FHWA-NJ-2015-010

Performance Testing for HMA Quality Assurance

FINAL REPORT
September 2015

Submitted by

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In cooperation with

New Jersey
Department of Transportation
Bureau of Research
and
U.S. Department of Transportation
Federal Highway Administration

Disclaimer Statement

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No. FHWA-NJ-2015-010	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Performance Testing for HMA Quality Assurance		5. Report Date September 2015
		6. Performing Organization Code
7. Author(s) Thomas Bennert, Ph.D., Darius Pezeshki, M.S.		8. Performing Organization Report No.
9. Performing Organization Name and Address Rutgers University Piscataway, NJ 08854		10. Work Unit No.
		11. Contract or Grant No.
12. Sponsoring Agency Name and Address New Jersey Department of Transportation CN 600 Trenton, NJ 08625	Federal Highway Administration U.S. Department of Transportation Washington, D.C.	13. Type of Report and Period Covered Final Report 7/2012 – 9/2015
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

An extensive research effort was conducted to evaluate performance-based asphalt mixture design concepts for the New Jersey Department of Transportation (NJDOT). The NJDOT have utilized performance-based design procedures for their “Specialty” asphalt mixtures since 2006. However, performance criteria had not yet been developed for NJ’s “Conventional” asphalt mixtures, which includes dense-graded, stone matrix asphalt (SMA) and open-graded friction course (OGFC) mixtures. The research study also looked at the proposed method of “Balanced Mixture Design”, which does not utilize air voids at the determinate for optimum asphalt content. Instead, the procedure determines the range of asphalt contents where both rutting and fatigue cracking performance is satisfied and recommends the middle of that range as the optimum asphalt content. Lastly, the study evaluated the Overlay Tester equipment from a second manufacturer, Troxler Electronics, and how well this new unit compared to the original device manufactured by Shedworks, Inc. A mini Round Robin study was conducted to compare the two pieces of equipment and a brief statistical analysis comparing the test data was conducted.

The research study resulted in a proposed performance-based criteria for “Conventional” asphalt mixtures that is sensitive to both traffic level and location in the pavement (surface, intermediate or base). The criteria also maintains consistency in test procedures and limits with other performance-based asphalt mixtures in NJ. The Balanced Design methodology indicated that NJDOT’s dense-graded asphalt mixtures fatigue life would greatly benefit from a one percent increase in VMA, while resulting in very little decrease in rutting resistance. Upon review of the Troxler Electronics Overlay Tester and comparing it to the Shedworks device through round robin studies confirmed that the Troxler device could be utilized to determine the fatigue life of asphalt mixtures in accordance with the NJDOT B-10 test procedure. After evaluation, the unit was delivered to the NJDOT, where a 2-day training course was held to familiarize the NJDOT engineers with the sample preparation, testing, and data analysis required.

17. Key Words Performance-based Specifications, Balanced Mix Design, Overlay Tester, Effective Asphalt Content	18. Distribution Statement

19. Security Classif (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No of Pages 124 pp	22. Price

Form DOT F 1700.7 (8-69)

ACKNOWLEDGEMENTS

The Center for Advanced Infrastructure and Transportation (CAIT) would like to acknowledge the guidance of the engineering staff at the New Jersey Department of Transportation. In particular, Eileen Sheehy of the Material Bureau and Robert Blight and Susan Gresavage of Pavement Design and Management. The hard work of the laboratory staff at CAIT (Ed Wass Jr. and Brett DiFrancesco) is greatly appreciated.

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RESEARCH PROBLEM

The Superpave asphalt mixture design system is based on evaluating the performance of each constituent of the asphalt mixture; asphalt binder, aggregate/sand, and the mixture as a whole. In its development and initial release, a suite of performance tests were developed to accompany the new volumetric design system to verify asphalt mixtures would not prematurely rut or crack. Unfortunately, the cost of the test equipment, as well as the time it took to test the mixture design specimens, was impractical. This resulted in the Superpave design system to simply be a volumetric based asphalt mixture design system with only moisture damage being evaluated using AASHTO T283, *Resistance of Compacted Hot Mix Asphalt (HMA) to Moisture-Induced Damage*.

During its early implementation with the New Jersey Department of Transportation (NJDOT), the initial Superpave mixtures were found to be coarser, had less asphalt binder, and harder to place and compact than the previous Marshall asphalt mixtures designed for the identical traffic level. What resulted were asphalt mixtures that were prone to poor longitudinal joint construction and asphalt pavements failing quicker due to fatigue cracking related distress.

To combat the fatigue-prone Superpave mixtures, the NJDOT began making slight modifications to the Superpave mixture design procedure, especially the proposed gyration table. Upon immediate implementation of Superpave, the NJDOT utilized the following:

- Very Heavy Traffic, "V": N_{design} = 125 gyrations
- Heavy Traffic, "H": N_{design} = 100 gyrations
- Moderate Traffic, "M": N_{design} = 75 gyrations

Within the first few years of implementation, the NJDOT eliminated the "V" Superpave mixtures, which were recommended for "very heavy" traffic volumes of 30 million ESAL's or greater, and began using "H" Superpave mixtures in their place. This resulted in a slight increase in asphalt content in the mixtures, although it did not resolve the fatigue cracking and longitudinal joint issue. NJDOT has recently dropped another gyratory level, from "H" to "M", to once again attempt to increase the asphalt content in their asphalt mixtures. In doing so, when placing HMA on heavily traveled roads, a polymer-modified asphalt binder is specified to reduce the rutting potential.

Adding to the already fatigue prone asphalt mixtures observed in New Jersey, the asphalt industry in New Jersey has been pressuring the NJDOT to utilize more recycled asphalt pavement (RAP) in their mixtures. Historically, due to the oxidized and stiff asphalt binder associated with RAP, higher percentages of RAP have been associated with an increase in fatigue and low temperature cracking potential when compared to virgin or low RAP content asphalt mixtures. In 2010, Rutgers University completed a pilot study for the NJDOT Materials Bureau evaluating fatigue resistance of virgin and RAP asphalt mixtures in the Overlay Tester (Figure 1). On average, the virgin asphalt mixtures were able to achieve a fatigue life of 150 cycles or greater, while the RAP

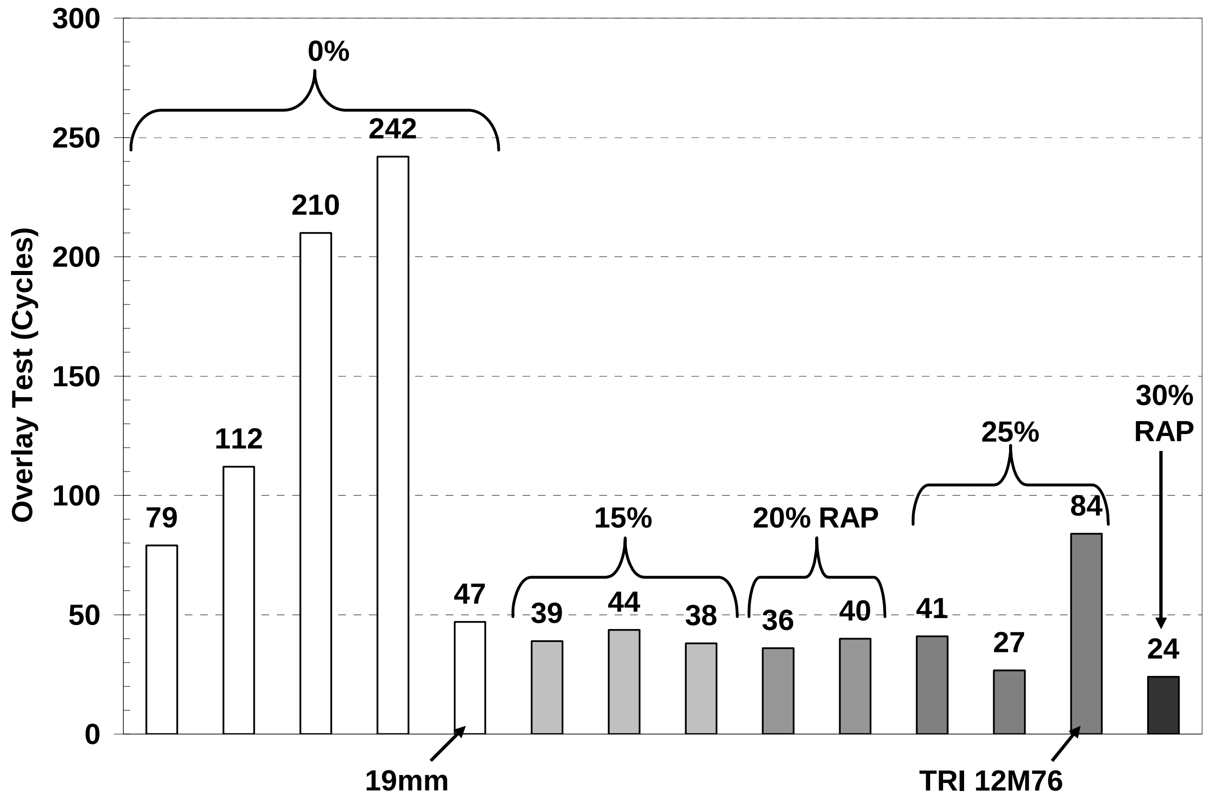


Figure 1 – Overlay Tester Results for Different RAP Content Mixes in New Jersey

mixtures were not able to reach 50 cycles. Unfortunately, the NJDOT does not have a test/design procedure in place to evaluate the performance of their asphalt mixtures during design and actual plant production to ensure premature fatigue cracking is not an issue.

OBJECTIVE

The objective of the research study was to evaluate the use of performance-based specifications for mixture design and quality control purposes. To accomplish the objectives, the research project was broken down into four major tasks;

1. Literature Review – focusing on performance testing for HMA and relevant specifications pertaining to HMA performance testing during mixture design and quality control.
2. Development of Database of Performance Properties – Task 2 focused on collecting and testing plant produced asphalt mixtures for varying times of asphalt mixtures, that included; HMA, SMA, and OGFC.
3. Balanced Mix Design Procedure – Task 3 focused on evaluating the concept of a HMA mixture design procedure that utilized performance testing, instead of volumetrics, to determine the optimum asphalt content. The Balanced Mix Design procedure included rutting and fatigue cracking test procedures to "balance" the performance of the asphalt mixture.

4. Implementation of the Texas Overlay Tester at NJDOT – Task 4 encompasses evaluating a new Overlay Tester built by Troxler Electronics through a series of round robin testing. The baseline comparison is the test results of the Shedworks Overlay Tester, which is the original device used in New Jersey.

STATE OF THE PRACTICE OF PERFORMANCE-BASED ASPHALT MIXTURES IN NEW JERSEY

Recently, the New Jersey Department of Transportation (NJDOT) has focused almost all of their pavement construction efforts towards pavement rehabilitation. This is not due to the lack of a need for more and larger roadways, but simply due to the fact that available space to construct new pavements is lacking in the most densely populated state in the United States. Therefore, a significant portion of the NJDOT's pavement budget is allocated towards rehabilitating and maintaining its current transportation infrastructure. Unfortunately, in recent years, the NJDOT has realized they are not getting the return on their investment as they had hoped. Current pavement rehabilitation efforts have resulted in pavement lives of approximately one-half of their intended design life. The primary distress found among most of the asphalt pavements in New Jersey is longitudinal cracking. Most of the asphalt mixtures placed in New Jersey are lean on asphalt content, resulting in stiff asphalt mixtures that cause issues with compaction and inevitably result in durability problems. In some cases, the issue can be classified as "…the wrong mix for the wrong application". And to make matters worse, the NJDOT has been continually under pressure by the asphalt industry to increase the amount of RAP utilized in their asphalt mixtures. Until recently, the NJDOT has worried that the addition of RAP into already lean asphalt mixtures may result in pavement lives even shorter than what the NJDOT is currently experiencing.

To help improve the performance of the asphalt mixtures being placed on New Jersey roadways, the NJDOT has developed a Performance-Based Mixture Design and Quality Control program. The basis of the program is to "engineer" asphalt mixtures for specific performance needs. For example, general maintenance mixtures require lesser performance than asphalt mixtures placed on composite pavements or bridge deck overlays where horizontal and vertical movements are much greater. Therefore, the asphalt mixtures to be placed on these structures will have different asphalt contents, asphalt binder types, volumetric targets and even different levels of performance requirements. This approach is a drastic improvement over the current mentality that the same asphalt mixture can be placed on all applications and be expected to perform as intended.

New Jersey Department of Transportation's Performance-Based Acceptance Procedure

The NJDOT has established a general acceptance procedure that the asphalt plants/contractors are required to follow to be allowed to produce and place their respective Performance-Based asphalt mixture. The general procedure is as follows:

1. Step 1 requires that the asphalt plant conduct a volumetric design using the proposed materials and mixture design specifications. After the asphalt plant has successfully conducted their own volumetric design, the NJDOT Regional Offices verify the volumetrics at their laboratory. Once the volumetrics have been verified and the constituents (aggregates and asphalt binder) of the asphalt mixture have been approved, the asphalt plant/contractor is allowed to proceed to Step 2.
2. In Step 2, the asphalt plant/contractor must submit either laboratory prepared loose mix or the virgin materials to a laboratory approved by the NJDOT Bureau of Materials. The laboratory will then prepare the required test specimens for the respective performance tests. If the test specimens meet the specified performance criteria, the asphalt plant/contractor is then allowed to move to Step 3. Otherwise, the mixture must be redesigned.
3. In Step 3, the asphalt plant/contractor must produce the mixture through the asphalt plant and construct a test strip. The location of the test strip is preferred to be close to the actual location of construction (i.e. – shoulder area), but it is at the discretion of the contractor as long as it is approved by the NJDOT. Loose mix used to produce the test strip is sampled and supplied to a laboratory approved by the NJDOT Bureau of Materials. The same test procedure and performance criteria from Step 2 must again be met with the plant produced material. If the test specimens fail, the asphalt plant/contractor must again produce the mixture through the plant and construct another test strip, essentially repeating Step 3 until the mixture passes the performance criteria established. Once the test strip material passes the loose mix criteria, the asphalt plant/contractor is allowed to produce and place the material on the project.
4. In Step 4, the contractor must sample material during production for continued performance testing to ensure the mixture properties still meet the required specifications. The frequency of sampling is dependent on the respective Performance-Based mixture being produced, as well as the quantity.
   Three different hot mix asphalt performance test methods are utilized to test the

Performance-Based mixtures in New Jersey. In most cases, both rutting and fatigue cracking are evaluated using one of the following test procedures:

- Asphalt Pavement Analyzer (AASHTO T340, *Determining Rutting Susceptibility of Hot Mix Asphalt (HMA) Using the Asphalt Pavement Analyzer (APA));*
- Flexural Beam Fatigue (AASHTO T321, *Determining the Fatigue Life of Compacted Hot Mix Asphalt (HMA) Subjected to Repeated Flexural Bending*);
- Overlay Tester (NJDOT B-10, *Test Method for the Overlay Test*)

The type of fatigue test utilized is dependent on whether the mode of cracking is dependent on the flexural properties of the pavement or the expansion/contraction of PCC slabs.

New Jersey Department of Transportation's (NJDOT) Performance Based Asphalt Mixtures – Specifications and Field Installation

Currently, the NJDOT has five Performance-Based asphalt mixtures that require the testing and protocols previously mentioned. These five mixtures include;

1. High Performance Thin Overlay (HPTO);
2. Binder Rich Intermediate Course (BRIC);
3. Bridge Deck Waterproofing Surface Course (BDWSC);
4. Bottom Rich Base Course (BRBC); and
5. High RAP (HRAP).

Each one of these mixtures is explained in detail in the following sections.

High Performance Thin Overlay (HPTO)

By Superpave definition, the NJDOT's High Performance Thin Overlay (HPTO) is a fine-graded, 9.5mm nominal maximum aggregate size (NMAS) mixture. The HPTO is used as a rut-resistant/durable thin lift mixture for maintenance/pavement preservation applications, as well as a superior leveling course when extended staging time is expected. When small quantities are needed (< 100 mix tons), the HPTO has also been used for overlays on top of bridge decks. The required aggregate blend gradation, minimum asphalt content and design/production volumetric requirements are shown in Tables 1 and 2. The HPTO requires the use of a polymer-modified PG76-22 asphalt binder and the addition of natural sand and/or recycled asphalt pavement (RAP) is not allowed.

Table 1 – Aggregate Blend Gradation of NJDOT's HPTO

HPTO Grading of Total Aggregate	
Sieve Size	Percent Passing by Mass
3/8"	100
#4	65-85
#8	33-55
#16	20-35
#30	15-30
#50	10-20
#100	5-15
#200	5.0-8.0
Minimum Percent Asphalt by Mass of Total Mix	7.0

Table 2 – Volumetric Requirements for NJDOT's HPTO

Volumetric Requirements for Design and Control of HPTO					
	Required Density (% of Gmm)		Voids in Mineral Aggregate	Dust to Binder Ratio	Draindown AASHTO T 305
	N_{des} (50 Gyr)	N_{max} (100 Gyr)	(VMA)		
Design Requirements	96.5	≤ 99.0	≥ 18.0 %	0.6-1.2	≤ 0.1 %
Control Requirements	95.5 - 97.5	≤ 99.0	≥ 18.0 %	0.6–1.3	≤ 0.1 %

Rutting performance testing, using the Asphalt Pavement Analyzer (APA), is required during mixture design, test strip production, and mainline production for the HPTO. For acceptance, the HPTO must achieve a maximum of 4.0mm of rutting at 8,000 loading cycles in the APA at testing conditions of 64°C, 100 psi hose pressure, and 100 lb wheel loads.

