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Laboratory Evaluation of Foamed Warm Mix Asphalt

Submitted to:

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Bureau of Materials

Conducted by:

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16. Abstract

Many of New Jersey's asphalt suppliers have elected to invest in Warm Mixed Asphalt systems that utilize water to foam the asphalt. Foaming the asphalt binder reduces the viscosity of the asphalt binder by increasing its surface area. Theoretically, this provides a more uniform coating on the aggregates, as well increasing the workability of the asphalt mixture. Unfortunately, limited research and data has been reported on the use and performance of foamed asphalt for warm mix asphalt. This project will evaluate the potential mix design changes that may be required to allow foamed WMA, as well as the general material performance. A laboratory investigation generating foamed warm mix asphalt will be conducted.

17. Key Words	18. Distribution Statement
Warm Mix Asphalt, Foaming Systems, Binders, Aggregate, Laboratory Testing	

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INTRODUCTION

Although the use and implementation of warm mix asphalt (WMA) has grown in popularity across the United States, there has been limited usage in New Jersey. To date, this may be explained by suppliers/contractors not fully embracing the potential benefits of WMA, while New Jersey Department of Transportation (NJDOT) taking a cautious approach to implementing a relatively new method of asphalt production.

In an effort to promote its use and better understand the behavior of WMA, the NJDOT developed a WMA protocol to be utilized with plant produced WMA. The protocol requires both an HMA and WMA section to be placed and loose mix collected and evaluated using advanced laboratory characterization test methods to rutting, fatigue cracking and moisture damage potential test procedures. This report summarizes the characterization testing of a WMA and HMA mixture produced and placed in NJ on state route 184.

PLANT PRODUCTION DATA

Plant production information was collected during the production of the WMA mixtures. For this study, two different foamed WMA mixtures were produced using a Gencor Green Machine asphalt foaming system (Figure 1); one with an anti-strip additive and one without an anti-strip additive. The use of an anti-strip was evaluated to determine whether or not foamed WMA benefitted from the inclusion of a modifier to help resist moisture damage potential.

Plant production parameters during the production of the WMA mixtures were:

- Burner Set Point = 270^{o}F
- Discharge Temperature = 265 to 275^{o}F
- Production Rate = 275 to 300 tons per hour
- Silo Storage Time: < 2 hours

During production, aggregate moisture contents were determined as follows:

- #8 Stone = 1.9%
- #10 Stone = 4.0%
- Natural Sand = 5.2%
- RAP = 4.1%

Figure 1 – Gencor Green Machine Modified Drum Plant

The asphalt mixtures were placed on New Jersey State Route 184 in Perth Amboy, NJ. Pictures of the existing pavement condition are shown Figures 3 to 5. Unfortunately, the existing pavement condition was relatively poor due to heavy truck traffic in the industry park area.

Figure 2 – HMA Paving on NJ Route 184

Figure 3 - Existing Pavement Condition at an Intersection of Route 184

Figure 4 - Paving Train During Production (from Right to Left – Paver, Material Transfer Vehicle, and Delivery Truck)

TEST PROCEDURES

In accordance with the NJDOT Provisional WMA specification (shown in Appendix A), the asphalt supplier must provide compacted HMA and WMA test specimens for mixture performance testing. The testing matrix required is shown below in Table 1.

Table 1 - Test Procedure and Specimen Requirements for NJDOT WMA Implementation Projects

Performance Tests for HMA Control						
Type of Test	Test Method	Pavement Distress	Test Specimen Air Voids	Compacted Specimen Height (mm)	Number of Test Specimens	Test Temperature
AMPT E*	AASTHO TP 79	Rutting Susceptibility	6.5 ± 0.5 %	170 [1]	2	129ºF (54ºC)
Asphalt Pavement Analyzer (APA)	AASTHO TP 63	Rutting Susceptibility	6.5 ± 0.5 %	170	2	147ºF (64ºC)
Hamburg Wheel Tracking	AASTHO T 324	Moisture Damage	6.5 ± 0.5 %	170	2	122ºF (50ºC)
Tensile Strength Ratio (TSR)	AASTHO T 283	Moisture Damage	6.5 ± 0.5 %	95	4	77ºF (25ºC)
Overlay Tester	NJDOT B-10	Fatigue Cracking Potential	6.5 ± 0.5 %	170[3]	2	77ºF (25ºC)

[1] Final Cut and trimmed test specimens. Lab compacted specimens should be approximately 1.0% higher.
[2] Three specimens of 170 mm height may be used instead of the required 6 specimens of 77 mm height.
[3] Four specimens of 115 mm height may be used instead of the required 2 specimens at 170 mm height.

As mentioned earlier, three different mixtures were evaluated during this study: 1) Normal HMA, 2) WMA with Anti-strip, and 3) WMA with no Anti-Strip. All of the mixtures were produced using the same NJDOT approved asphalt mixture job mix formula.

Dynamic Modulus (E*) – Mixture Stiffness

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 5). 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 5 - 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.

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

where:

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

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

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)

The resultant Master stiffness curves for the HMA and WMA produced on Rt 184 is shown in Figure 6. As expected, the stiffness of the two WMA mixtures was lower than the HMA, especially at the higher test temperatures, represented in Figure 2 as the lower loading frequencies. The test results in Figure 6 also indicate that minimal differences are found at the higher loading frequencies, which represents colder testing temperatures.

