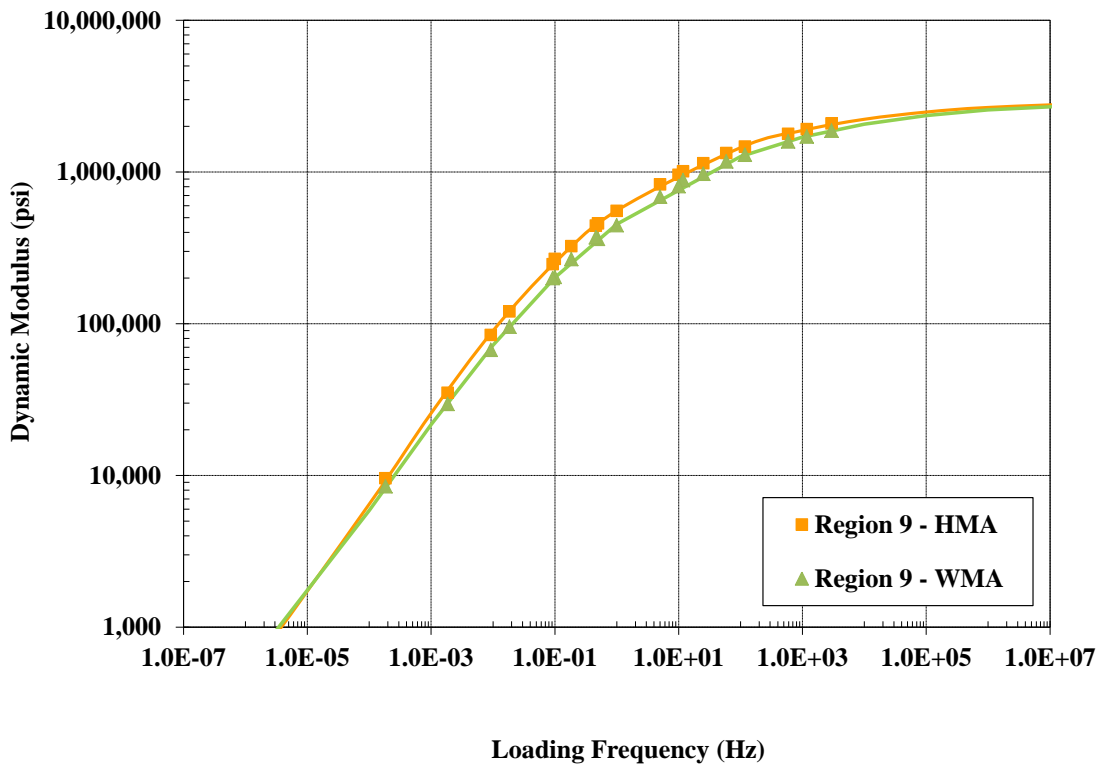


Figure 16 – Master Stiffness Curves for Region 9 (I-81), Specimen Set # 13

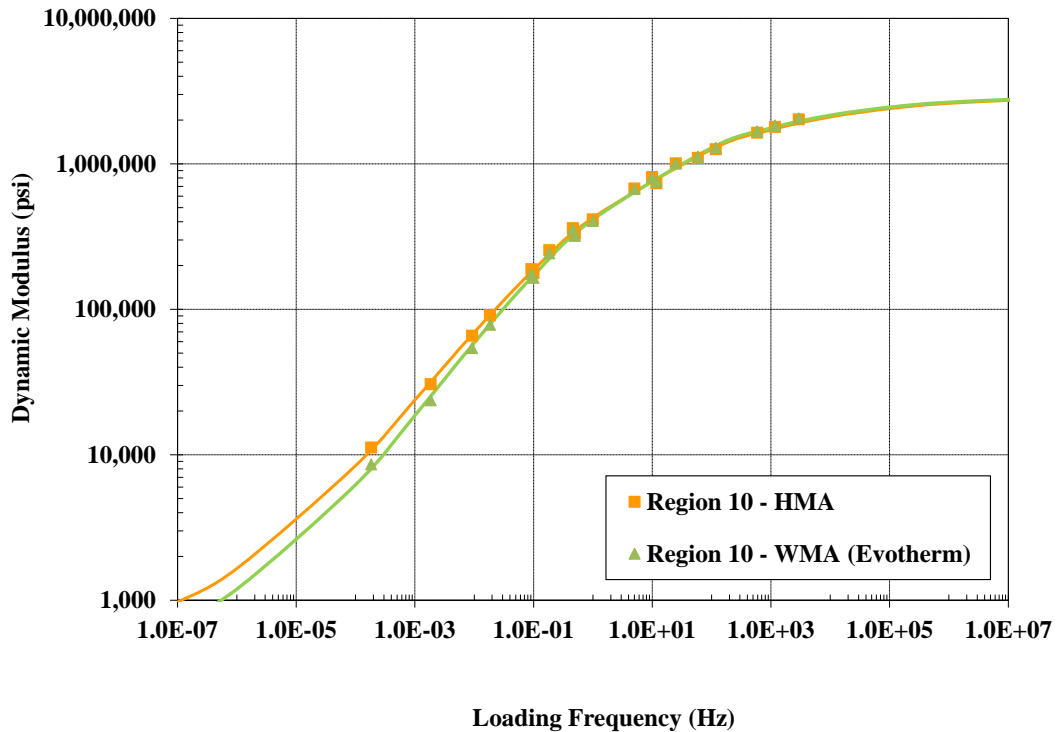


Figure 17 – Master Stiffness Curves for Region 10 (NY-27A), Specimen Set # 14

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 (%)			
												NYS DOT	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”, *Transportation 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.