HPTO Field Implementation – Interstate 287 Southbound

An example of the application and performance of NJDOT's HPTO can be found on Interstate 287 Southbound between mileposts 30.2 and 35.5. The full-depth asphalt pavement in that area carries approximately 44 million ESAL's. In 2008, the pavement distress survey conducted within the NJDOT's Pavement Management program identified milepost section 30.2 to 35.5 SB as having a Structural Distress Index (SDI) of 1.7 (with 0 being worst and 5 being the best condition), triggering a rehabilitation requirement (Figure 2). The primary distress associated was top-down, longitudinal fatigue cracking. It should be noted that the distressed overlay (from a Mill 2 inch/ Pave 2 inch application) had lasted 8 years.

A field forensic program identified that a 1 inch mill could be utilized to limit the amount of RAP produced on the job while eliminating the top-down cracking and crack sealer previously used to seal the exposed cracking. After milling, a 1 inch HPTO overlay was applied to help improve the cracking resistance along this section of I-287. The HPTO was placed after a hot PG64-22 tack coat was applied to ensure sufficient bonding to the milled surface was achieved.

Additional SDI testing and analysis was conducted in 2010 and 2012 and shown in Figure 2. The SDI results, 1.5 and 3.5 years after the HPTO was placed, show that the current HPTO application is performing exceptionally well with an SDI = 3.9 and has not changed since construction.

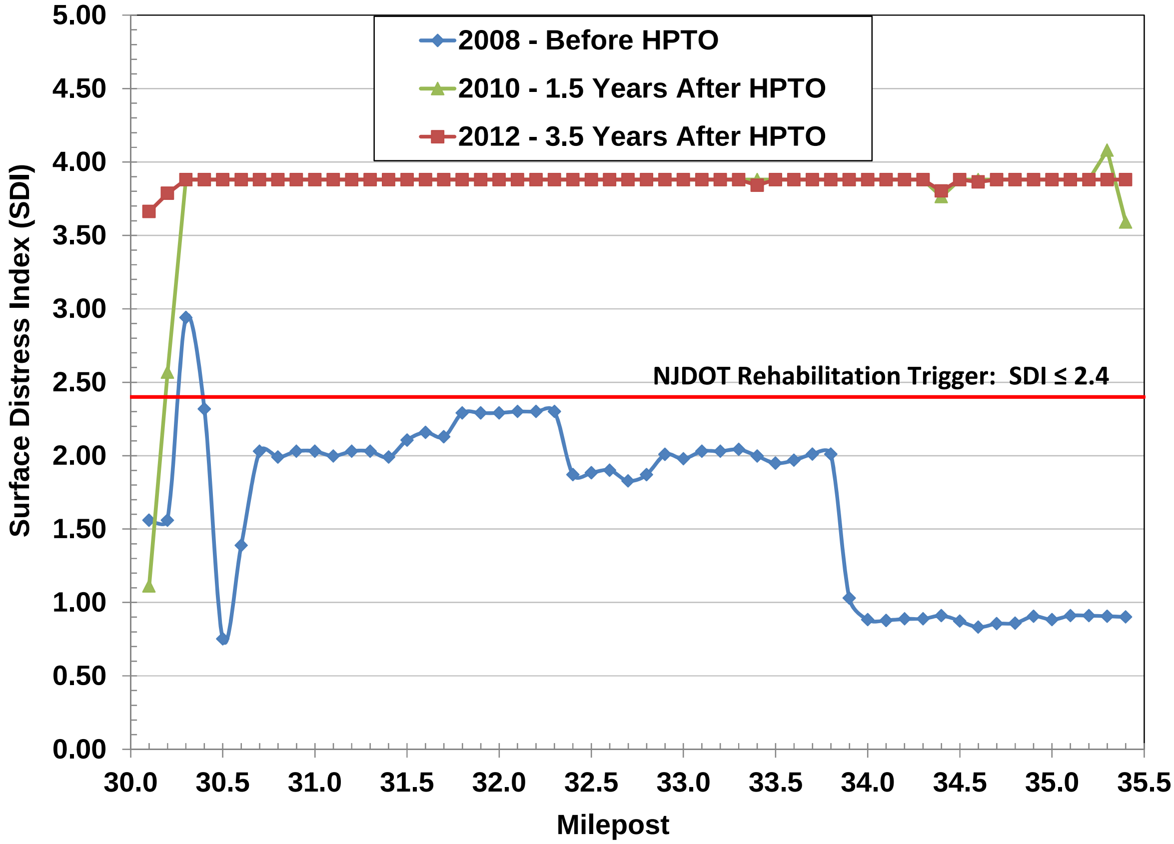


Figure 2 – Structural Distress Index (SDI) for Before and After High Performance Thin Overlay Application on Interstate 287 in New Jersey

Binder Rich Intermediate Course (BRIC)

The main use of NJDOT's Binder Rich Intermediate Course (BRIC) is for placement over existing PCC and at the bottom of an HMA overlay to aid in minimizing reflective cracking of the HMA overlay due to horizontal and vertical movements at the PCC joint/crack due to environmental and traffic loading. The BRIC is a 4.75 nominal maximum aggregate size (NMAS) mixture consisting of the aggregate gradation shown in Table 3 and a minimum asphalt content of 7.0 percent. The grade of asphalt binder is required to be at least a PG70-28. Additional volumetric requirements for design and during production are shown in Table 4. NJDOT's BRIC mixture was adapted from the Crack Attenuating Mixture (CAM) developed and used by the Texas Department of Transportation (TxDOT).

Table 3 – Aggregate Blend Gradation of NJDOT's BRIC

BRIC Grading of Total Aggregate	
Sieve Size	Percent Passing by Mass
3/8"	100
#4	90-100
#8	55-90
#30	20-55
#200	4.0-10.0
Minimum Percent Asphalt by Mass of Total Mix	7.0

Table 4 – Volumetric Requirements for NJDOT's BRIC

Volumetric Requirements for Design and Control of BRIC					
	Required Density (% of Gmm)		Voids in Mineral Aggregate	Dust to Binder Ratio	Draindown AASHTO T 305
	N_{des} (50 Gyr)	N_{max} (100 Gyr)	(VMA)		
Design Requirements	97.5	≤ 99.0	≥ 18.0 %	0.6-1.2	≤ 0.1 %
Control Requirements	96.5 - 98.5	≤ 99.0	≥ 18.0 %	0.6–1.3	≤ 0.1 %

In the past, the NJDOT has never specified the use of a PG70-28 asphalt binder. However, during initial research studies to evaluate its possible use, it was found that the PG70-28 asphalt binder performed better than PG64-22 and PG76-22, two commonly used asphalt binder grades in New Jersey, in both the Flexural Beam Fatigue (AASHTO T321), which simulates vertical deflection at the PCC joint/crack due to traffic loading, and the Overlay Tester (TxDOT TEX 248F), which simulates horizontal movement at the PCC joint/crack due to environmental/temperature cycling. Examples of test results generated during these studies are shown in Figures 3 and 4. The test results also confirm the results reported by Bennert and Maher (2008) regarding better fatigue resistance through the use of asphalt binders with lower low temperature PG grades.

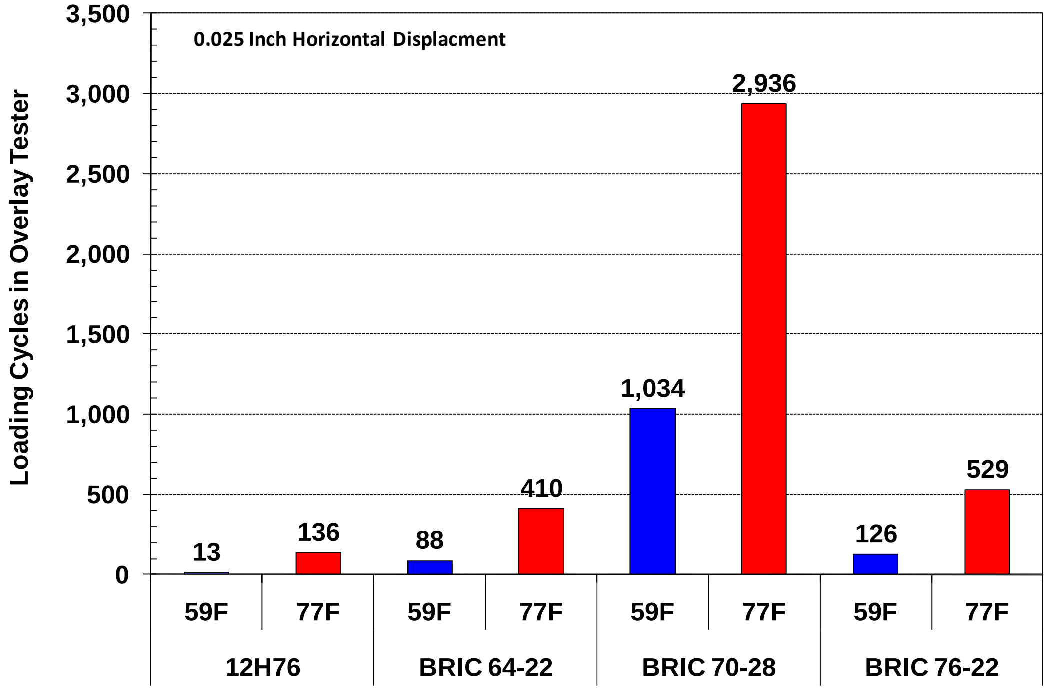


Figure 3 – Overlay Tester Results for NJDOT BRIC Mixture with Different PG Graded Asphalt Binders

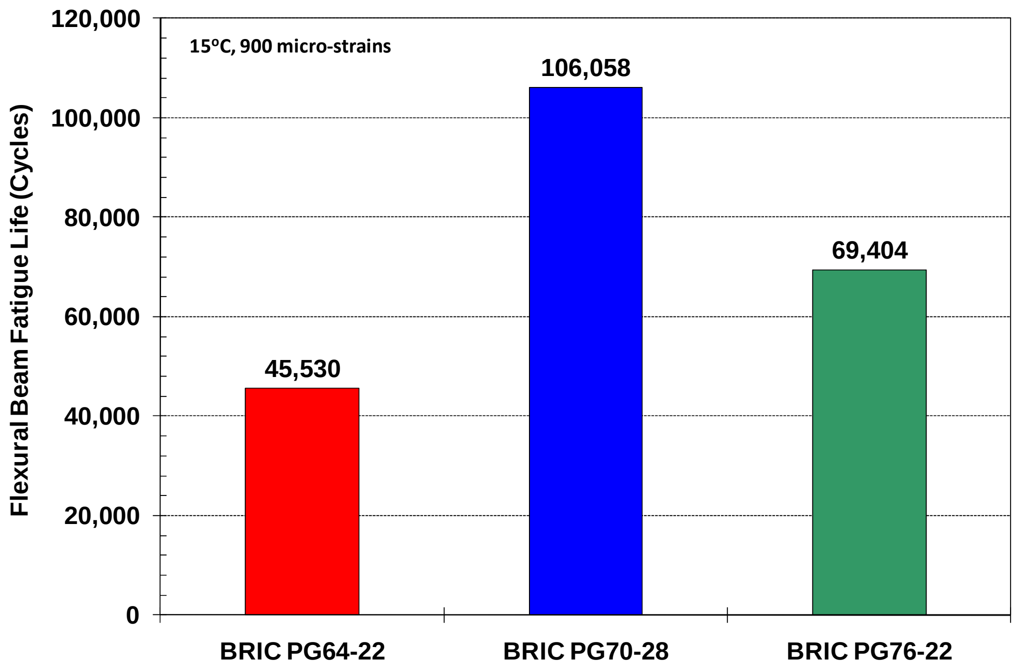


Figure 4 – Flexural Beam Fatigue Results of NJDOT's BRIC Mixture with Different PG Graded Asphalt Binders

To verify the performance of the BRIC, the mixture is required to be evaluated for rutting performance using the Asphalt Pavement Analyzer (AASHTO T340) and cracking resistance using the Overlay Tester (TxDOT TEX 248F). The performance requirements for the mixture design, test strip, and production material are as follows:

- Asphalt Pavement Analyzer (AASHTO T340)
  - 64^{o}C, 100 lb wheel load, 100 psi hose pressure
  - Maximum rut depth of 6.0mm @ 8,000 loading cycles
- Overlay Tester (TxDOT TEX 248F)
  - 25^{o}C test temperature, 0.025 inch horizontal displacement, 10 second loading frequency
  - Minimum of 700 cycles

It should also be noted that the NJDOT is implementing the use of the BRIC mixture with a stone matrix overlay (SMA) being placed over it. This is to ensure that a fatigue resistant asphalt mixture can withstand residual vertical and horizontal movement not "absorbed" by the BRIC mixture. The placement of stiff asphalt mixtures above or below a highly crack resistant mixture often results in a "crack jumping" phenomenon, where a crack forms above, and sometimes below, the more flexible mixture (Figure 5).

Figure 5 – Cracking Above and Below a Highly Fatigue Resistant Mixture

Bridge Deck Waterproofing Surface Course (BDWSC)

The main purpose of NJDOT's Bridge Deck Waterproofing Surface Course (BDWSC) is to provide a rut and fatigue resistant and impermeable bridge deck overlay that can be placed using static, rolling compaction techniques. With an aging infrastructure, the NJDOT does not allow the use of vibratory compaction techniques when placing asphalt overlays on bridge decks. This has resulted in numerous bridge deck overlays compacted to low densities, creating a highly porous bridge deck overlay. Past attempts using an asphalt-treated membrane has not improved the general performance of the overlay, as infiltrated water has usually found a pathway to the bridge deck.

Since 2008, the NJDOT has implemented the use of a BDWSC asphalt mixture to overlay and preserve its bridge decks. The BDWSC is a 9.5 mm nominal maximum aggregate size (NMAS), highly modified asphalt mixture purposely designed for low permeability. Tables 5 and 6 shows the aggregate blend gradation and minimum asphalt content of the BDWSC and design and production volumetrics of the BDWSC, respectively.

Table 5 – Aggregate Blend Gradation of NJDOT's BDWSC

BDWSC Grading of Total Aggregate	
Sieve Size	Percent Passing by Mass
1/2"	100
3/8"	80-100
#4	55-85
#8	32-42
#16	20-30
#30	12-20
#50	7-16
#100	3-12
#200	2.0-6.0
Minimum Percent Asphalt by Mass of Total Mix	7.0

According to the specifications, the mixtures are recommended to be modified using either a polymer-modified asphalt binder or a concentrated thermoplastic polymeric asphalt modifier. The specification does not provide a PG grade recommendation as the mixture performance dictates final acceptance of the BDWSC.

Table 6 – Volumetric Requirements of NJDOT's BDWSC

Volumetric Requirements for Design and Control of BDWSC				
	Required Density (% of Gmm)	Voids in Mineral Aggregate	Dust to Binder Ratio	Draindown AASHTO T 305
	N_{des} (50 Gyr)	(VMA)		
Design Requirements	99	≥ 18.0 %	0.3-0.9	≤ 0.1 %
Control Requirements	98 - 100	≥ 18.0 %	0.3–0.9	≤ 0.1 %

Performance verification testing of the BDWSC consists of rutting potential measured in the Asphalt Pavement Analyzer (AASHTO T340) and fatigue cracking resistance measured in the Flexural Beam Fatigue (AASHTO T321). The performance requirements for the mixture design, test strip, and production material are as follows:

- Asphalt Pavement Analyzer (AASHTO T340)
  - 64^{o}C, 100 lb wheel load, 100 psi hose pressure
  - Maximum rut depth of 3.0mm @ 8,000 loading cycles
- Flexural Beam Fatigue (AASHTO T321)
  - 15^{o}C test temperature, 10 Hz frequency, Sinusoidal waveform, 1,500 micro-strains
  - Minimum of 100,000 cycles

During construction, the BDWSC specification states to ensure that the paving surface is clean and apply the tack coat using the same tack coat material as required for the adjacent roadway paving on the Project. A tack coat application of a hot, PG76-22 with a sand "grit" to help reduce the potential of the BDWSC from sliding and shoving is also specified.

BDWSC Implementation – Rt. 80 ACROW Bridge

In November 2009, the NJDOT constructed and overlaid a temporary overpass/bridge on Rt. 80 (Figure 6). The steel paneled bridge deck was originally overlaid with 2.5 to 3.5 inches of a 12.5mm Superpave mixture with a PG76-22 asphalt binder. The bridge was open to westbound traffic on March 26th, 2010. Within two weeks after the bridge was open to traffic, the NJDOT's Contractor began patching the HMA due to excessive and rapid deterioration from cracking and shoving (Figure 7).