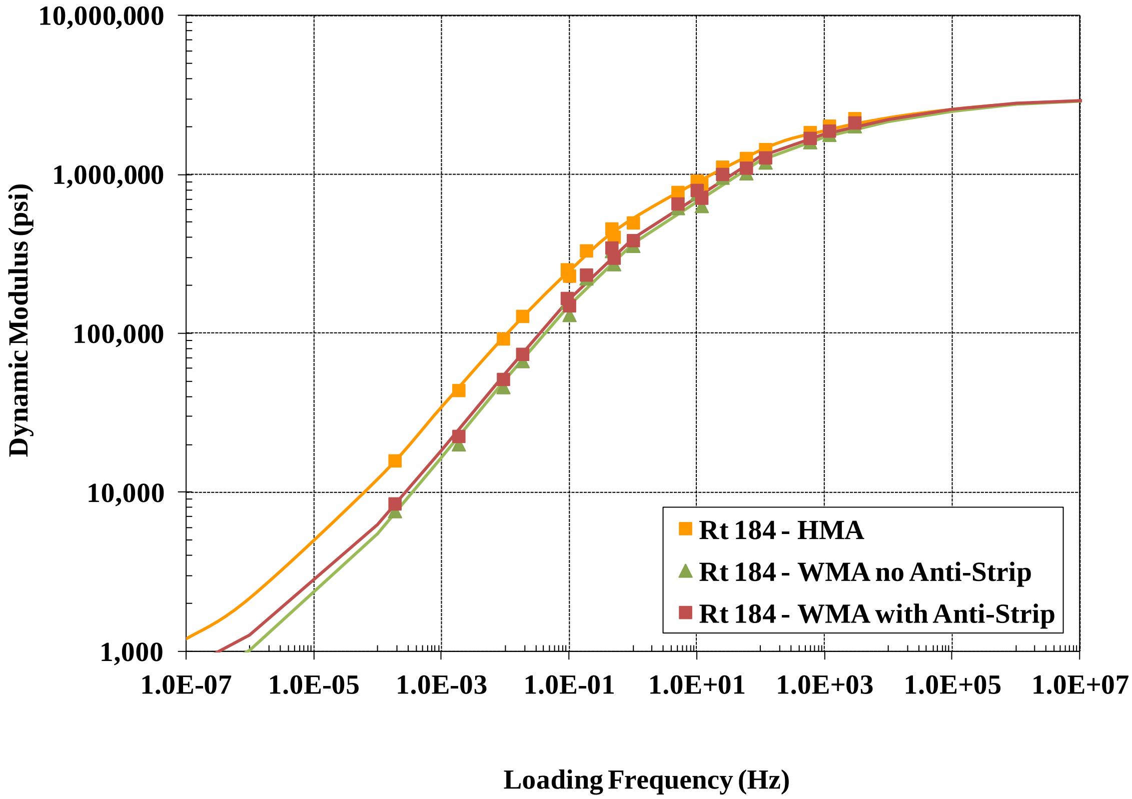


Figure 6 - Master Stiffness Curves of HMA and WMA Produced on Rt 184

Rutting Evaluation

The rutting potential of the asphalt mixtures were evaluated in the study using two test procedures; 1) The Asphalt Pavement Analyzer (AASHTO T340) and 2) The Repeated Load – Flow Number (AASHTO TP79).

Asphalt Pavement Analyzer (APA)

Compacted asphalt mixtures were testing were their rutting potential using the Asphalt Pavement Analyzer (APA) in accordance with AASHTO TP63, *Determining Rutting Susceptibility of Asphalt Paving Mixtures Using the Asphalt Pavement Analyzer (APA).* Prior to testing, the samples were conditioned for a minimum of 4 hours at the test temperature of 64^{o}C. The samples are tested for a total of 8,000 cycles using a hose pressure of 100 psi and wheel load of 100 lbs.

The test results for the APA testing are shown as Figure 7. The results show that the HMA material had a lower APA rutting than both of the WMA mixtures.

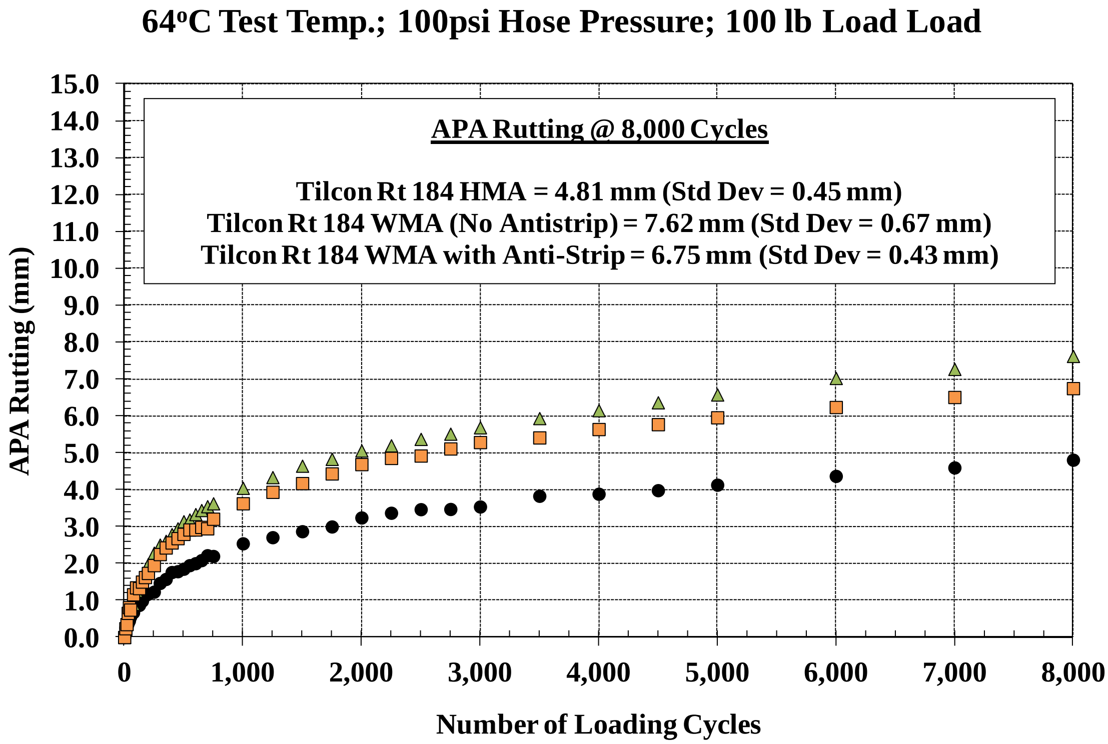


Figure 7- Asphalt Pavement Analyzer (APA) Test Results for Rt 184 HMA and WMA

Repeated Load – Flow Number Test

Repeated Load permanent deformation testing was measured and collected in uniaxial compression using the Asphalt Mixture Performance Tester (AMPT) 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 54.4°C, which corresponds to New Jersey's average 50% reliability high pavement temperature at a depth of 25 mm according the LTPPBind 3.1 software. These testing parameters (temperature and applied stress) conform to the recommendations currently proposed in NCHRP Project 9-43. Testing was conducted until a permanent vertical strain of 5% or 10,000 cycles was obtained.

The test results from the Flow Number test show the same trend as both the APA tests, as well as the high temperature stiffness measured during the Dynamic Modulus test.

Table 2 - Repeated Load (Flow Number) Testing Summary

AMPT Flow Number (AASHTO TP79) 54^{o}C, 600 kPa Deviatoric Stress (NCHRP 9-43 Specs)			
Mix Type	**Sample ID**	**Flow Number (cycles)**	**Cycles to Achieve 5% Strain**
HMA	#1	131	409
	#2	168	509
	Average	***150***	***459***
WMA - No Antistrip	#1	66	202
	#2	66	216
	Average	***66***	***209***
WMA + Antistrip	#1	95	355
	#2	56	190
	Average	***76***	***273***

Under NCHRP Projects 9-33 and 9-43, tentative criteria were established that recommended minimum Flow Number values for minimum ESAL levels. Tables 3 and 4 contain these values, respectively. Based on the proposed criteria from the NCHRP research, both mixtures would be appropriate for pavements of less than 10 million ESAL's.

Table 3 – Recommended Flow Number vs ESAL Level for HMA

Traffic Level, Million ESAL's	Minimum Flow Number
<3	N.A.
3 to < 10	53
10 to < 30	190
≥ 30	740

Table 4 - Recommended Flow Number vs ESAL Level for WMA

Traffic Level, Million ESAL's	Minimum Flow Number
<3	N.A.
3 to < 10	30
10 to < 30	105
≥ 30	415

Overlay Tester (TxDOT Tex-248-F) – Fatigue Cracking Evaluation

The Overlay Tester, described by Zhou and Scullion (2007), has shown to provide an excellent correlation to field cracking for both composite pavements (Zhou and Scullion, 2007; Bennert et al., 2009) as well as flexible pavements (Zhou et al., 2007). 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.