Figure 6 – Steel Deck ACROW Bridge on Rt 80 in New Jersey

Figure 7 – Patching of Rapid Deterioration on Rt. 80 ACROW Bridge in New Jersey

Approximately one and a half months after the asphalt overlay was opened to traffic, it was removed due to excessive failures and repeated patching. It was determined that the BDWSC would be placed on the ACROW bridge deck using a PG76-22 asphalt binder as a tack coat and sand broadcasted onto the tacked steel panels to help mitigate potential sliding. The asphalt supplier had a pre-approved BDWSC mixture design, and therefore, only needed to have material supplied during construction. Test results indicated average Flexural Beam Fatigue and Asphalt Pavement Analyzer to be 163,000 cycles and 1.8 mm of APA rutting, respectively. It should be noted that at the time of this project, the NJDOT was utilizing a Flexural Beam Fatigue strain level of 2,000 micro-strains, instead of the current 1,500 micro-strains.

After construction, the westbound side was immediately opened to traffic. After approximately 7.5 months of traffic and zero distress, the lanes were shifted and the eastbound side of Rt. 80 was open to traffic. An additional 6 months of trafficking resulted in again no distresses on the temporary bridge overlay. After approximately 1.5 years of service, the temporary bridge was removed with the bridge deck mixture looking as it had been originally placed (Figure 8).

Figure 8 – Rt 80 ACROW Bridge with NJDOT's BDWSC Asphalt Overlay

Bottom Rich Base Course (BRBC)

The main purpose of NJDOT's Bottom Rich Base Course (BRBC) is to provide a fatigue resistant base course mixture that would allow for the design and performance of a perpetual pavement. In the classical perpetual pavement design (Figure 9), a flexible fatigue resistant base course mixture is constructed at the bottom of the asphalt layer to provide adequate resistance from bottom-up cracking. The aggregate gradation, shown in Table 7, is consistent with NJDOT's 19 mm Superpave specification. However, the target volumetrics and design gyration level are modified in order to produce a mixture with a higher asphalt content than normally contained in NJDOT's 19mm Superpave mixtures (Table 9). The specification recommends an asphalt binder PG grade of a PG76-28, although similar to the BDWSC, it is the final mixture performance of the BRBC that dictates its acceptance or not. Other asphalt binder grades are allowed if the required mixture performance criteria are achieved.

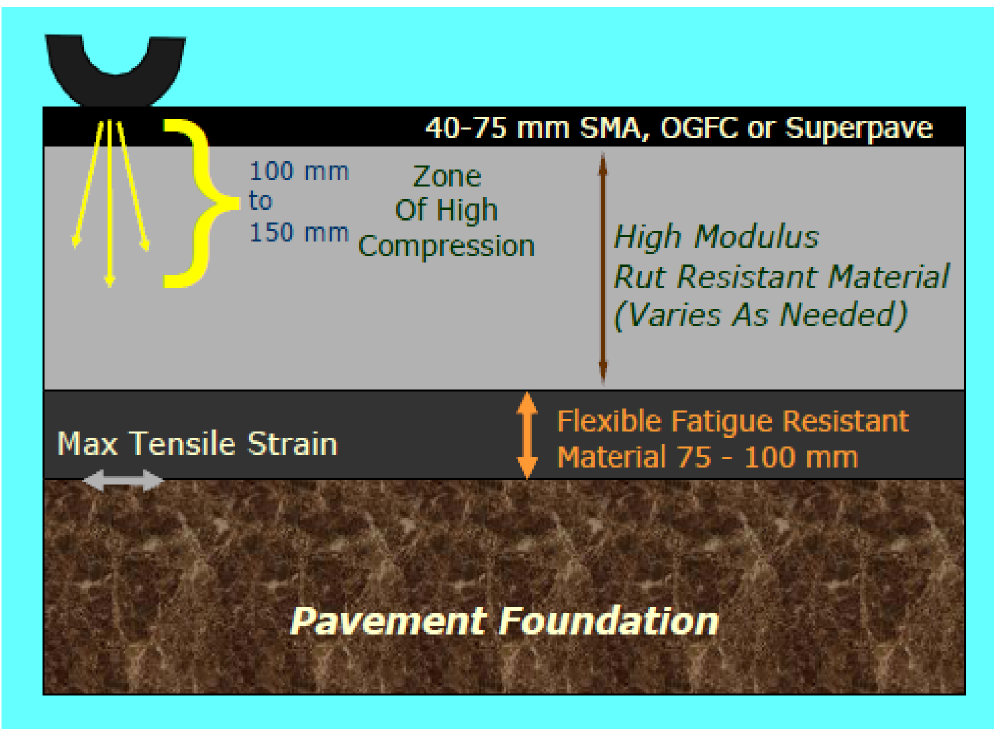


Figure 9 – General Schematic of a Perpetual Asphalt Pavement (After Newcomb et al., 2000)

Table 7 – Aggregate Blend Gradation of NJDOT's BRBC

BRBC Grading of Total Aggregate	
Sieve Size	Percent Passing by Mass
1"	100
3/4"	90-100
1/2"	-90
#8	23-49
#200	2.0-8.0
Minimum Percent Asphalt by Mass of Total Mix	5.0

Table 8 – Volumetric Requirements for NJDOT's BRBC

Volumetric Requirements for Design and Control of BRBC				
	Required Density (% of Gmm)	Voids in Mineral Aggregate	Dust to Binder Ratio	Draindown AASHTO T 305
	N_{des} (50 Gyr)	(VMA)		
Design Requirements	96.5	≥ 13.5 %	0.6-1.2	≤ 0.1 %
Control Requirements	95.5 – 97.5	≥ 13.5 %	0.6–1.2	≤ 0.1 %

The performance tests and criteria for NJDOT's BRBC are as follows:

- Asphalt Pavement Analyzer (AASHTO T340)
    - 64°C, 100 lb wheel load, 100 psi hose pressure
    - Maximum rut depth of 5.0mm @ 8,000 loading cycles
- Flexural Beam Fatigue (AASHTO T321)
    - 15°C test temperature, 10 Hz frequency, Sinusoidal waveform
    - Minimum of 6 test specimens (3 tested at 400 micro-strains and 3 tested at 800 micro-strains, in accordance with NCHRP Project 9-38)
    - Minimum of 100,000,000 cycles @ 100 micro-strains as determined using the method developed under NCHRP Project 9-38.

BRBC Implementation – Interstate 295

The NJDOT first implemented the BRBC on Interstate 295 during the summer of 2010. The pavement consisted of a highly deteriorated PCC pavement that was long overdue for reconstruction. To alleviate future issues with reflective cracking in a composite pavement, the NJDOT decided to rubblize the PCC pavement and apply an asphalt overlay. Initial pavement designs using the 1993 DARWIN pavement design system recommended an asphalt thickness of approximately 12 inches thick. Unfortunately, an HMA layer thickness of 12 inches would require large undercut areas under the twenty-something overpasses along Route I-295 to maintain existing clearance. Engineers at Rutgers University and the NJDOT decided to utilize an elastic layer analysis program (JULEA) to evaluate the maximum tensile strains at the bottom of the HMA layer with varying asphalt layer thicknesses. It was determined through the sensitivity analysis that the HMA layer could be reduced to 8 inches while resulting in a maximum tensile strain at the bottom of the HMA layer of 82 micro-strains (still below the Endurance Limit described earlier). The reduction in thickness would reduce the amount of HMA required for the project by one-third (170,000 tons) and eliminated 64,000 SY of PCCP removal and undercutting. Therefore, the NJDOT decided upon the final pavement structure as such:

- Surface course: 2 inches of a Stone Matrix Asphalt (SMA) with a PG76-22 asphalt binder;
- Intermediate course: 3 inches of a 19 mm dense-graded HMA (Superpave) with a PG76-22 and 25 percent RAP; and
- Base course: 3 inches of NJDOT BRBC.

Three HMA suppliers submitted mixture designs for the BRBC with varying success. One supplier was able to achieve the performance requirement with their first design while another supplier had to make three revisions in order to pass the mixture design performance testing phase. In all cases, it was found that the rutting criteria was easy to meet with the flexural fatigue requirement of 100,000,000 cycles at 100 micro-strains (as determined using the methodology established by NCHRP Project 9-38) being the harder of the two to pass. An example of the graphical output of the NCHRP 9-38 analysis is shown in Figure 10. The graph shows the test results for production data of the BRBC and also the intermediate course, NJDOT 19M76. The comparison of the results in Figure 10 indicates that the BRBC can achieve the 100,000,000 cycles at strain levels twice the magnitude of the NJDOT 19M76. It should be noted that in most pavement structures in New Jersey, the “M” compaction level (75 gyrations) is commonly used for surface, intermediate and base course mixtures.

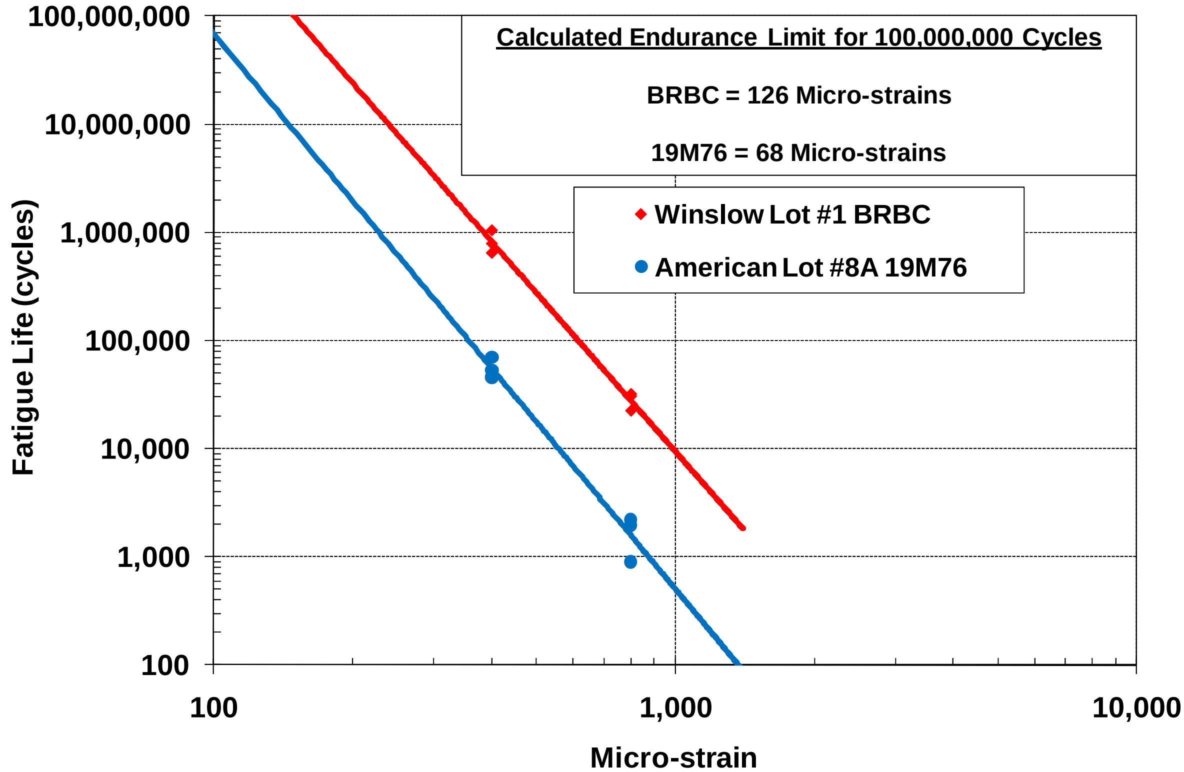


Figure 10 – NCHRP P-38 Endurance Limit Graphical Output

Unlike the other performance-based mixes that the NJDOT uses, the performance testing required for the BRBC takes approximately one week to complete, as opposed to two days. This is due to the time required to complete the beam fatigue testing. Therefore, for production purposes, it was decided only to conduct flexural beam fatigue tests at the 800 micro-strain level for all Lots, except for Lot #1, where the full set of beam fatigue tests would be conducted. The assumption made was that the general slope of the fatigue life line shown in Figure 10 should not change dramatically due to slight changes with the asphalt mixture, only shift up or down based on the magnitude of the fatigue life measured at 400 and 800 micro-strains. Therefore, if it is assumed that the slope will not deviate drastically, it can be concluded that as long as the fatigue life at 800 micro-strains was equal to or greater than that achieved in Lot #1, the 400 micro-strain level would not be required as the final extrapolated endurance limit would always be greater than the Lot #1 material. Only if the fatigue results at 800 micro-strains were lower than those determined from Lot #1 would it require that the 400 micro-strain testing be necessary.

Figure 11 shows the beam fatigue test results at 800 micro-strains for the sampling intervals determined by the NJDOT. The test results indicate that all Lots produced after Lot #1 achieved the required level of fatigue performance. The figure also shows the superior fatigue resistance of the BRBC when compared to the originally proposed intermediate course mixture (19M76). Additionally, it should also be known that while achieving the required level of fatigue performance, the BRBC also maintained the required rutting resistance (Figure 12).

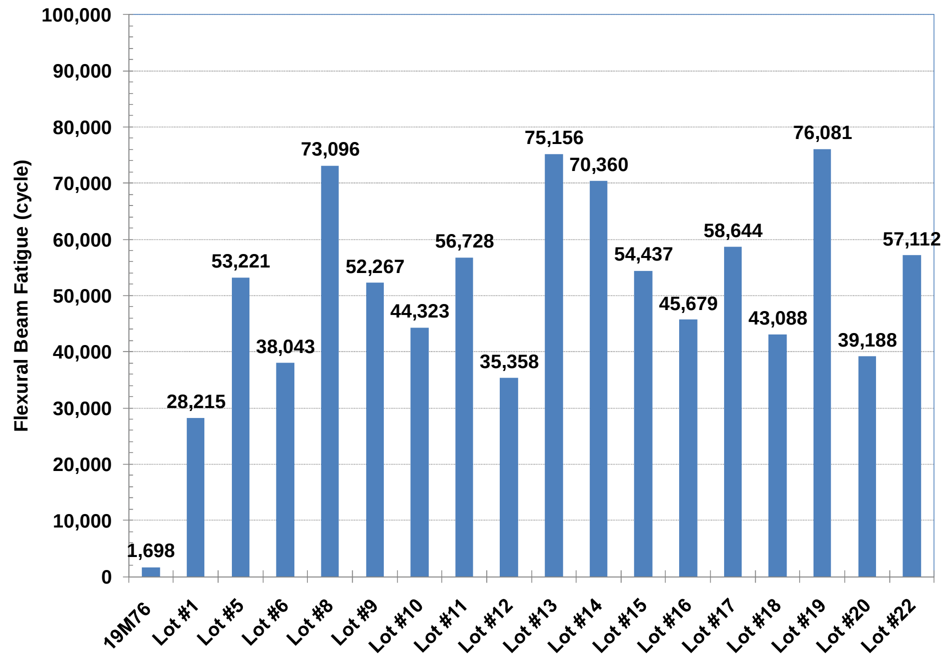


Figure 11 – Flexural Fatigue Performance at 800 Micro-strain for New Jersey I-295 BRBC Mixture

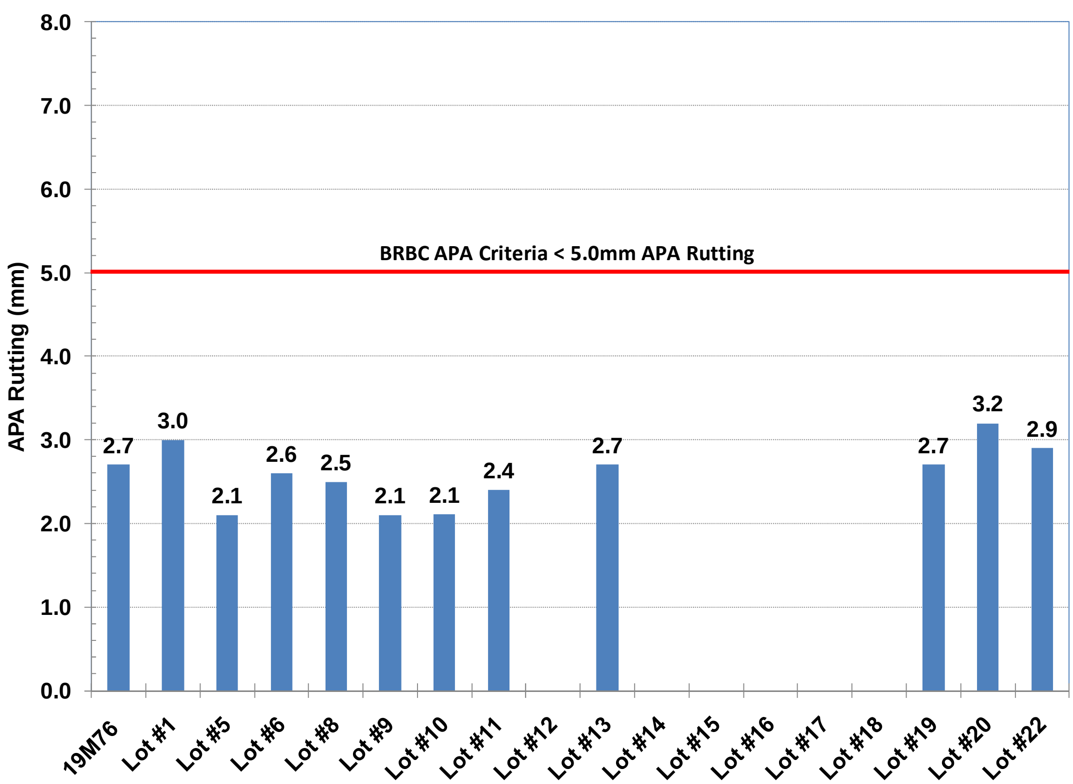


Figure 12 – Asphalt Pavement Analyzer (APA) Performance for New Jersey I-295 BRBC Mixture

High RAP (HRAP)

The benefit of utilizing a performance-based concept is that it puts the responsibility on the asphalt supplier to design and produce an asphalt product that meets the minimum requirements established by the state agency [5]. In doing so, the asphalt supplier is also provided more flexibility on how to produce the asphalt mixture; in this case, high RAP mixes. Warm mix asphalt, rejuvenators, softer asphalt binders, and/or increasing asphalt content would be some of the possible “solutions” an asphalt supplier could utilize to produce higher RAP mixtures.

In 2012, the New Jersey Department of Transportation (NJDOT) implemented a performance-based specification for “high RAP” (HRAP) mixes that requires the final mixture to meet a fatigue cracking and permanent deformation tests. The HRAP specification does not include a maximum RAP content, but is governed by a minimum RAP content; 20 percent minimum in the surface and 30 percent minimum in the intermediate and base layers. The performance testing encompasses passing a minimum number of fatigue cycles in the Overlay Tester (NJDOT B-10) and a maximum rut depth in the Asphalt Pavement Analyzer (AASHTO T340). Table 9 shows the performance requirements associated with the HRAP specification. The criteria established in Table 9 are based on a database of virgin asphalt mixtures. Essentially, the NJDOT HRAP specification says that if you can produce a high RAP mixture that performs as well as a virgin mix, than the NJDOT will accept it.

Table 9 – HRAP Performance Requirements

Test	Requirement			
	Surface Course		Intermediate Course	
	PG 64-22	PG 76-22	PG 64-22	PG 76-22
APA @ 8,000 loading cycles (AASHTO T 340)	< 7 mm	< 4 mm	< 7 mm	< 4 mm
Overlay Tester (NJDOT B-10)	> 150 cycles	> 175 cycles	> 100 cycles	> 125 cycles

As mentioned, the performance requirements are based on virgin mixtures, but the magnitude of the performance is also based on the application/need. For example, a surface course mixture to be placed on a heavy volume interstate would require less than 4.0 mm of rutting in the APA while achieving a minimum of 175 cycles in the Overlay Tester. However, for an intermediate or base mixture to be placed in a lower trafficked pavement, the APA requirement is lowered to less than 7.0 mm while only needing to achieve 100 cycles in the Overlay Tester. Therefore, the need for performance in the pavement dictates the required mixture performance in the laboratory.

Along with the performance testing requirements, slight adjustments were also made to the conventional asphalt mixture design volumetric properties in New Jersey. The volumetric requirements for the HRAP mixtures are shown in Table 10. All requirements are identical to conventional hot mix asphalt except for a 1 percent increase in the Voids in Mineral Aggregate (VMA). The same criteria are used for the Production Control, except the supplier is allowed to have compacted air voids of 95 percent to 98.5 percent of theoretical maximum specific gravity.

Table 10 – Design and Volumetric Requirements for NJDOT's HRAP Mixtures

Compaction Levels	Required Density (% of Theoretical Max. Specific Gravity)		Voids in Mineral Aggregate (VMA)[2], % (minimum)					Voids Filled With Asphalt (VFA) %	Dust-to-Binder Ratio
			Nominal Max. Aggregate Size, mm						
	@N_{des}[1]	@N_{max}	25.0	19.0	12.5	9.5	4.75		
L	96.0	≤ 98.0	13.0	14.0	15.0	16.0	17.0	70 - 85	0.6 - 1.2
M	96.0	≤ 98.0	13.0	14.0	15.0	16.0	17.0	65 - 85	0.6 - 1.2

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. For verification, specimens must be between 95.0 and 97.0 percent of maximum specific gravity at N_{des}.
2. For calculation of VMA, use bulk specific gravity of the combined aggregate including aggregate extracted from the RAP.

The performance acceptance testing for the HRAP specification is conducted at three separate time intervals; 1) Verifying Mixture Design, 2) Plant Produced Test Strip (placed off the project limits), and 3) Plant Produced and Placed on Project. At each time interval, the HRAP mixture must meet the performance criteria shown earlier in Table 9. Otherwise, the mixture has failed and either has to be produced again or a redesign must be conducted.

<u>HRAP Implementation – I295</u>

The New Jersey Department of Transportation (NJDOT) implemented the performance-based HRAP specification on a 2012 project on Interstate 295 Southbound, Milepost 11.26 to 14.48. The project required a NJDOT 9.5M76 (i.e. - 9.5mm nominal maximum aggregate size, 75 design gyrations and a PG76-22 asphalt binder) and a NJDOT 12.5M64. The project required approximately 2,900 tons of the 9.5M76 and 1,800 tons of the 12.5M64 (i.e. – a 12.5 mm nominal maximum aggregate size, 75 design gyrations with a PG64-22 asphalt binder).

In preparation for the mixture design and the production, the asphalt supplier fractionated their RAP into two stockpiles; Coarse RAP (+ No. 4 sieve) and Fine RAP (-No. 4 sieve). The fractionated stockpiles allowed for better control of the RAP and more precise use of the RAP binder. The Fine RAP stockpile had an average asphalt content of 7.0 percent, while the Coarse RAP stockpile had an average asphalt content of 3.7

percent. Performance grading of extracted and recovered RAP binder indicated that the RAP binder had a continuous PG grade of PG83.8-18.8(29.1).

The asphalt mixture supplier submitted five (5) different designs for each mixture before the mixtures were able to meet both the volumetric and performance requirements. In the end, the asphalt mixtures produced for the project are shown in Table 11. The asphalt supplier utilized 25 percent RAP in the surface and 35 percent RAP in the intermediate layer, both 10 percent higher than what is currently allowed by the NJDOT. Also, since the specification does not specify a particular asphalt binder grade, an appropriate asphalt binder was selected that would allow for each of the final mixtures to meet the required rutting and fatigue cracking performance.

Table 11 – Final Mixture Properties for the Surface and Intermediate Course Mixes

Property	I295 Final HRAP Mixtures	
	9.5M76 (Surface Course)	12.5M64 (Intermed. Course)
RAP % Used	25%	35%
JMF Asphalt Content (%)	6.0%	5.8%
% Binder Replacement	27.4%	29.7%
PG Grade of Virgin Binder (Continuous Grade)	PG70-22 (74.6-26.99)	PG64-28 (64.8-28.29)
Fractionated RAP Portion Used	100% Fine RAP Fraction	50% Fine RAP Fraction 50% Coarse RAP Fraction

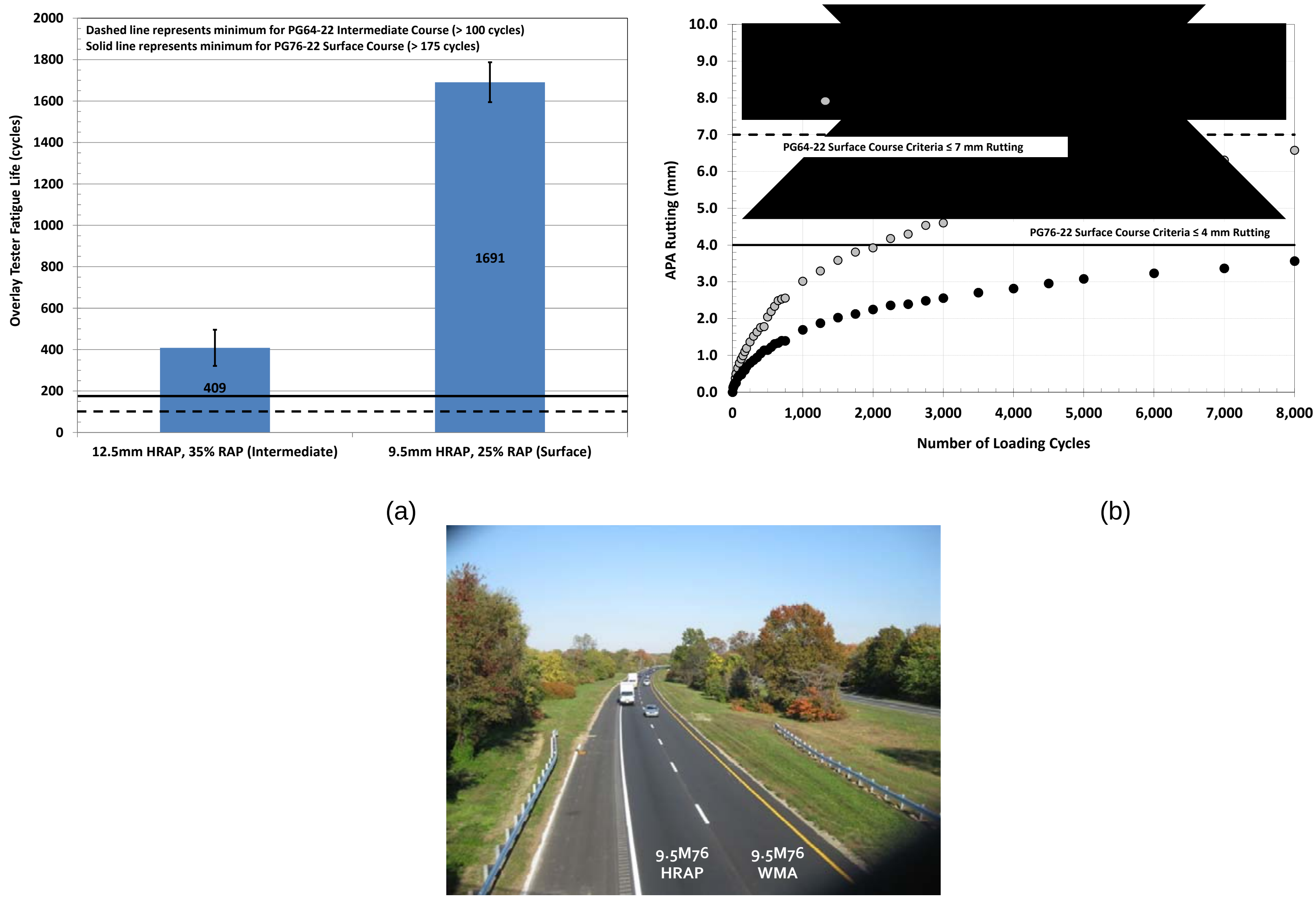
In accordance with the HRAP specification, the loose mix is required to be collected and tested for rutting and fatigue cracking using the Asphalt Pavement Analyzer (AASHTO T340) and Overlay Tester (NJDOT B-10), respectively. Test results for the mixtures are shown in Figure 13. As Figures 13a and b indicate, the HRAP Surface and Intermediate Course mixtures far exceeded the minimum cracking requirements of the NJDOT HRAP specification, while still meeting the maximum allowable rutting in the Asphalt Pavement Analyzer (AASHTO T340). As can be visually seen in Figure 13c, the HRAP lane looks identical to the WMA pavement immediately adjacent to the HRAP lane, where the WMA pavement was produced and placed with only 15 percent RAP.

Construction data regarding compacted, in-place density and roughness (International Roughness Index – IRI) indicated that the HRAP mixtures did not create an issue with respect to achieving density and ride quality requirements. The average results were;

- 9.5M76 HRAP (Surface)
    - Average Core Density = 6.6 percent (1.73 percent Standard Deviation)
    - IRI (inches/mile) = 54.2 in/mile
- 12.5M64 HRAP (Intermediate)
    - Average Core Density = 5.6 percent (1.06 percent Standard Deviation)

The contractor received full bonus for compacted density on two of the five Lots produced on the project, with both of these Lots being the one with 35 percent RAP

(12.5M64). These sections are planned to be evaluated over the next few years to evaluate their long-term performance.



(a) (b)

(c)

Figure 13 – a) Overlay Tester Cracking Results; b) Asphalt Pavement Analyzer Rutting Results; c) Final HRAP Pavement on I295

Summary of Current State of Practice of Performance-Based Asphalt Mixtures in New Jersey

With a deteriorating transportation infrastructure, decreasing transportation funding, and an increasing traffic volumes, the New Jersey Department of Transportation (NJDOT) has begun to implement a performance-based asphalt mixture design system for their asphalt mixtures. These mixtures, comprising of approximately 10 percent of the total asphalt tonnage placed in the state, are selected based on the extreme needs of the pavement structure in question (i.e. – composite pavement, bridge deck overlay, etc.). Each of these performance-based mixtures is required to undergo performance testing during the mixture design, test strip, and project construction phase to ensure the final mixture achieves the desired performance to the specific pavement structure.

Although the NJDOT has only begun to implement the performance-based asphalt mixtures since 2008, monitored field performance of these mixtures has indicated that these materials are all performing exceptionally well, and in some cases (i.e. – ACROW bridge in Rt 80), performing far beyond what conventional NJDOT asphalt mixtures are capable of. While New Jersey's HMA suppliers/contractors were skeptical and somewhat reluctant to begin this new age of performance-based asphalt mixtures, they understand New Jersey's need for these mixtures. As the performance-based mixtures have become more widely accepted and the methodology of design and production becomes more efficient, it is hopeful that New Jersey will be able to implement some form of performance-based specification for all asphalt mixtures.

DEVELOPMENT OF INITIAL DATABASE OF PERFORMANCE TEST RESULTS

The first important step in developing any Performance-Based specification is the development of the performance criteria. The performance criteria should be based on native aggregates, binder grades, and mixture designs utilized in the respective state. Field observation must also be tied into the criteria development. The use of Pavement Management System (PMS) data provides a means of comparing field and laboratory results. However, comparisons can also be as simple as general field observations and acknowledging when the field section has or has not performed well.

Proposed Test Procedure and Criteria Selection - Rutting

Based on New Jersey's experience with rutting and permanent deformation testing in the laboratory, the Asphalt Pavement Analyzer (AASHTO T340) is proposed to be selected as the test procedure for evaluating rutting potential in a performance-based design procedure for asphalt mixtures. With the APA being selected for the other performance-based mixtures described earlier, it makes sense to select the test procedure to be consistent with the other performance-based test procedures.

The Asphalt Pavement Analyzer (APA) is conducted in accordance with AASHTO T340, *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 are used in the testing. Testing is continued until 8,000 loading cycles and APA rutting deformation is recorded at each cycle. The APA device used for testing at Rutgers University is shown in Figures 14a and b.

(a) (b)

Figure 14 – a) Asphalt Pavement Analyzer (APA) at Rutgers University; b) Inside the Asphalt Pavement Analyzer Device

Prior to testing, each sample is heated for 6 hours (+/- 15 minutes) at the testing temperature to ensure temperature equilibrium within the test specimen was achieved. For New Jersey conditions, a test temperature of 64^{o}C is selected. Testing starts with 25 cycles used as a seating load to eliminate any sample movement during testing. After the 25 seating cycles completed, the data acquisition begins sampling test information until a final 8,000 loading cycles is reached.

Comparing field observations with typical performance in the Asphalt Pavement Analyzer (APA), it is proposed that the following APA criteria be selected for the APA rutting criteria;

- Less than 4.0 mm (< 4.0 mm) for the following asphalt mixtures;
    - PG76-22 asphalt mixtures
    - SMA mixtures
    - OGFC mixtures
- Less than 7.0 mm (< 7.0 mm) for the following asphalt mixtures;
    - PG64-22 asphalt mixtures

The APA rutting criteria shown above is based on generally reported field performance. The assumption being that since rutting has not been reported, except for some isolated intersection areas, the rutting criteria noted represents good rutting resistance. The criteria above also matches that of the NJDOT HRAP specification discussed earlier. Utilizing identical performance values again provides consistency within the NJDOT specifications for dense-graded asphalt mixtures.

Proposed Test Procedure and Criteria Selection – Fatigue Cracking

For the selection of a fatigue cracking test, there are a number of requirements that one needs to consider before selection can occur.

- Does the test procedure correlate to field performance?
- Is the test procedure easy to analyze (Pass/Fail criteria is the easiest to implement)?
- Can the test procedure be utilized on both field cores and laboratory produced test specimens to help in QC and forensic testing applications?

Based on the above qualities, as well as having a history and good and poor performing asphalt mixtures in New Jersey, the Overlay Tester is proposed to be utilized for the fatigue cracking performance test. And again, similar to the APA for rutting, a few of the other performance-based mixtures already utilize the Overlay Tester, so its selection again provides consistency across the NJDOT specifications.