The test results for the Overlay Tester are shown in Figure 8. The test results clearly show that the HMA mixture had a significantly lower fatigue life than the two WMA mixtures. Rutgers University has found that this is typical of WMA mixtures as the reduction in production temperature lowers the oxidation of the virgin binder, as well as reducing the absorption of the asphalt binder, increasing the effective asphalt content of the mix.

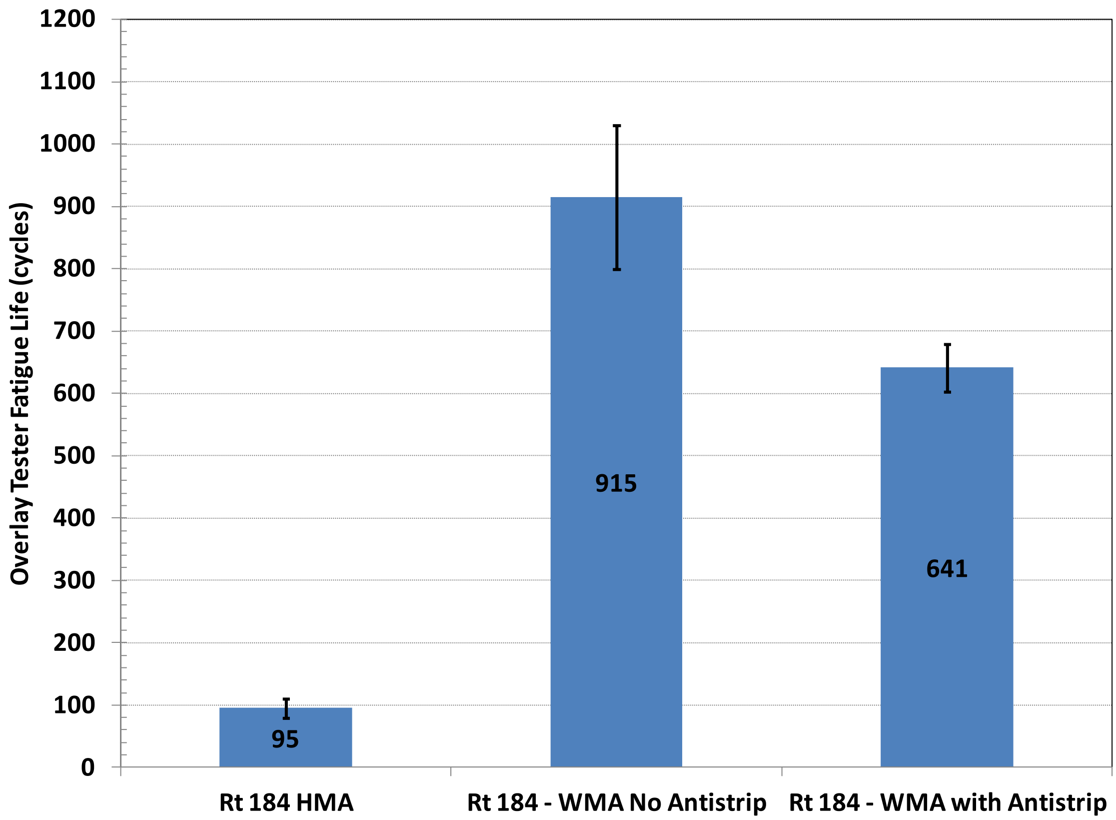


Figure 8 - Overlay Tester Results for NJ Rt 184 HMA and WMA Mixes

<u>Resistance to Moisture-Induced Damage</u>

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*. The TSR values and IDT strengths are shown in Table 5. The results show that all three mixtures resulted in very similar TSR values with the WMA with anti-strip mixture having a slightly higher TSR value.

Table 5 - Tensile Strength Ratio (TSR) Values for HMA and WMA

Tilcon Keasby, Rt 184 - HMA			
Specimen Type	Indirect Tensile Strength		Average TSR (%)
	Dry	Conditioned	
AASHTO T283 Conditioned	69.0	55.5	***86.6%***
	57.6	54.1	
	63.3	***54.8***	

Tilcon Keasby, Rt 184 - WMA without Anti-Strip			
Specimen Type	Indirect Tensile Strength		Average TSR (%)
	Dry	Conditioned	
AASHTO T283 Conditioned	59.4	51.0	***87.1%***
	60.5	53.4	
	59.9	***52.2***	

Tilcon Keasby, Rt 184 - WMA with Anti-Strip			
Specimen Type	Indirect Tensile Strength		Average TSR (%)
	Dry	Conditioned	
AASHTO T283 Conditioned	49.8	52.4	***93.8%***
	52.5	43.5	
	51.1	***47.9***	

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 number of cycles to reach 0.5 inches (12.5 mm) of rutting is commonly used for comparison purposes and for some state agency pass/fail specifications. For a PG64-22 asphalt binder, the mixtures must achieve a minimum of 10,000 cycles before achieving 0.5 inches of rutting.

The test results (Figures 9 to 11) show that the Hamburg data for the HMA would clearly pass the 10,000 passes before 12.5mm rutting. However, both WMA mixtures, even with the anti-strip added, would have failed the minimum criteria.