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 15 shows a picture of the Overlay Tester used in this study. Sample preparation and test parameters used in this study followed that of NJDOT B-10 testing specifications. These include:

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

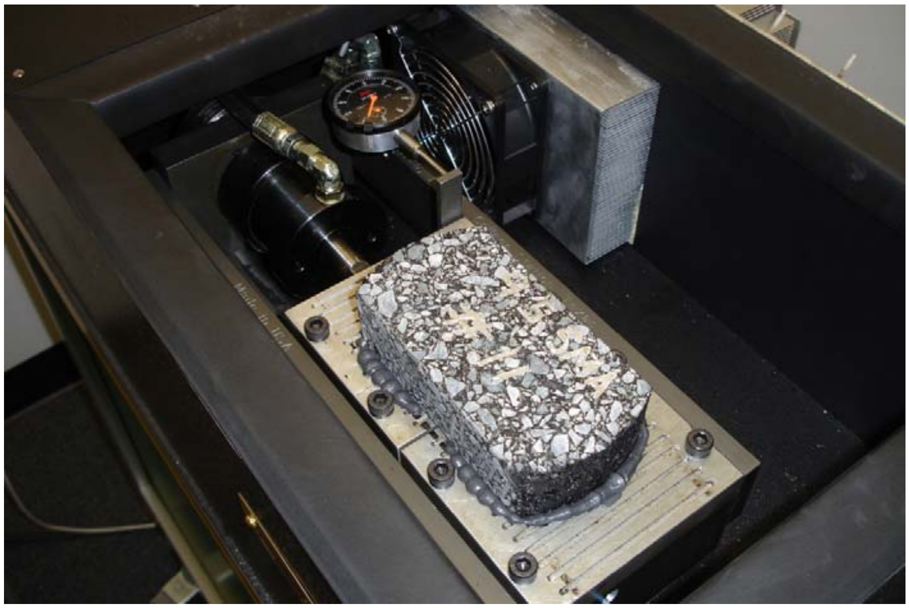


Figure 15 – Picture of the Overlay Tester (Chamber Door Open)

At the time of the initiation of this research project, a limited amount of data was available to help establish a performance criteria. Therefore, the first year of this project entailed collecting loose mix from a number of paving projects and conducting the Overlay Tester to assess the fatigue performance results. The loose mix was brought back to the laboratory and reheated at compaction temperatures that were estimated to be $15^{o}F$ lower than the measured production/discharge temperatures. Unfortunately, due to the frequency of producing certain asphalt mixtures, some mixture types were not represented in the same magnitude as the others. In total, after the year of testing, the database consisted of the following:

- Dense-graded mixes: 25 projects
- SMA mixes: 6 projects
- OGFC mixes: 5 projects

Histogram frequency charts were generated for each of the asphalt mixtures evaluated and are shown as Figures 16 through 18. The test results indicate the following:

- Dense-graded mixes: Average = 91 cycles; Max = 207 cycles; Min = 18 cycles
- SMA mixes: Average = 729 cycles; Max = 1352 cycles; Min = 210 cycles
- OGFC mixes: Average = 1039 cycles; Max = 1924 cycles; Min = 183 cycles

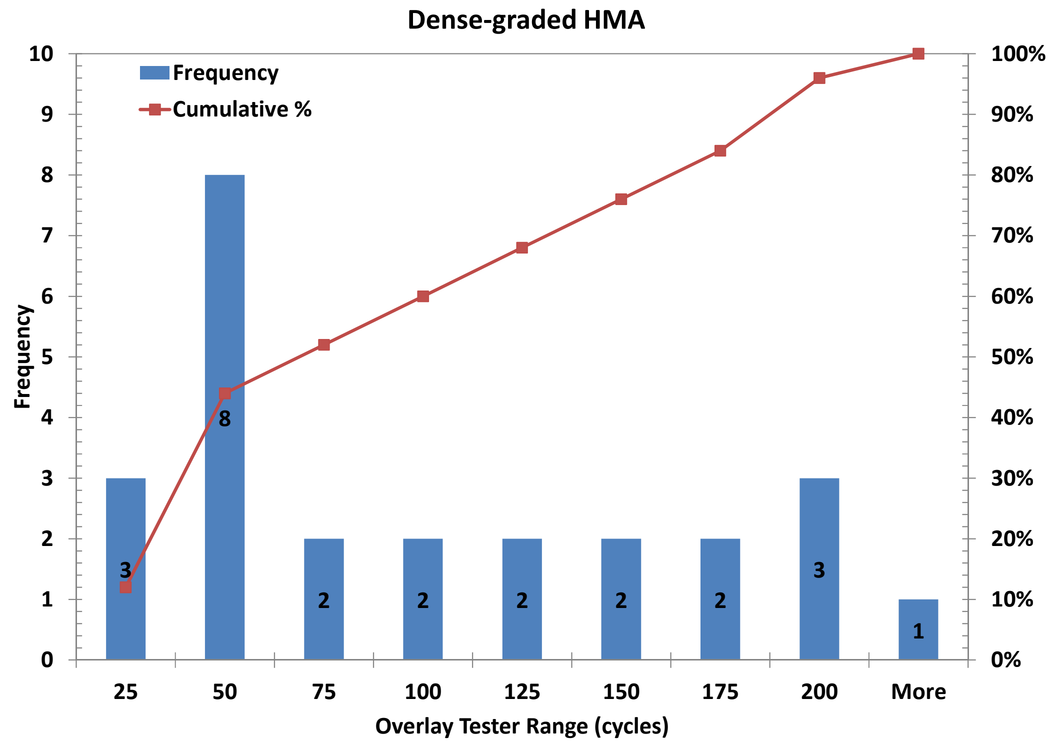


Figure 16 – Frequency Distribution Chart for Overlay Tester Fatigue Life for Dense-Graded Mixes

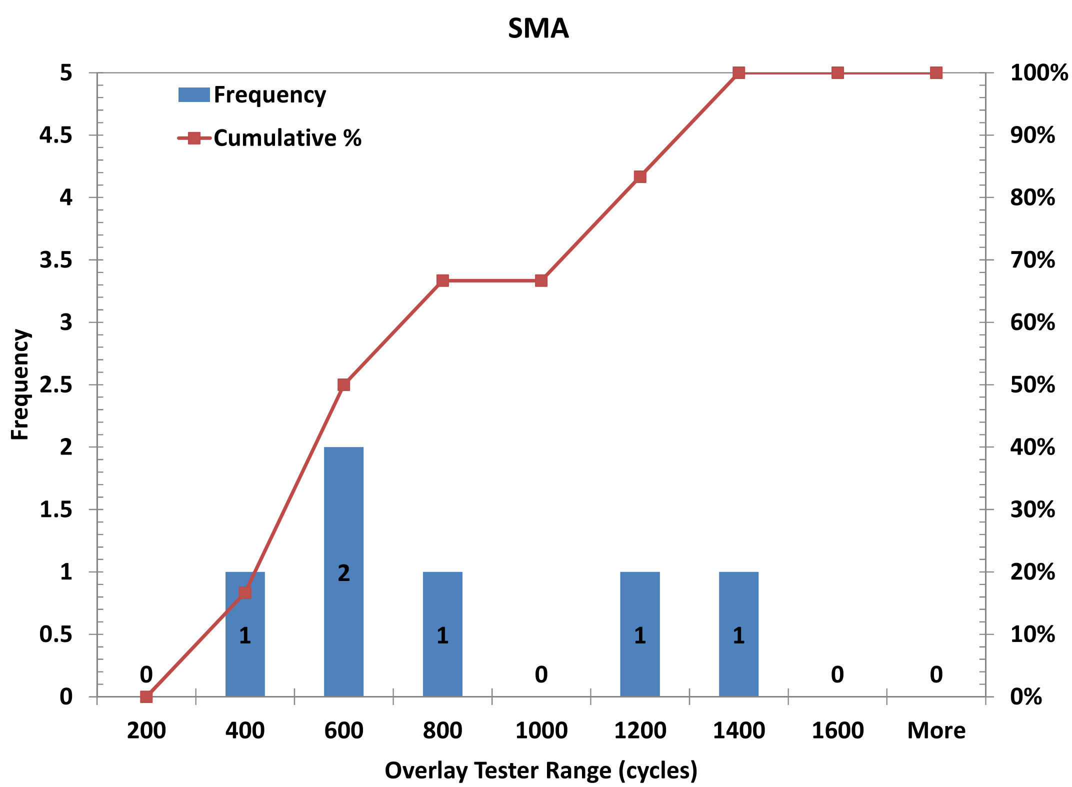


Figure 17 – Frequency Distribution Chart for Overlay Tester Fatigue Life for SMA Mixes

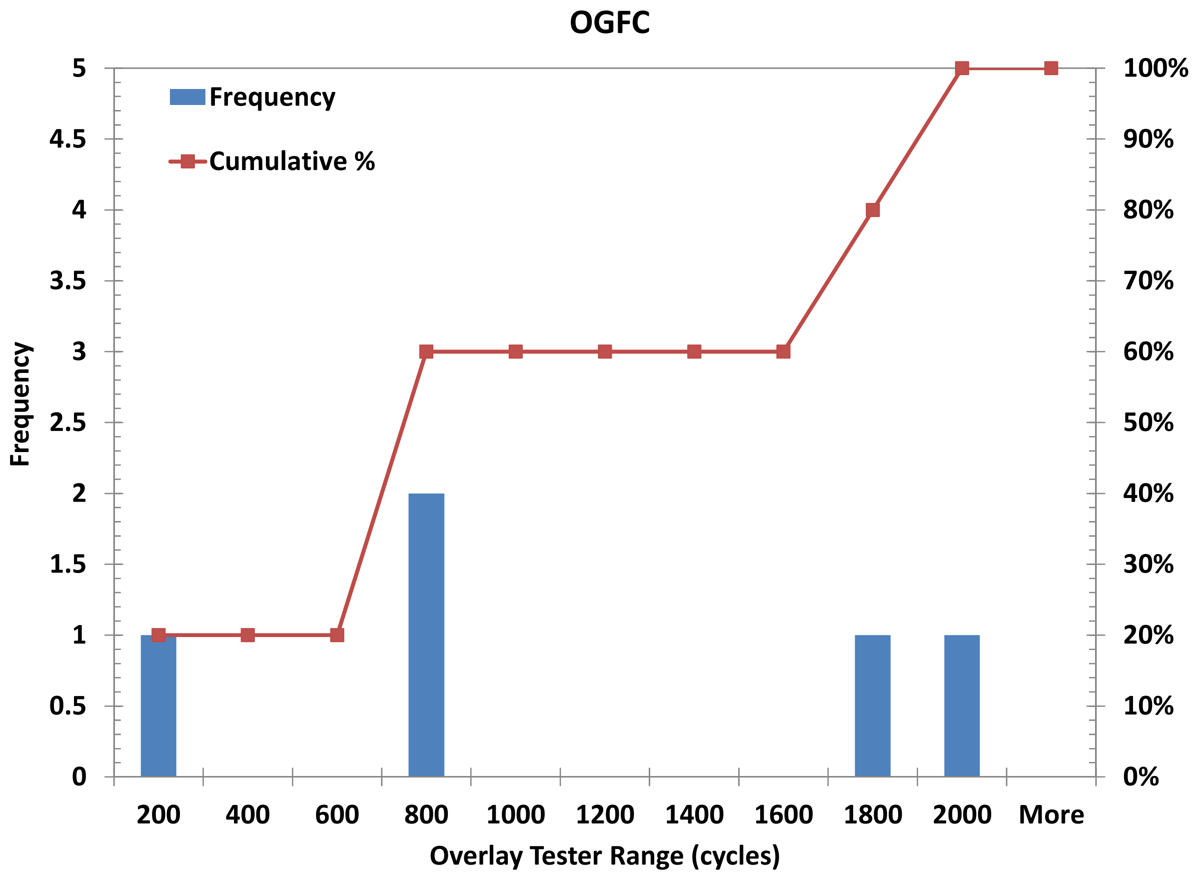


Figure 18 – Frequency Distribution Chart for Overlay Tester Fatigue Life for OGFC Mixes

Along with the laboratory testing of New Jersey specific asphalt mixtures, the Rutgers University also contacted the Texas Transportation Institute (TTI) to collect information regarding to TTI's performance-based mixture designs for the Texas Department of Transportation (TxDOT). TxDOT is currently adopting the Hamburg Wheel Tracking device for rutting performance and the Overlay Tester for fatigue cracking performance of asphalt mixtures. Both devices were selected due to the long history of data developed in the state of Texas on a variety of asphalt mixtures and their respective field performance. Based on conversations with Tom Scullion, Senior Research Engineer at the TTI, the following Overlay Tester fatigue life criteria are being implemented by TxDOT:

- Dense-grade mixtures:
    - Surface Courses > 150 cycles
    - Intermediate Courses > 100 cycles
    - Base Courses > 50 cycles
- SMA mixtures > 200 cycles
- OGFC mixtures > 300 cycles

At the June 2013 Quarterly Meeting with the NJDOT Research Bureau, Eileen Sheehy from the NJDT Materials Bureau and Robert Blight of the Pavement Design and

Management Bureau, the New Jersey data, along with the TxDOT criteria were presented. After review, the following Overlay Tester fatigue life criteria were selected as follows:

- Dense-graded mixtures:
  - Surface Course
    - PG76-22 mixtures > 175 cycles
    - PG64-22 mixtures > 150 cycles
  - Intermediate Course
    - PG76-22 mixtures > 125 cycles
    - PG64-22 mixtures > 100 cycles
  - Base Course > 50 cycles
- SMA mixtures > 300 cycles
- OGFC mixtures > 300 cycles

New Jersey "Conventional" Mixture Performance-Based Criteria

Laboratory testing of New Jersey asphalt mixtures and personal communication with state agencies utilizing performance-based mixture design methods provided guidance for selecting New Jersey's Performance-Based criteria for "conventional" asphalt mixtures. The final selection of the criteria is shown as Table 12. The criteria for the dense-graded asphalt mixtures was held to that currently being used for the NJDOT HRAP specification to maintain consistency across the NJDOT specifications. Meanwhile, the SMA and OGFC performance requirements were selected by the NJDOT based on the typical mixture performance and their respective field performance to date. As the NJDOT continues to utilize SMA and OGFC mixtures in the future, modifications to the current proposed criteria may need to be modified.

Table 12 – Proposed Performance-Based Criteria for NJDOT's "Conventional" Asphalt Mixtures

Test Procedure	Dense-graded Hot Mix Asphalt (HMA)						Open-graded Friction Course (OGFC) & Stone Matrix Asphalt (SMA)
	Surface Course		Intermediate Course		Base Course		
	PG64-22	PG76-22	PG64-22	PG76-22	PG64-22	PG76-22	
APA @ 8,000 Cycles & 64^{o}C (AASHTO T340)	< 7.0 mm	< 4.0 mm	< 7.0 mm	< 4.0 mm	< 7.0 mm	< 4.0 mm	< 4.0 mm
Overlay Tester (NJDOT B-10)	> 150 Cycles	> 175 Cycles	> 100 Cycles	> 125 Cycles	> 50 Cycles		> 300 Cycles

BALANCED MIXTURE DESIGN

The concept of balancing rutting (stability) and fatigue (durability) has been around for a while and can date back to some of the original Marshall and Hveem mixture design work, as depicted in the figure below (Figure 19. When utilizing a balanced mixture design method for asphalt mixtures, the optimum asphalt content is not a function of the compacted air voids at a predetermined compaction level, but a function of optimizing the asphalt content to achieve the best rutting and fatigue performance. Obviously, from a construction standpoint, there needs to be some consideration towards the workability and in-place density levels of the final pavement. However, when utilizing the balanced design concept with established laboratory rutting and fatigue performance criteria, the final asphalt mixture should construct and perform as expected.

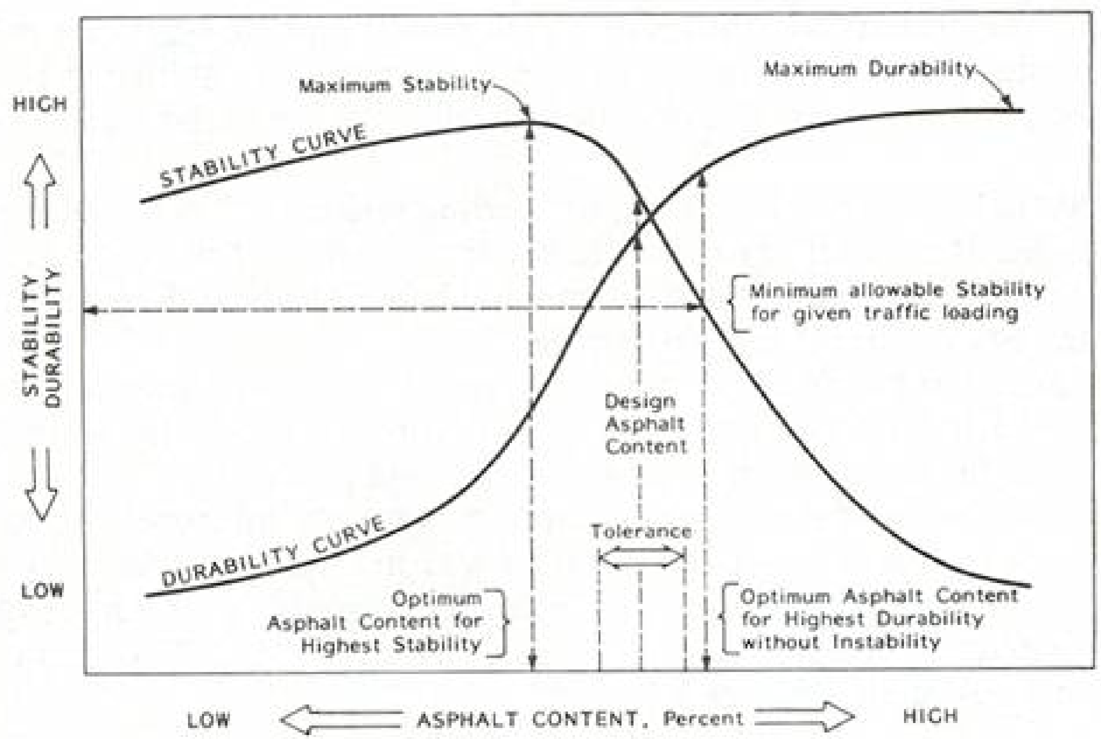


Figure 19 – Importance of Balancing Rutting (Stability) and Fatigue (Durability)

The original intention of the Superpave Mix Design procedure was to incorporate performance testing to verify the rutting, fatigue cracking and thermal cracking performance of the asphalt mixtures. However, due to the complexity and cost of the test procedures ultimately recommended, the performance testing was deemed to be impractical and was never implemented on a national level. However, it was soon realized that the volumetric properties alone can not be relied on to determine if there will be issues with performance.