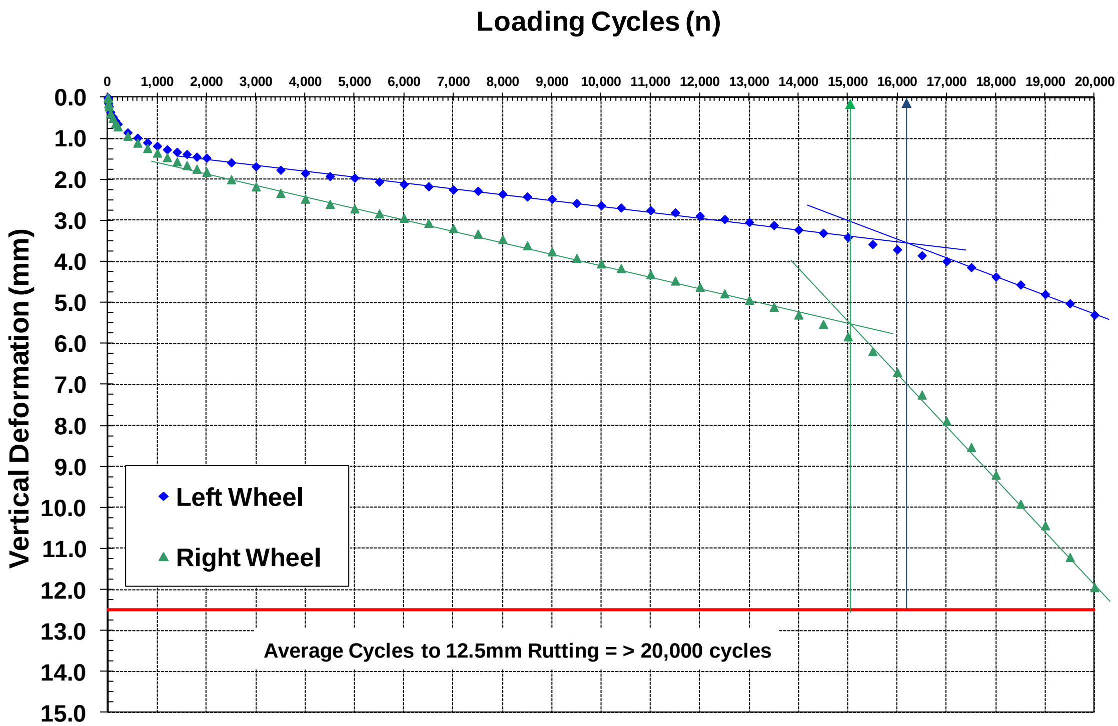


Figure 9 - Hamburg Wheel Tracking Results for Rt 184 HMA Mixture

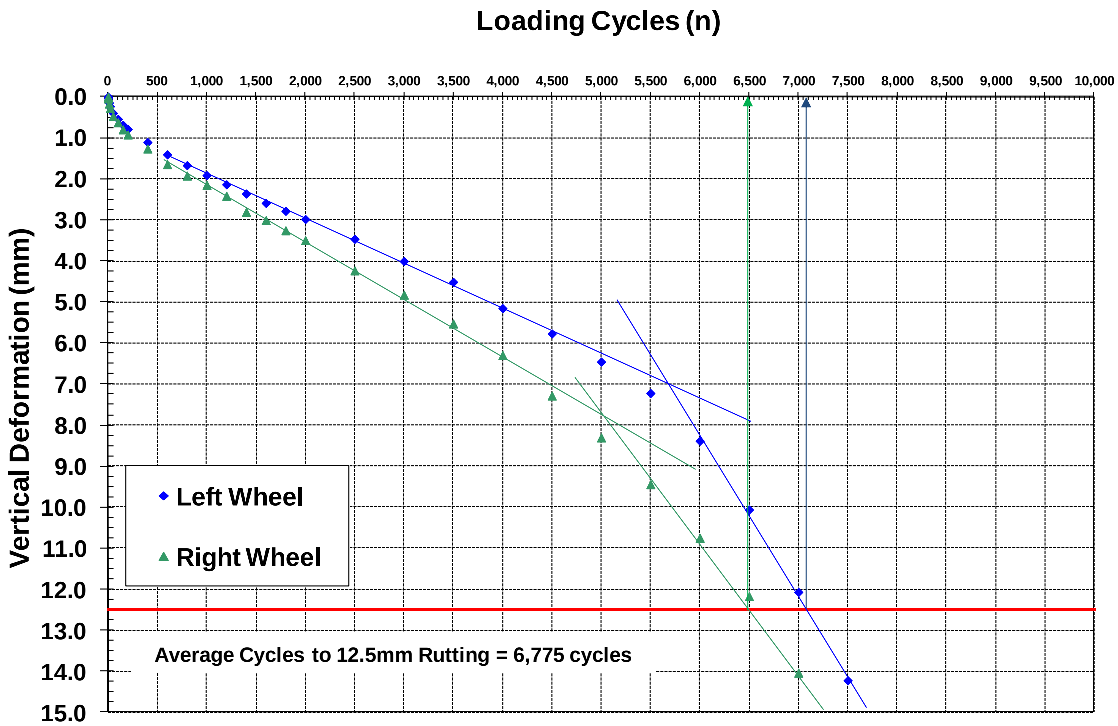


Figure 10 – Hamburg Wheel Tracking Results for Rt 184 WMA with No Anti-Strip

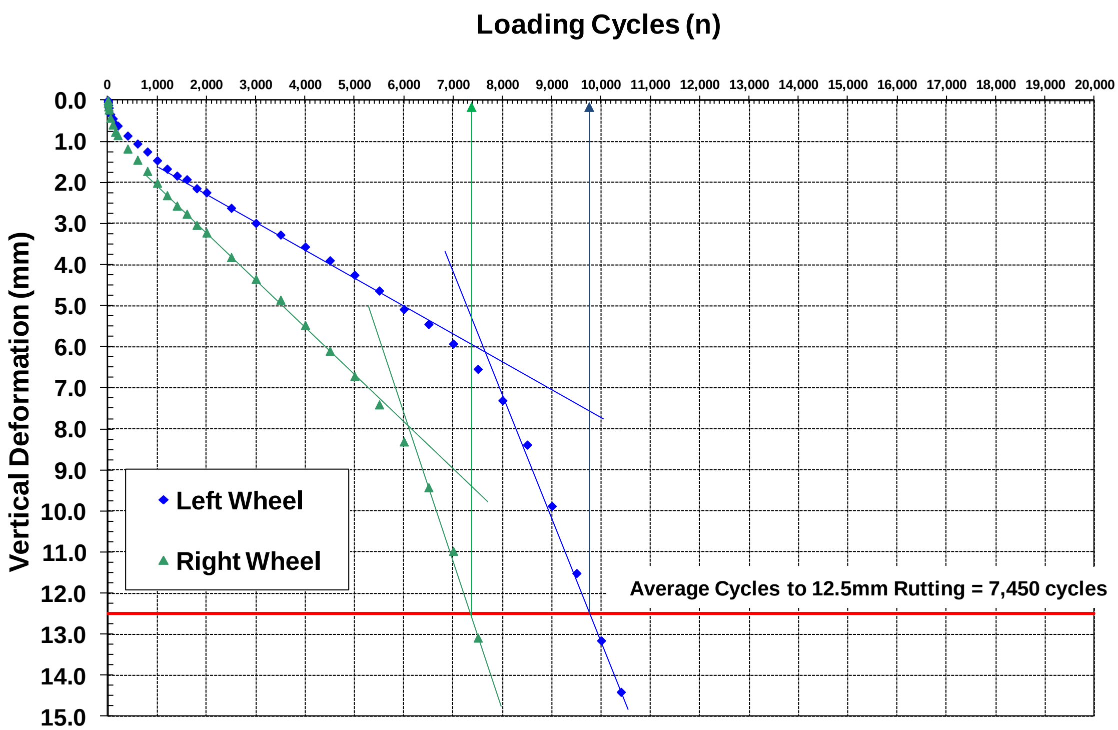


Figure 11 - Hamburg Wheel Tracking Results for Rt 184 with Anti-Strip

CONCLUSIONS

The test results from the HMA and WMA materials placed on New Jersey Rt 184 indicates:

- The WMA mixtures are not as stiff as the HMA mixture at elevated temperatures. It is hypothesized that this is due to lower levels of oxidation aging for the asphalt binder during production, as well as lower amounts of asphalt binder absorption increasing the effective asphalt content in the mix.
- However, this resulted in a slightly greater potential for rutting when comparing the mixtures in the Asphalt Pavement Analyzer and the Flow Number. Using the criteria established under NCHRP projects 9-33 and 9-43, both the HMA and WMA mixtures should be suitable for pavements with ESAL levels under 10 million ESAL's.
- Although the WMA mixtures appeared to be more susceptible to rutting, they clearly achieved a significantly greater resistance to fatigue cracking when evaluated in the Overlay Tester.
- When assessing the mixtures' resistance to moisture damage potential, all three mixtures achieved tensile strength (TSR) values greater than 80%. However, the test results for the Hamburg Wheel Tracking showed a significant difference between the HMA and WMA mixtures, with the HMA mixtures performing significantly better. The anti-strip additive helped to improve the moisture damage resistance when evaluated using the TSR procedure, but the same improved was not found with the Hamburg Wheel Tracking test.