In 2006, the Texas Transportation Institute (TTI) re-introduced the concept of a Balanced Mixture Design in their report, *Integrated Asphalt (Overlay) Mixture Design, Balancing Rutting and Cracking Requirements* (Zhou et al., 2006). The researchers utilized the Wet Hamburg Wheel Tracking device to index rutting resistance, while indexing the fatigue cracking performance of asphalt mixtures with the Overlay Tester. Over the past few years, the Texas Department of Transportation (TxDOT) and TTI had generated a significant database of laboratory test performance that had been correlated to observed field performance with these laboratory tests and believed they could be utilized to verify asphalt mixtures during design. Their general methodology was as such (Figure 20).

1. Select materials (aggregate and asphalt binder);
2. Develop aggregate gradation, mix with asphalt binder at different binder contents, and compact to gyration level (based on traffic);
3. Determine volumetric properties at each asphalt content;
4. Compact Hamburg and Overlay Tester specimens at each asphalt content to a known air void range (typically 6 to 7 percent air voids to represent typical initial in-place air voids)
5. Utilize performance criteria to verify whether mixture met the rutting and fatigue requirements.
6. Adjust final asphalt content to meet the balanced performance.

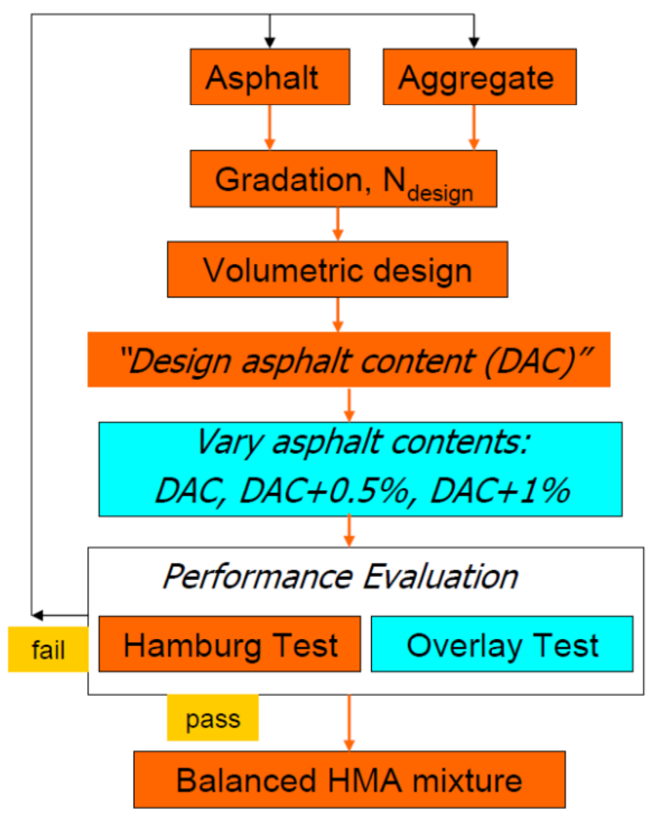


Figure 20 – TxDOT Balanced Mixture Design Concept (After Rand, 2009)

An example of what the typical Balanced Mix Design output looks like. As shown in Figure 21, the yellow area marks the range in asphalt contents that optimizes the rutting and fatigue cracking properties of the mixture evaluated. In this case, it was found that a range in asphalt content of 5.3 to 5.8 percent optimizes the mixtures performance. It should be noted that this is based on the set criteria TxDOT has established using the Wet Hamburg Wheel Tracking device and the Overlay Tester.

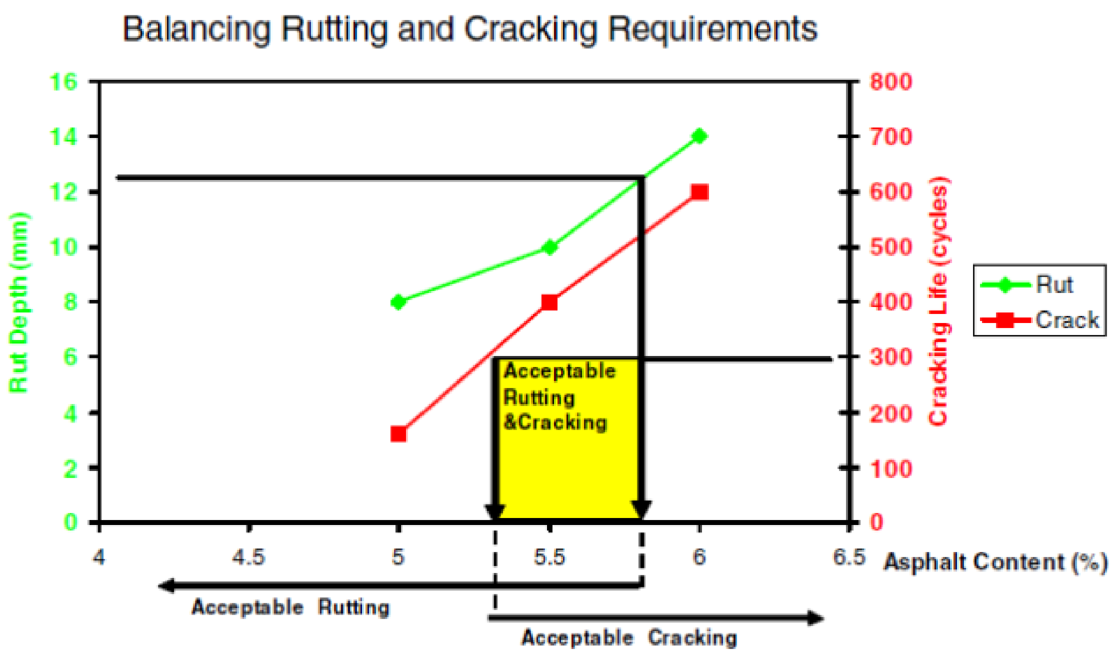


Figure 21 – Balanced Mix Design Results (Adapted from Zhou et al., 2007)

New Jersey's Balanced Mix Design Approach

In the TxDOT Balanced Mix Design procedure, TxDOT prefers to utilize the Wet Hamburg Wheel Tracking device to assess rutting potential. However, as shown earlier, the NJDOT has had a long history of using the Asphalt Pavement Analyzer (APA) as a test to evaluate rutting potential, and therefore, it is utilized in the NJDOT's Balanced Mix Design. The Overlay Tester was also selected for the NJDOT Balanced Design due to its ability to trend with field performance, especially when recycled asphalt pavement (RAP) is used.

The selection of the performance criteria for the NJDOT Balanced Mix Design is based on the work discussed earlier. For the fatigue resistance, a minimum of 175 cycles is required in the Overlay Tester, regardless of the asphalt binder performance grade. Meanwhile, the APA rutting is dependent on the traffic level the asphalt mixture is intended to be placed on. For lower volume road (< 10 million ESAL's) where a PG64-22 asphalt binder would be specified in New Jersey, the maximum APA rutting allowed is 7.0 mm. For moderate to higher volume roads (> 10 million ESAL's) where a PG76-22 asphalt binder would be specified in New Jersey, the maximum APA rutting allowed is 4.0 mm.

For the New Jersey Balanced Mix Design approach, the flowchart shown in Figure 3 was followed, except that the APA test was substituted for the Hamburg Test. Also, the mixture designs utilized were based on current NJDOT approved mix designs. This was done to compare how the current mixtures compared to the Balanced Mixture Design approach.

Another small caveat with respect to the mixture design is that in this study, RAP was utilized during design (15 percent). Current NJDOT mix design specifications do not require the asphalt suppliers to incorporate RAP during the mixture design process. However, to produce HMA with RAP, the asphalt supplier must adjust stockpile and asphalt content percentages due to differences in the RAP.

Materials/Mixture Design

NJDOT approved job mix formulas were procured for 8 different asphalt mixtures commonly used in New Jersey. These include;

- Trap Rock Industries (Kingston)
    - 9.5M64 and 9.5M76
    - 12.5M64 and 12.5M76
- Tilcon Mt. Hope
    - 9.5M64 and 9.5M76
    - 12.5M64 and 12.5M76

Tables 13 and 14 show the aggregate gradations and optimum asphalt content for the NJDOT approved mixtures.

Table 13 – NJDOT Approved 9.5 mm Nominal Maximum Aggregate Size Mixtures

Property	**% Passing**	
Sieve Size	Tilcon - Mt Hope	Trap Rock
1/2" (12.5 mm)	100	100
3/8" (9.5 mm)	94.4	96.0
No. 4 (4.75 mm)	60.3	64.8
No. 8 (2.36 mm)	36.2	48.6
No. 16 (1.18 mm)	26.9	35.3
No. 30 (0.600 mm)	19.6	24.7
No. 50 (0.425 mm)	12.6	16.5
No. 100 (0.15 mm)	6.9	9.5
No. 200 (0.075 mm)	4.1	5.6
Asphalt Content (%)	5.0	5.4
Design VMA (%)	15.0	17.1
Effective AC by Vol (%)	11.0	13.1

Table 14 – NJDOT Approved 12.5 mm Nominal Maximum Aggregate Size Mixtures

Property	**% Passing**	
Sieve Size	Tilcon - Mt Hope	Trap Rock
3/4" (19 mm)	100	100.0
1/2" (12.5 mm)	99.2	94.0
3/8" (9.5 mm)	91.4	86.2
No. 4 (4.75 mm)	57.2	51.5
No. 8 (2.36 mm)	33.9	37.5
No. 16 (1.18 mm)	25.1	24.8
No. 30 (0.600 mm)	18.3	17.9
No. 50 (0.425 mm)	11.8	11.2
No. 100 (0.15 mm)	6.5	7.2
No. 200 (0.075 mm)	3.9	4.8
Asphalt Content (%)	5.1	4.6
Design VMA (%)	14.6	15.3
Effective AC by Vol (%)	10.6	11.3

As noted in the TxDOT Balanced Mix Design Flowchart, each of the mixtures evaluated in this study were evaluated under volumetric criteria and performance testing. First, each of the mixtures were compacted to a design gyration level of 75 gyrations and the resultant compacted air voids were calculated at asphalt contents of 4.5, 5, 5.5, and 6.0 percent asphalt. At the identical asphalt contents, the APA and Overlay Tester performance specimens were also produced. However, all performance samples were compacted to within an air void range of 5.5 to 6.5 percent air voids, which represented typical in-situ pavement densities.

It should again be noted that the mixtures in this study included 15 percent RAP for both the volumetric and performance evaluations. Although current procedures in New Jersey are to design the asphalt mixtures without RAP and then adjust the virgin asphalt content and aggregate gradation later for the added RAP, the addition of the RAP during the mixture designs in this study was upon the request of the NJDOT.

<u>Tilcon, Mt Hope Mixtures</u>

9.5 mm Nominal Maximum Aggregate Size (NMAS) Mixtures

The compacted air voids and resultant mixture performance for the 9.5 mm nominal maximum aggregate size mixtures are shown in Figures 22 and 23 for the 9.5M64 and Figures 24 and 25 for the 9.5M76 mixtures, respectively. For the 9.5M64 mixture, it shows that the addition of RAP in the mixture requires an additional 0.5 percent virgin asphalt to achieve the design air void target of 4 percent. This resulted in an optimum asphalt content of 5.5 percent. Meanwhile, the Balanced Design shows that the optimal range in asphalt content to achieve both good rutting and fatigue cracking properties is 5.2 to 5.9 percent asphalt content.