APPENDIX A – NJDOT WMA Pilot Project Specification

Section 401 – Hot Mix Asphalt (HMA) Courses

ADD THE FOLLOWING TO 401.01:
401.01 Description

This Section also describes the requirements for constructing base course, intermediate course, and surface course of Warm Mix Asphalt (WMA).

ADD THE FOLLOWING TO 401.02.01:
401.02.01 Materials

Warm Mix Asphalt 902.10

ADD THE FOLLOWING TO 401.02.02:
401.02.02 Equipment

Modify the HMA plant per manufacture's requirements to produce WMA.

ADD THE FOLLOWING SUBSECTION TO 401.03:

401.03.06 Warm Mix Asphalt (WMA)

A. **Paving Plan.** At least 20 days before beginning placing the WMA, submit a detailed plan of operation as specified in 401.03.03.A to the RE for approval. Include detailed description of the proposed WMA to be used and the manufacturer's recommendations. Submit for Department approval a plan of the location for the WMA on the project.

B. **Weather Limitations**Place WMA according to the weather limitations in 401.03.03.B.

C. **Test Strip.** Construct a test strip as specified in 401.03.03.C.

D. **Transportation and Delivery of HMA.** Deliver WMA as specified in 401.03.03.D.

E. **Spreading and Grading.** Spread and grade WMA as specified in 401.03.03.E. Record the laydown temperature (temperature immediately behind the paver) at least once per hour during paving. Submit the temperatures to the RE and to the HMA Plant producing the WMA.

F. **Compacting.** Compact WMA as specified in 401.03.03.F.

G. **Opening to Traffic**Follow the requirements of 401.03.03.G for opening WMA to traffic.

H. **Air Void Requirements.** Ensure that the WMA is compacted to meet the air void requirements as specified in 401.03.03.H.

I. **Thickness Requirements.** Ensure that the WMA is paved to meet the thickness requirements as specified in 401.03.03.I.

J. **Ride Quality Requirements.** Ensure that the WMA is paved to meet the ride quality requirements as specified in 401.03.03.J

ADD THE FOLLOWING TO 401.04:
401.04 Measurement and Payment

The Department will measure and make payment for Items as follows:

Item	*Pay Unit*
WARM MIX ASPHALT ___ ___ ___ SURFACE COURSE	TON
WARM MIX ASPHALT ___ ___ ___ INTERMEDIATE COURSE	TON
WARM MIX ASPHALT ___ ___ ___ BASE COURSE	TON

ADD THE FOLLOWING TO 901.01:

902.01.05 Warm Mix Asphalt (WMA) Additives and Processes

Use one or more of the following types of WMA Additives or Processes:

1. Organic additives such as a paraffin wax or a low molecular weight esterified wax.
2. Manufactured synthetic zeolite (sodium aluminum silicate).
3. Chemical additive that acts as a surfactant or dispersing agent.
4. Controlled asphalt foaming system designed to work with the asphalt plant to produce WMA.

Submit information on the WMA additive or process with the Paving Plan required in 401.03.06.A. Include in the submission, the name and description of the additive or process, the manufacturer's recommendations for usage of the additive or process, recommendations for mixing and compaction temperatures, and details on at least one project on which the additive was used in the United States. In the details of a project, include tonnage, type of mix, dosage, mixing and compaction temperatures, available test results, and contact information for project. For controlled foaming systems, also submit the operating parameters of the system including accuracy of the meter, operating range, and temperature of the binder Provide the target and operating tolerances for the % water injection and temperatures for the binder. Provide a method for validating this with changing production rates.

Ensure that a technical representative of the manufacturer is available for consultation for the first day or night of production.

ADD THE FOLLOWING TO 902.02.04:

F. Performance Testing for HMA Control Mix. For comparison with the Warm Mix Asphalt on the project, performance testing of the HMA on the project is required on at least one sample. Ensure that the Superpave Gyratory Compactor at the HMA Plant is capable of producing specimens 172 mm high. Compact the number of specimens as required in Table 902.10.04-2. A spreadsheet is available from the ME to assist in determining the mass of mixture to use to obtain specimens with the correct height and air voids content.

Table 902.10.04-2 – Test Procedure and Specimen Requirements for NJDOT WMA Implementation Projects

Performance Tests for HMA Control						
Type of Test	Test Method	Pavement Distress	Test Specimen Air Voids	Compacted Specimen Height (mm)	Number of Test Specimens	Test Temperature
AMPT E*	AASTHO TP 79	Rutting Susceptibility	6.5 ± 0.5 %	170 [1]	2	Multiple
Asphalt Pavement Analyzer (APA)	AASTHO TP 63	Rutting Susceptibility	6.5 ± 0.5 %	170	2	148ºF (64ºC)
Hamburg Wheel Tracking	AASTHO T 324	Moisture Damage	6.5 ± 0.5 %	170	2	ºF (50ºC)
Tensile Strength Ratio (TSR)	AASTHO T 283	Moisture Damage	6.5 ± 0.5 %	170	2	N.A.
Overlay Tester	NJDOT B-10	Fatigue Cracking Potential	6.5 ± 0.5 %	170[3]	2	77ºF (25ºC)
[1] Final Cut and trimmed test specimens. Lab compacted specimens should be approximately 1.0% higher.						

[2] Three specimens of 170 mm height may be used instead of the required 6 specimens of 77 mm height.
[3] Four specimens of 115 mm height may be used instead of the required 2 specimens at 170 mm height.

Once sampled from the truck prior to leaving the plant, do not keep the asphalt mixtures at compaction temperature for no longer than 30 minutes greater than the anticipated travel time to the field location. For example, if the travel time to the construction site is 30 minutes, then compact the loose mix within 1 hour from the time of sampling. To accurately compare the performance data, it is very important to maintain a similar conditioning time for the mixtures at their respective compaction temperatures. Erratic conditioning times will greatly influence the general stiffness properties of the mixtures and result in bias in the collected performance data.

Along with the test specimens, submit the following plant production and construction information:

- Moisture content of stockpiles (if possible)
- Set burner temperature
- Asphalt mixture discharge temperature
- Production rate
- Silo storage time
- Compaction temperature in field (immediately behind paver) (obtained from the Contractor)
- RAP content
- Mix Design and lot data sheet

ADD THE FOLLOWING TO 902:
902.10 WARM Mix Asphalt (WMA)

902.10.01 WMA Definitions and Mix Designations

WMA is a method of producing asphalt pavement at a mixing and compaction temperatures at least 30ºF lower than Hot Mix Asphalt (HMA) using either a WMA additive or a controlled asphalt foaming system. For PG 64-22, normal mixing temperatures are in the range of 300 to 315ºF and normal compaction temperatures are in the range of 285 to 300ºF. For PG 76-22, normal mixing temperatures are in the range of 315 to 325ºF and normal compaction temperatures are in the range of 305 to 315ºF.

The requirements for specific WMA mixtures are identified by the abbreviated fields in the Item description as defined as follows:

WARM MIX ASPHALT 12.5H64 SURFACE COURSE

1. **"WARM MIX ASPHALT"** "Warm Mix Asphalt" is located in the first field in the Item description for the purpose of identifying the mixture requirements.
2. **"12.5"** The second field in the Item description designates the nominal maximum size aggregate (in millimeters) for the job mix formula (sizes are 4.75, 9.5, 12.5, 19, 25, and 37.5 mm).
3. **"H"** The third field in the Item description designates the design compaction level for the job mix formula based on traffic forecasts as listed in Table 902.10.03-2 (levels are L=low, M=medium, and H=high).
4. **"64"** The fourth field in the Item description designates the high temperature (in °C) of the performance-graded binder (options are 64, 70, and 76 °C). All binders shall have a low temperature of –22 °C, unless otherwise specified.
5. **"SURFACE COURSE"** The last field in the Item description designates the intended use and location within the pavement structure (options are surface, intermediate, or base course).

902.10.02 Composition of Mixtures

Provide materials as specified:

Aggregates for Hot Mix Asphalt	901.05
Asphalt Binder	902.01.01
WMA Additive	902.01.05

If a WMA additive is pre-blended in the asphalt binder, ensure that the asphalt binder meets the requirements of the specified grade after the addition of the WMA additive. If a WMA additive is added at the HMA plant, ensure that the addition of the additive will not negatively impact the grade of asphalt binder. Follow the manufacturer's recommendations for percentage of WMA additive needed.

Mix WMA in a plant that is listed on the QPL for HMA Plants and conforms to the requirements for HMA Plants as specified in 1009.01.

Composition of the mixture for WMA surface course is coarse aggregate, fine aggregate, and asphalt binder, and may also include mineral filler, a WMA additive, and up to 15 percent Reclaimed Asphalt Pavement (RAP). For controlled asphalt foaming system WMA, the Department may require an anti-stripping additive. Ensure that the finished mix does not contain more than a total of 1 percent by weight contamination from Crushed Recycled Container Glass (CRCG).

The composition of the mixture for WMA base or intermediate course is coarse aggregate, fine aggregate, and asphalt binder, and may also include mineral filler, a WMA additive, and up to 35 percent of recycled materials. For controlled asphalt foaming system WMA, the Department may require an anti-stripping additive. The 35 percent of recycled materials may consist of a combination of RAP, CRCG, Ground Bituminous Shingle Material (GBSM), and RPCSA, with the following individual limits:

Table 902.10.02-1 Use of Recycled Materials in HMA Base or Intermediate Course

Recycled Material	Maximum Percentage
RAP	25
CRCG	10
GBSM	5
RPCSA	20

Combine the aggregates to ensure that the resulting mixture meets the grading requirements specified in Table 902.10.03-1. In determining the percentage of aggregates of the various sizes necessary to meet gradation requirements, exclude the asphalt binder.

Ensure that the combined coarse aggregate, when tested according to ASTM D 4791, has less than 10 percent flat and elongated pieces retained on the No. 4 sieve and larger. Measure aggregate using the ratio of 5:1, comparing the length (longest dimension) to the thickness (smallest dimension) of the aggregate particles.

Ensure that the combined fine aggregate in the mixture conforms to the requirements specified in Table 902.10.02-2. Ensure that the material passing the No. 40 sieve is non-plastic when tested according to AASHTO T 90.

Table 902.10.02-2 Additional Fine Aggregate Requirements for WMA

Tests	Test Method	Minimum Percent
Uncompacted Void Content of Fine Aggregate	AASHTO T 304, Method A	45
Sand Equivalent	AASHTO T 176	45

902.10.03 Mix Design

For production of WMA, use an HMA mix design that meets the requirements of 902.02.03 and has been approved by the ME.

Test the mix design to ensure that it meets a minimum tensile strength ratio of 80 percent, when tested according to AASHTO T 283. If a controlled foaming system is used to produce the WMA, produce specimens for tensile strength ratio from plant produced mix. The ME will require tensile strength ratio testing for all WMA mixes.

For WMA mix design verification, submit with the mix design forms 2 gyratory specimens and 1 loose sample corresponding to the composition of the JMF. For controlled asphalt foaming systems, produce the specimens from material produced from the plant using the controlled asphalt foaming system. The ME will use these to verify the properties of the JMF. Compact the specimens to the design number of gyrations (N_{des}). For the mix design to be acceptable, all gyratory specimens must comply with the requirements specified in Table 902.10.03-1 and Table 902.10.03-3. The ME reserves the right to be present at the time the gyratory specimens are molded. For controlled asphalt foaming system mixes, the ME will approve the mix for only the plant that was used in producing the mix for verification.

In addition, submit samples as detailed in 902.10.04.E for performance testing of the WMA mixture. The ME will perform performance testing of the WMA for final approval of the mix design.

902.10.04 Sampling and Testing

A. **General Acceptance Requirements.** The RE or ME may reject and require disposal of any batch or shipment that is rendered unfit for its intended use due to contamination, segregation, improper temperature, lumps of cold material, or incomplete coating of the aggregate. For other than improper temperature, visual inspection of the material by the RE or ME is considered sufficient grounds for such rejection.

For WMA, ensure that the temperature of the mixture at discharge from the plant or surge and storage bins meets the WMA manufacturer's recommendations. Do not allow the mixture temperature to exceed 300°F at discharge from the plant.

Combine and mix the aggregates and asphalt binder to ensure that at least 95 percent of the coarse aggregate particles are entirely coated with asphalt binder as determined according to AASHTO T 195. If the ME determines that there is an on-going problem with coating, the ME may obtain random samples from 5 trucks and will determine the adequacy of the mixing on the average of particle counts made on these 5 test portions. If the requirement for 95 percent coating is not met on each sample, modify plant operations, as necessary, to obtain the required degree of coating.

Ensure that the equipment for controlled asphalt foaming system is running according to the manufacturer's recommendations. Ensure that the metering of water and temperature of the binder for foaming the asphalt is controlled to produce a uniform mixture.

B. **Sampling.** The ME will take 5 stratified random samples of WMA for volumetric acceptance testing from each lot of approximately 3500 tons of a mix. When a lot of WMA is less than 3500 tons, the

ME will take samples at random for each mix at the rate of one sample for each 700 tons. The ME will perform sampling according to AASHTO T 168, NJDOT B-2, or ASTM D 3665.

Use a portion of the samples taken for volumetric acceptance testing for composition testing.

C. Quality Control Testing. The WMA producer shall provide a quality control (QC) technician who is certified by the Society of Asphalt Technologists of New Jersey as an Asphalt Technologist, Level 2. The QC technician may substitute equivalent technician certification by the Mid-Atlantic Region Technician Certification Program (MARTCP). Ensure that the QC technician is present during periods of mix production for the sole purpose of quality control testing and to assist the ME. The ME will not perform the quality control testing or other routine test functions in the absence of, or instead of, the QC technician.

The QC technician shall perform sampling and testing according to the approved quality control plan, to keep the mix within the limits specified for the mix being produced. The QC technician may use acceptance test results or perform additional testing as necessary to control the mix.

To determine the composition, perform ignition oven testing according to AASHTO T 308.

For each acceptance test, perform maximum specific gravity testing according to AASHTO T 209 on a test portion of the sample taken by the ME. Sample and test coarse aggregate, fine aggregate, mineral filler, and RAP according to the approved quality control plan for the plant.