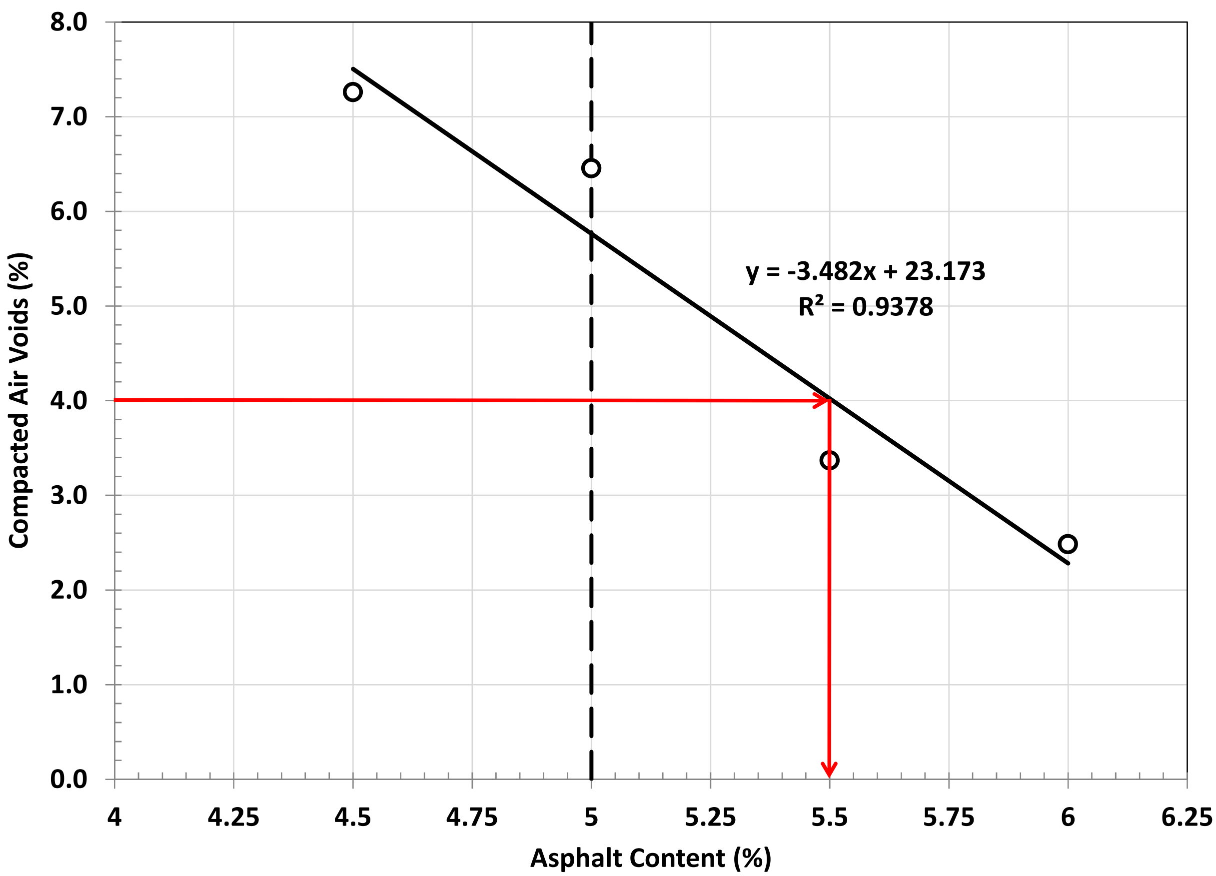


Figure 22 – Tilcon Mt. Hope 9.5M64 Compacted Air Voids vs Asphalt Content

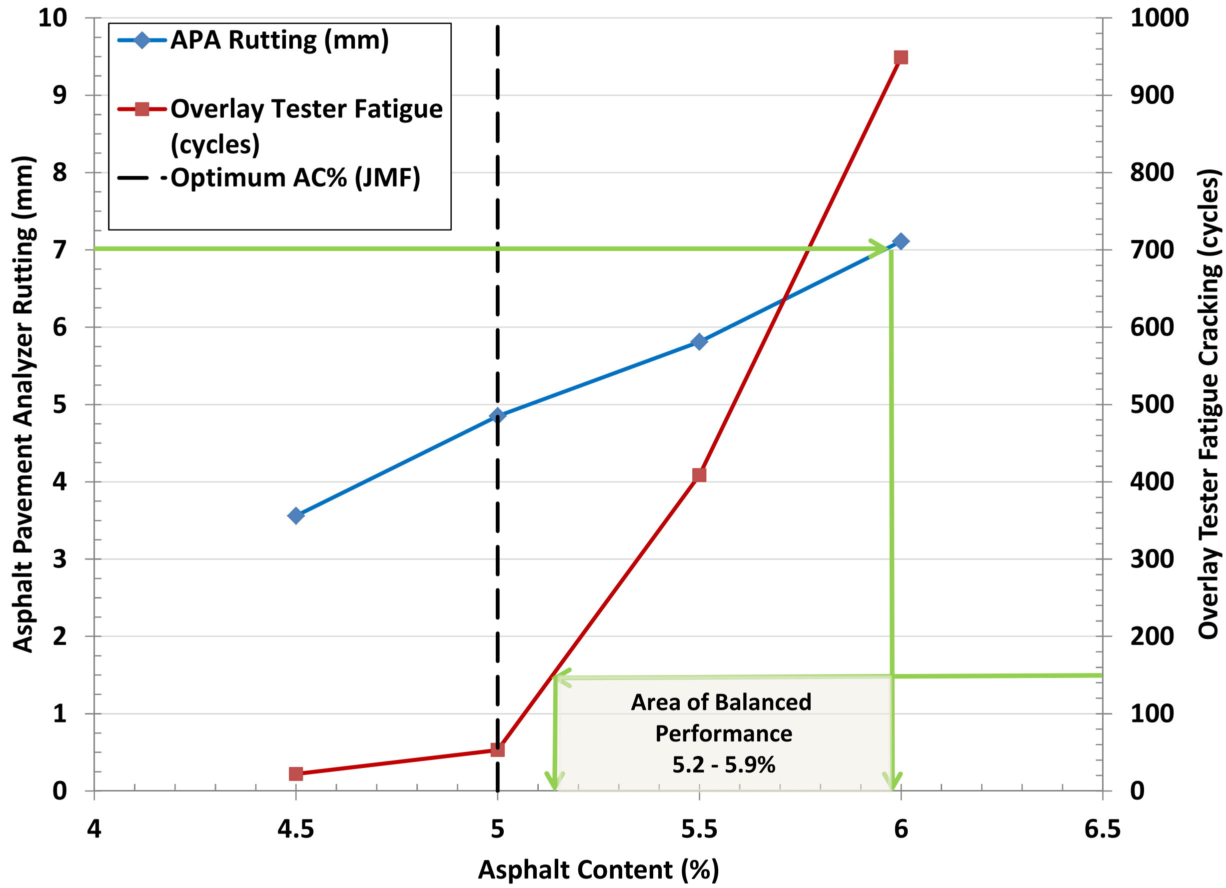


Figure 23 – Tilcon Mt. Hope 9.5M64 Balanced Performance vs Asphalt Content

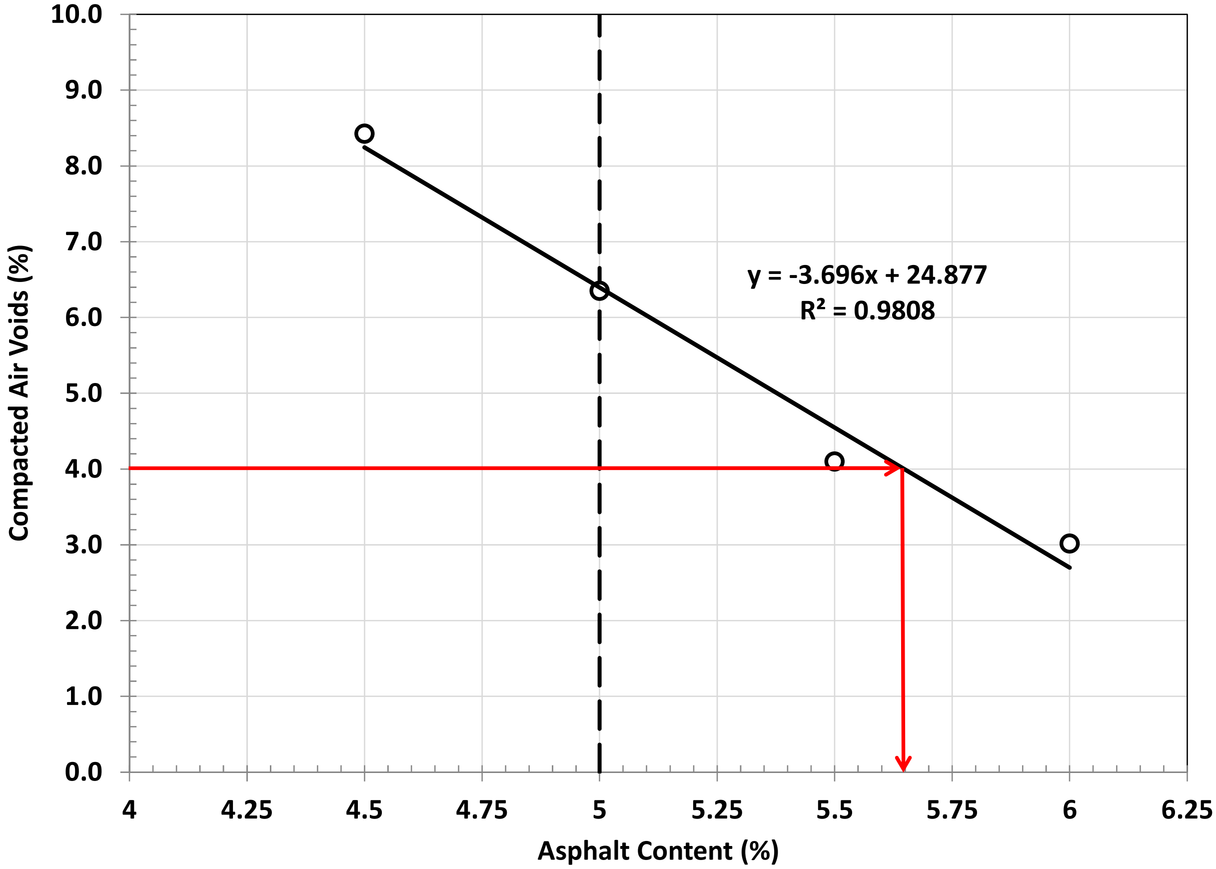


Figure 24 - Tilcon Mt. Hope 9.5M76 Compacted Air Voids vs Asphalt Content

Figures 24 and 25 present the 9.5M76 results for the Tilcon, Mt. Hope mixture. Similar to the 9.5M64 mixture, the addition of 15 percent RAP increases the optimum asphalt to approximately 5.6 percent. Meanwhile, the Balance Design results indicate that an asphalt content range of approximately 5.1 to 5.6 percent would result in an asphalt mixture with good rutting and fatigue resistance.

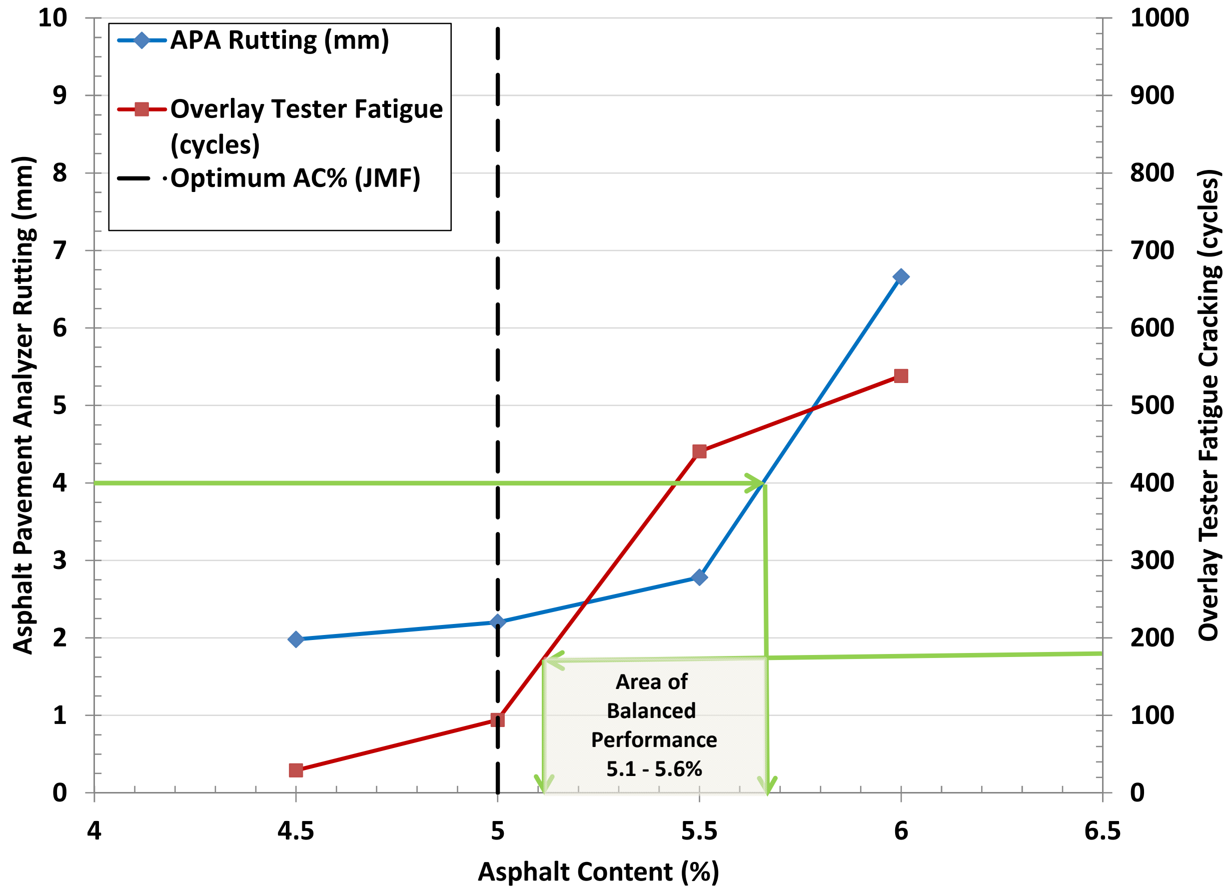


Figure 25 – Tilcon Mt. Hope 9.5M76 Balanced Performance vs Asphalt Content

12.5 mm Nominal Maximum Aggregate Size (NMAS) Mixtures

The Tilcon Mt. Hope 12.5M64 asphalt mixture is shown in Figures 26 and 27. Similar to the 9.5 mm Tilcon Mt. Hope mixtures, the addition of 15 percent RAP during mixture design results in the need for additional virgin asphalt content. The optimum asphalt content determined in this study was approximately 5.5 percent, while the approved JMF showed 5.1 percent asphalt content. Meanwhile, the Balanced Design performance results indicated that an optimal asphalt content to achieve both good rutting and fatigue performance would be between 5.2 and 5.8 percent.

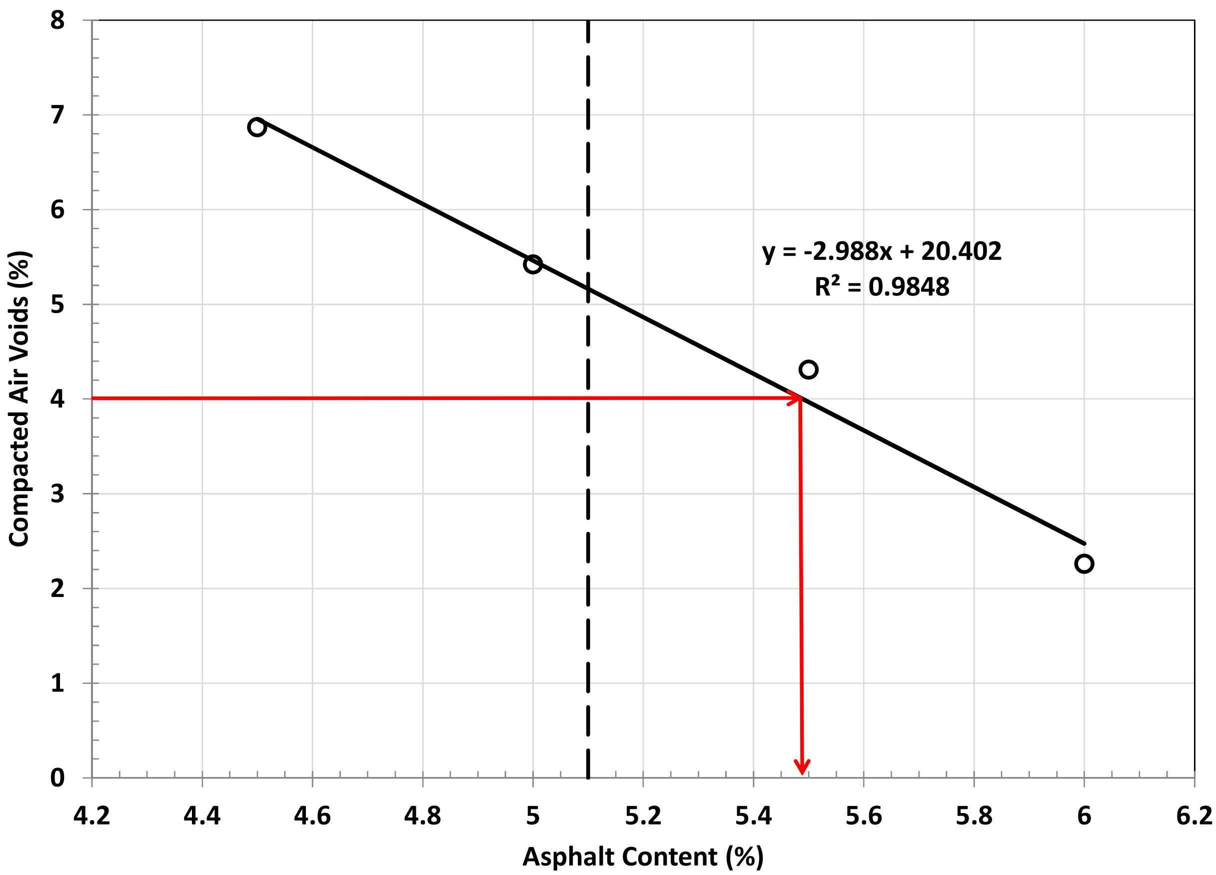


Figure 26 – Tilcon Mt. Hope 12.5M64 Compacted Air Voids vs Asphalt Content

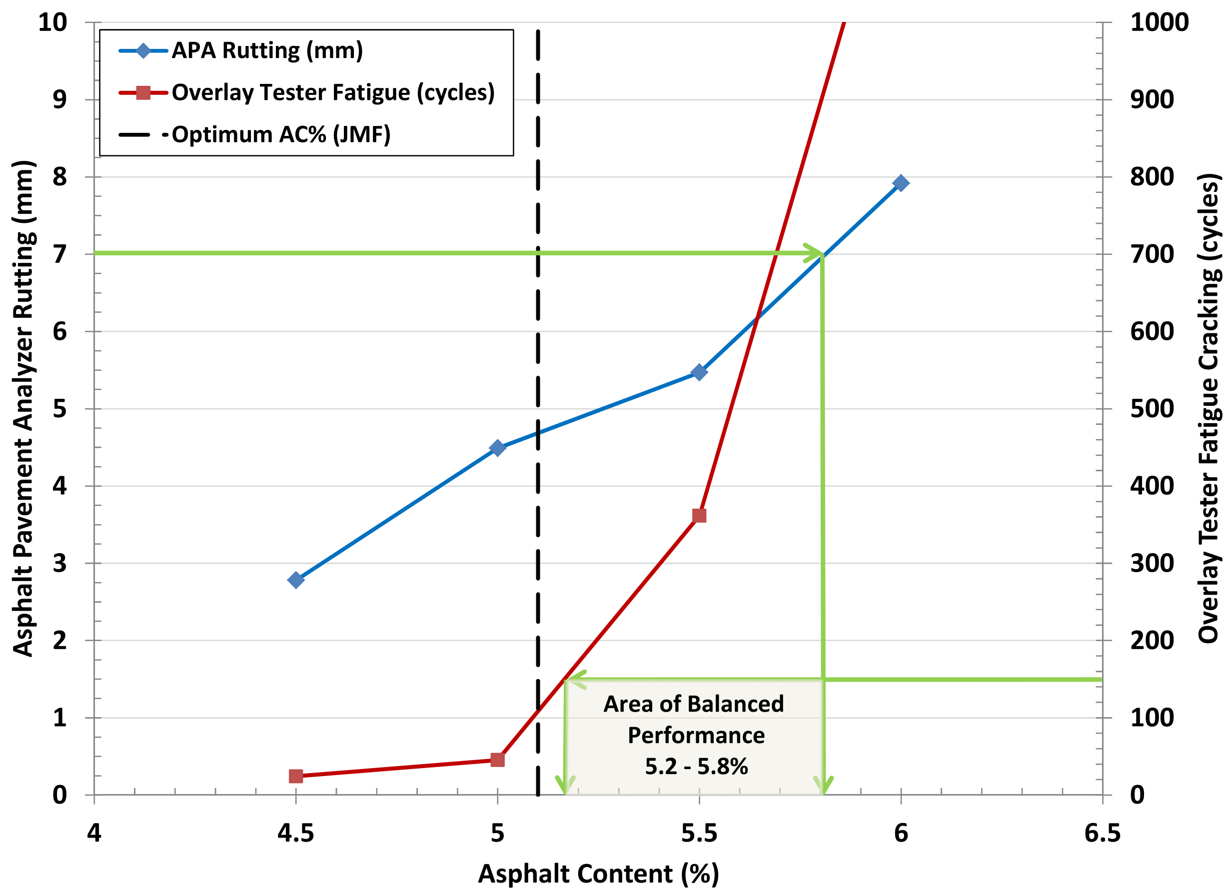


Figure 27 - Tilcon Mt. Hope 12.5M64 Balanced Performance vs Asphalt Content

The volumetric results for the 12.5M76 Tilcon Mt. Hope mixture are shown in Figure 28. Similar to all of the volumetric results shown earlier, the addition of the 15 percent RAP resulted in an increase in the optimum asphalt content of the mixture. For the 12.5M76, the resultant optimum asphalt content was 5.8 percent.