When using RAP, ensure that the supplier has in operation an ongoing daily quality control program to evaluate the RAP. As a minimum, this program shall consist of the following:

1. An evaluation performed to ensure that the material conforms to 901.05.04 and compares favorably with the design submittal.
2. An evaluation of the RAP material performed using a solvent or an ignition oven to qualitatively evaluate the aggregate components to determine conformance to 901.05.
3. Quality control reports as directed by the ME.

D. Acceptance Testing and Requirements. The ME will determine volumetric properties at N_{des} for acceptance from samples taken, compacted, and tested at the HMA plant. The ME will compact WMA to the number of design gyrations (N_{des}) specified in Table 902.10.03-2, using equipment according to AASHTO T 312. The ME will determine bulk specific gravity of the compacted sample according to AASHTO T 166. The ME will use the most current QC maximum specific gravity test result in calculating the volumetric properties of the WMA.

The ME will determine the dust-to-binder ratio from the composition results as tested by the QC technician.

Ensure that the WMA mixture conforms to the requirements specified in Table 902.10.04-1, and to the gradation requirements in Table 902.10.03-1. If 2 samples in a lot fail to conform to the gradation or volumetric requirements, immediately initiate corrective action.

The ME will test a minimum of 1 sample per lot for moisture, basing moisture determinations on the weight loss of an approximately 1600-gram sample of mixture heated for 1 hour in an oven at 280 ± 5°F. Ensure that the moisture content of the mixture at discharge from the plant does not exceed 1.0 percent.

Table 902.10.04-1 WMA Requirements for Control

Compaction Levels	Required Density (% of Theoretical Max. Specific Gravity)	Voids in Mineral Aggregate (VMA), % (minimum)						Dust-to-Binder Ratio
		Nominal Max. Aggregate Size, mm						
	@Ndes[1]	37.5	25.0	19.0	12.5	9.5	4.75	
L, M, H	95.0 – 98.5	11.0	12.0	13.0	14.0	15.0	16.0	0.6 - 1.3

1. As determined from the values for the maximum specific gravity of the mix and the bulk specific gravity of the compacted mixture. Maximum specific gravity of the mix is determined according to AASHTO T 209. Bulk specific gravity of the compacted mixture is determined according to AASHTO T 166.

E. **Performance Testing for WMA Implementation.** Ensure that the Superpave Gyratory Compactor at the HMA Plant is capable of producing specimens 172 mm high. For each day's production, compact the number of specimens as required in Table 902.10.04-2. A spreadsheet is available from the ME to assist in determining the mass of mixture to use to obtain specimens with the correct height and air voids content.

Table 902.10.04-2 – Test Procedure and Specimen Requirements for NJDOT WMA Implementation Projects

Performance Tests for HMA Control						
Type of Test	Test Method	Pavement Distress	Test Specimen Air Voids	Compacted Specimen Height (mm)	Number of Test Specimens	Test Temperature
AMPT E*	AASTHO TP 79	Rutting Susceptibility	6.5 ± 0.5 %	170[1]		129ºF (54ºC)
Asphalt Pavement Analyzer (APA)	AASTHO TP 63	Rutting Susceptibility	6.5 ± 0.5 %	77[2]	6	129ºF (54ºC)
Hamburg Wheel Tracking	AASTHO T 324	Moisture Damage	6.5 ± 0.5 %	77[2]	6	129ºF (54ºC)
Tensile Strength Ratio (TSR)	AASTHO T 283	Moisture Damage	7.0 ± 0.5 %	95	6	129ºF (54ºC)
Overlay Tester	NJDOT B-10	Fatigue Cracking Potential	6.5 ± 0.5 %	170[3]	2	129ºF (54ºC)

[1] Final Cut and trimmed test specimens. Lab compacted specimens should be approximately 1.0% higher.
[2] Three specimens of 170 mm height may be used instead of the required 6 specimens of 77 mm height.
[3] Four specimens of 115 mm height may be used instead of the required 2 specimens at 170 mm height.

Once sampled from the truck prior to leaving the plant, do not keep the asphalt mixtures at compaction temperature for no longer than 30 minutes greater than the anticipated travel time to the field location. For example, if the travel time to the construction site is 30 minutes, then compact the loose mix within 1 hour from the time of sampling. To accurately compare the performance data, it is very important to maintain a similar conditioning time for the mixtures at their respective compaction temperatures. Erratic conditioning times will greatly influence the general stiffness properties of the mixtures and result in bias in the collected performance data.

Along with the test specimens, submit the following plant production and construction information:

- Moisture content of stockpiles (if possible)
- Set burner temperature
- Asphalt mixture discharge temperature
- Production rate
- Silo storage time
- Compaction temperature in field (immediately behind paver) (obtained from the Contractor)
- RAP content
- Mix Design and lot data sheet
- Binder grade, supplier, and lot number
- For controlled foaming system, details on the settings for the foaming system

NJDOT B-10 – Overlay test for Determining Crack Resistance of HMA

A. Scope. This test method is used to determine the susceptibility of HMA specimens to fatigue or reflective cracking. This test method measures the number of cycles to failure.

B. Apparatus. Use the following apparatus:

1. Overlay Tester. An electro-hydraulic system that applies repeated direct tension loads to specimens. The machine features two blocks, one is fixed and the other slides horizontally. The device automatically measures and records loads, displacement, and temporary every 0.1 sec.
   The sliding block applies tension in a cyclic triangular waveform to a constant maximum displacement of 0.06 cm (0.025 in.). This sliding block reaches the maximum displacement and then returns to its initial position in 10 sec. (one cycle).
2. Temperature Control System. The temperature chamber must be capable of controlling the test temperature with a range of 32 to 95^{o}F (0 to 35^{o}C).
3. Measurement System. Fully automated data acquisition and test control system. Load, displacement, and temperature are simultaneously recorded every 0.1 sec.
4. Linear Variable Differential Transducer. Used to measure the horizontal displacement of the specimen (+/- 0.25 in.). Refer to manufacturer for equipment accuracy for LVDT.
5. Electronic Load Cell. Used to measure the load resulting from the displacement (5000 lb capacity). Refer to manufacturer for equipment accuracy for load cell.
6. Specimen Mounting System. Used two stainless steel base plates to restrict shifting of the specimen during testing. The mounting jig holds the two stainless steel base plates for specimen preparation.
7. Cutting Template. Refer to Figure 1.
8. Two Part Epoxy. Two part epoxy with a minimum 24 hour tensile strength of 600 psi (4.1 MPa) and 24 hour shear strength of 2,000 psi (13.8 MPa).
9. 10 lb weight (4.5 kg). Used to place on top of specimens while being glued to specimen platens**.**
10. ¼ inch Width Adhesive Tape. Placed over gap in plates to prevent from being epoxied together.
11. Paint or Permanent Marker. Used to outline specimens on platens for placement of epoxy.
12. 3/8-in. Socket Drive Handle with a 3-in. (7.6 cm) extension.

C. Procedure. Perform the following steps:

1. **Sample Preparation.**
   a. *Laboratory Molded Specimens* - Use cylindrical specimens that have been compacted using the gyratory compactor (AASHTO T 312). Specimen diameter must be 6 inches (150 mm) and a specimen height must be 4.5 inches +/- 0.2 inches (115 +/- 5 mm).
   Note 1 - Experience has shown that molded laboratory specimens of a known density usually result in a greater density (or lower air voids) after being trimmed. Therefore, it is recommended that the laboratory technician produce molded specimens with an air void level slightly higher than the targeted trimmed specimen. Determine the density of the final trimmed specimen in accordance with AASHTO T 166.
   b. Core Specimens – Specimen diameter must be 6 inches +/- 0.1 inch (150 mm +/- 2 mm). Determine the density of the final trimmed specimen in accordance with AASHTO T166.
2. **Trimming of Cylindrical Specimen.** Before starting, refer to the sawing device manufacturer's instructions for cutting specimens.
   a. Place the cutting template on the top surface of the laboratory molded specimen or roadway core. Trace the location of the first two cuts by drawing lines using paint or a permanent maker along the sides of the cutting template.

b. Trim the specimen ends by cutting the specimen perpendicular to the top surface following the traced lines. Discard specimen ends.
c. Trim off the top and bottom of the specimen to produce a sample with a height of (1.5 inches +/- 0.02 inches (38 mm +/- 0.5 mm).
Note 2 – Refer to Figure 2.
d. Measure the density of the trimmed specimen in accordance with AASHTO T 166. If the specimen does not meet the density requirement as specified for performance testing for the mix being tested, then discard it and prepare a new specimen.
e. Air dry the trimmed specimen to constant mass, where constant mass is defined as the weight of the trimmed specimen not changing by more than 0.05% in a 2 hour interval.

3. **Mounting Trimmed Specimen to Base Plates (Platens).**
   a. Mount and secure the base plates (platens) to the mounting jig. Cut a piece of adhesive tape approximately 4.0 inches (102 mm) in length. Center and place the piece of tape over the gap between the base plates.
   b. Prepare the epoxy following manufacturer's instructions.
   c. Cover a majority of the base plates (platens) with epoxy, including the tape. Glue the trimmed specimen to the base plates.
   d. Place a 10 lb (4.5 kg) weight on top of the glued specimen to ensure full contact of the trimmed specimen to the base plates. Allow the epoxy to cure for the time recommended by the manufacturer. Remove the weight from the specimen after the epoxy has cured.
   e. Turn over the glued specimen so the bottom of the base plates faces upward. Using a hacksaw, cut a notch through the epoxy which can be seen through the gap in the base plates. The notch should be cut as evenly as possible and should just begin to reach the specimen underneath the epoxy. Great care should be taken not to cut more than 1/16 inch (1.58 mm) into the specimen.
   f. Place the test sample assembly in the Overlay Tester's environmental chamber for a minimum of 1 hour before testing.
4. **Start Testing Device.** Please refer to manufacturer's equipment manual prior to operating equipment.
   a. Turn on the Overlay Tester. Turn on the computer and wait to ensure communication between the computer and the Overlay Tester occurs.
   b. Turn on the hydraulic pump using the Overlay Tester's software. Allow the pump to warm up for a minimum of 20 minutes.
   c. Turn the machine to load control mode to mount the sample assembly.
5. **Mounting Specimen Assembly to Testing Device.** Enter the required test information into the Overlay Tester software for the specimen to be tested.
   a. Mount the specimen assembly onto the machine according to the manufacturer's instructions and the following procedural steps.
      1. Clean the bottom of the base plates and the top of the testing machine blocks before placing the specimen assembly into the blocks. If all four surfaces are not clean, damage may occur to the machine, the specimen, or the base plates when tightening the base plates.
      2. Apply 15 lb-in of torque for each screw when fastening the base plates to the machine.
6. **Testing Specimen.**
   a. Perform testing at a constant temperature recommended by the New Jersey Department of Transportation for the mixture in question. This is typically either 59^{o}F (15^{o}C) or 77^{o}F (25^{o}C).
   Note 3 – Ensure the trimmed specimen has also reached the constant temperature required.
   b. Start the test by enabling the start button on the computer control program. Perform testing until a 93% reduction or more of the maximum load measured from the first opening cycle occurs. If 93% is not reached, run the test until a minimum of 1,200 cycles.

c. After the test is complete, remove the specimen assembly from the Overlay Tester machine blocks.

D. Report. Include the following items in the report:

1. Date and time molded or cored.
2. NJDOT mixture identification.
3. Trimmed specimen density.
4. Starting Load.
5. Final Load.
6. Percent decline (or reduction) in Load.
7. Number of cycles until failure.
8. Test Temperature.

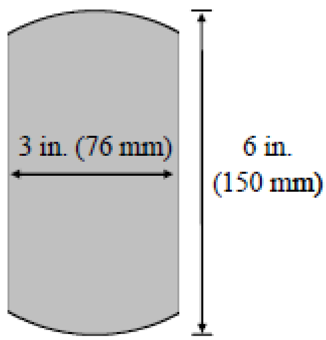
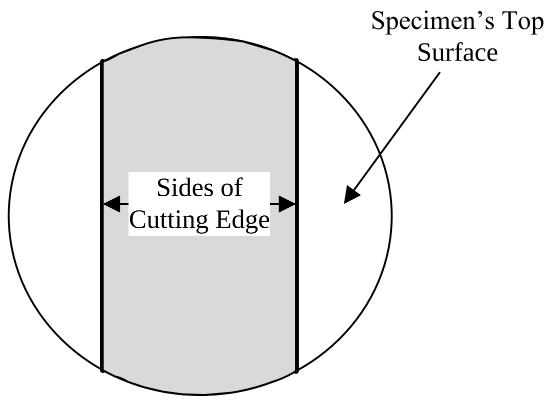
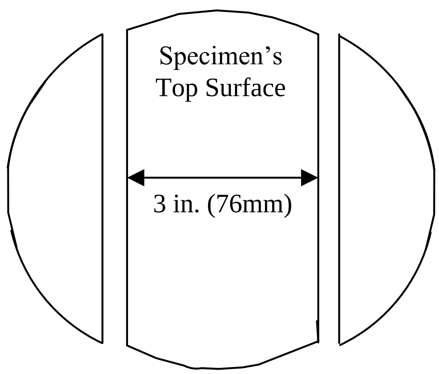


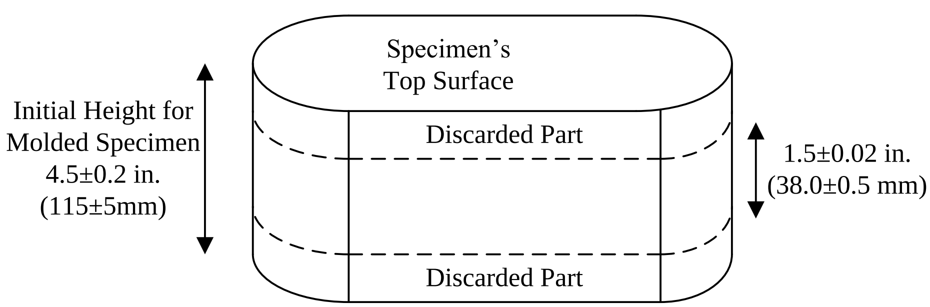
Figure 1 – **Cutting Template**



Tracing lines using cutting template



Trimming specimen's ends



Trimming specimen to required height

Figure 2 – **Trimming of Cylindrical Specimen**