The Balanced Design performance results are shown in Figure 29. For the Tilcon Mt. Hope 12.5M76 mixture, a range of asphalt contents between approximately 5.5 percent and an upper limit that could not be established, should result in good rutting and fatigue performance. For practical purposes, a 0.5 percent asphalt content increase is used to provide a representative range in asphalt contents. Therefore, since the upper asphalt content limit was not able to be determined in the laboratory, the assumed range for a Balanced Design is 5.5 – 6.0 percent asphalt content.

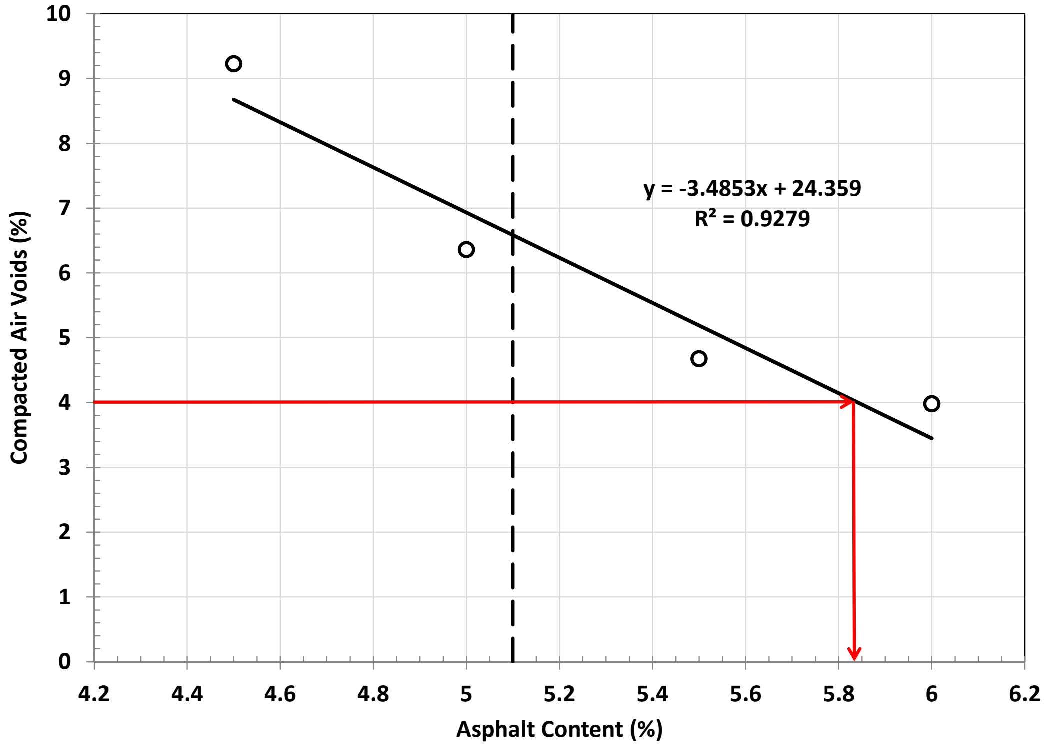


Figure 28 – Tilcon Mt. Hope 12.5M76 Compacted Air Voids vs Asphalt Content

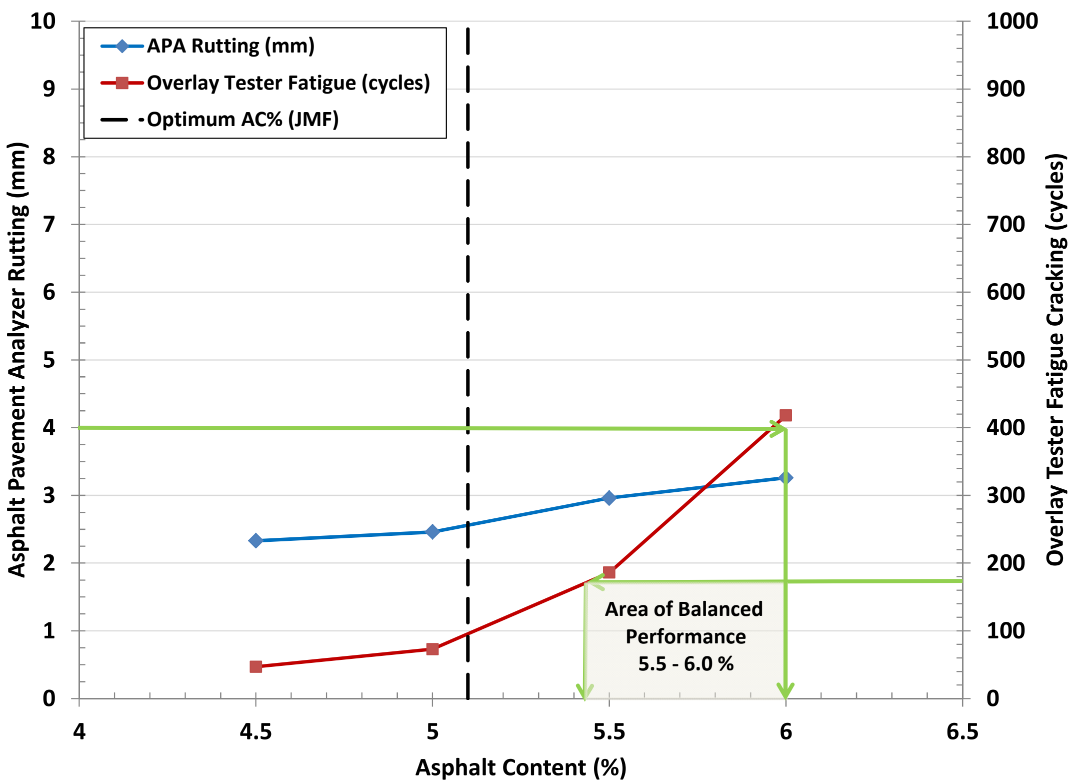


Figure 29 - Tilcon Mt. Hope 12.5M76 Balanced Performance vs Asphalt Content

In summary, an increase in asphalt content seems to be required for the Tilcon, Mt. Hope asphalt mixtures when introducing 15 percent RAP during the mixture design phase. As shown with the volumetric (air void) analysis, an average increase of 0.5 percent asphalt content is required to achieve the target 4 percent air voids. Meanwhile, the Balanced Design approach resulted in very similar "recommended" asphalt contents when compared to the volumetric analysis. Since a range of asphalt contents are a result of the Balanced Design method, the middle of the range is shown as the "optimum" asphalt content (Table 15).

Table 15 – Summary of Determined Asphalt Contents for Tilcon Mt. Hope Asphalt Mixtures

Mix Type	Optimum AC% (%)		Balanced Mix Design
	Virgin	15% RAP	Optimum AC% (%)
9.5M64	5.0	5.5	5.2 - 5.9 (5.6)
9.5M76	5.0	5.7	5.1 - 5.6 (5.4)
12.5M64	5.1	5.5	5.2 - 5.8 (5.5)
12.5M76	5.1	5.8	5.5 - 6.0 (5.8)

<u>Trap Rock Industries (TRI) Mixtures</u>

Similar to the Tilcon Mt. Hope mixtures, 4 different asphalt mixtures were produced using aggregates and RAP materials from Trap Rock Industries (TRI). For the volumetric analysis, three specimens were mixed for each asphalt content and compacted to a design gyration level of 75 gyrations. For each asphalt content, the average compacted air voids were determined. The Balanced Design specimens were produced in a similar manner and were evaluated for their respective rutting resistance and fatigue resistance using the Asphalt Pavement Analyzer and Overlay Tester.

9.5 mm Nominal Maximum Aggregate Size (NMAS) Mixtures

The results for the 9.5 mm NMAS Trap Rock Industries mixtures are shown below. Figures 30 and 31 present the test results for the 9.5M64 asphalt mixture. The volumetric test results show that even with the addition of 15 percent RAP during the mixture design phase resulted in very similar asphalt content to the virgin mixture design (5.5 percent vs 5.4 percent, respectively). The Balanced Design results for the 9.5M64 asphalt mixture indicates that a range of asphalt content of 5.2 to 5.9 percent would result in a good performing asphalt mixture that is balanced for both rutting and fatigue cracking resistance.

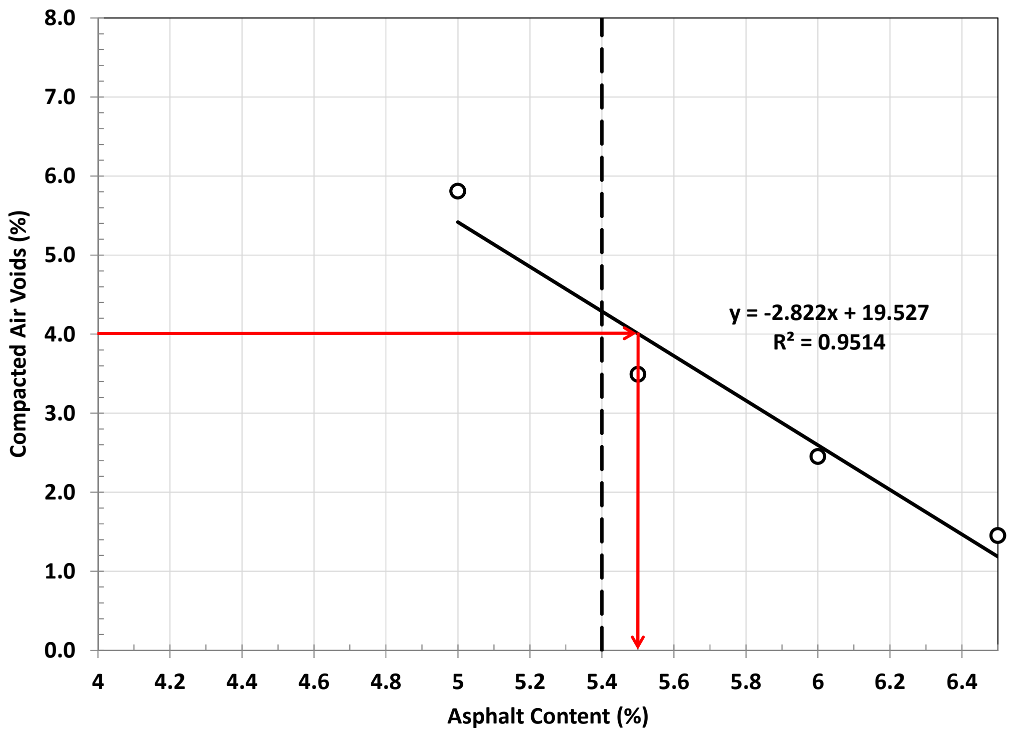


Figure 30 – Trap Rock Industries 9.5M64 Compacted Air Voids vs Asphalt Content

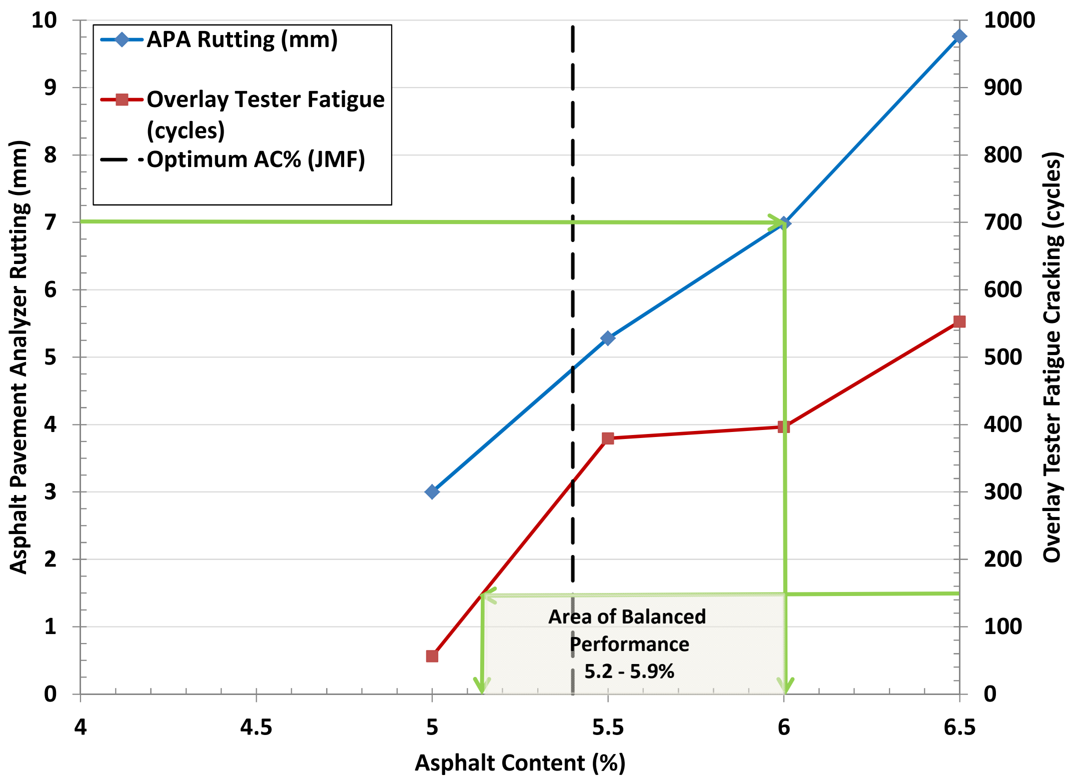


Figure 31 – Trap Rock Industries 9.5M64 Balanced Performance vs Asphalt Content

The volumetric and Balanced Design results for the Trap Rock Industries 9.5M76 mixture is shown in Figures 32 and 33. Similar to the 9.5M64 mixture, the volumetric asphalt content compares closely to the virgin mixture design, although the volumetric results generated in this study with 15 percent RAP does indicate that the asphalt mixture could use additional virgin asphalt binder. Meanwhile, the Balanced Design results for the 9.5M76 Trap Rock Industries indicates that an optimal range of asphalt content to achieve a rutting and fatigue resistance mixture should be approximately 5.8 to 6.0 percent. This is approximately 0.5 percent higher than what the currently approved asphalt mixture contains.

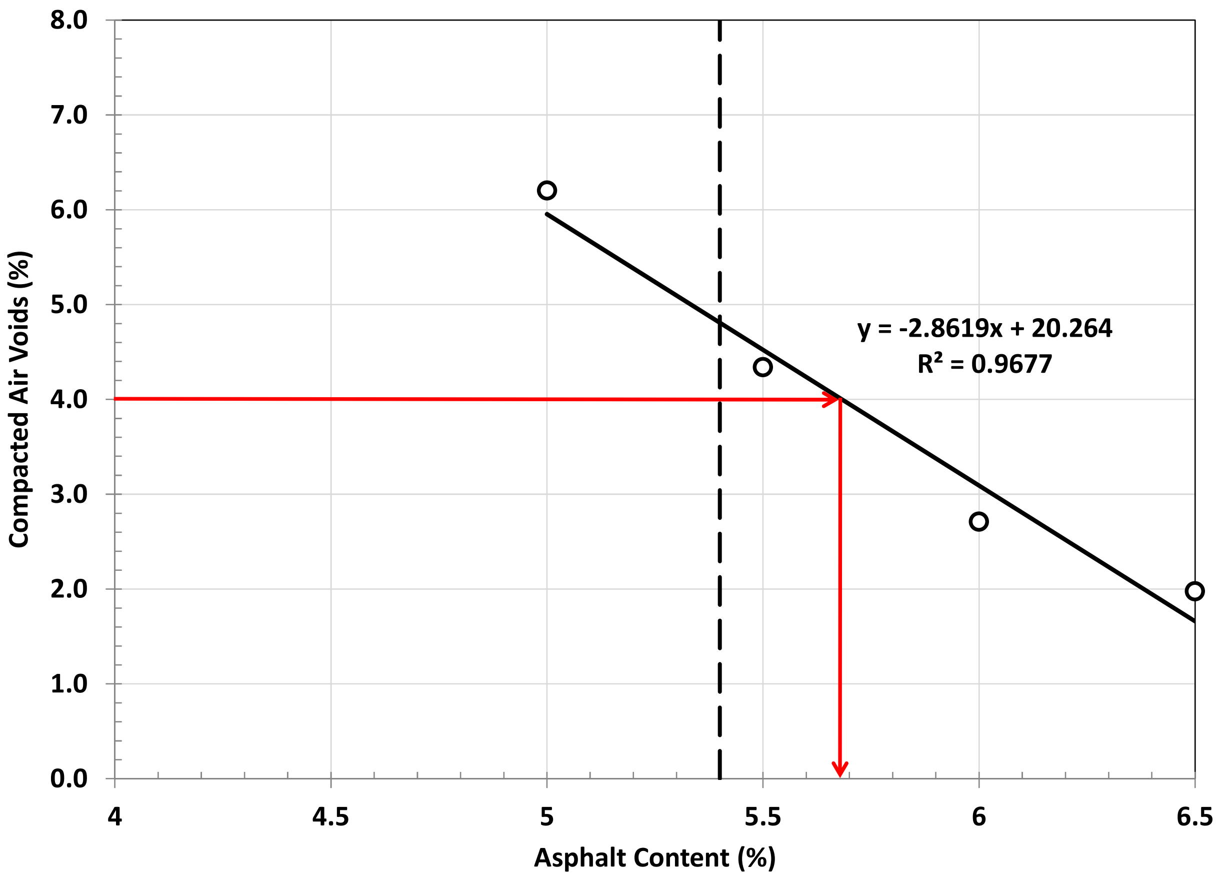


Figure 32 - Trap Rock Industries 9.5M76 Compacted Air Voids vs Asphalt Content

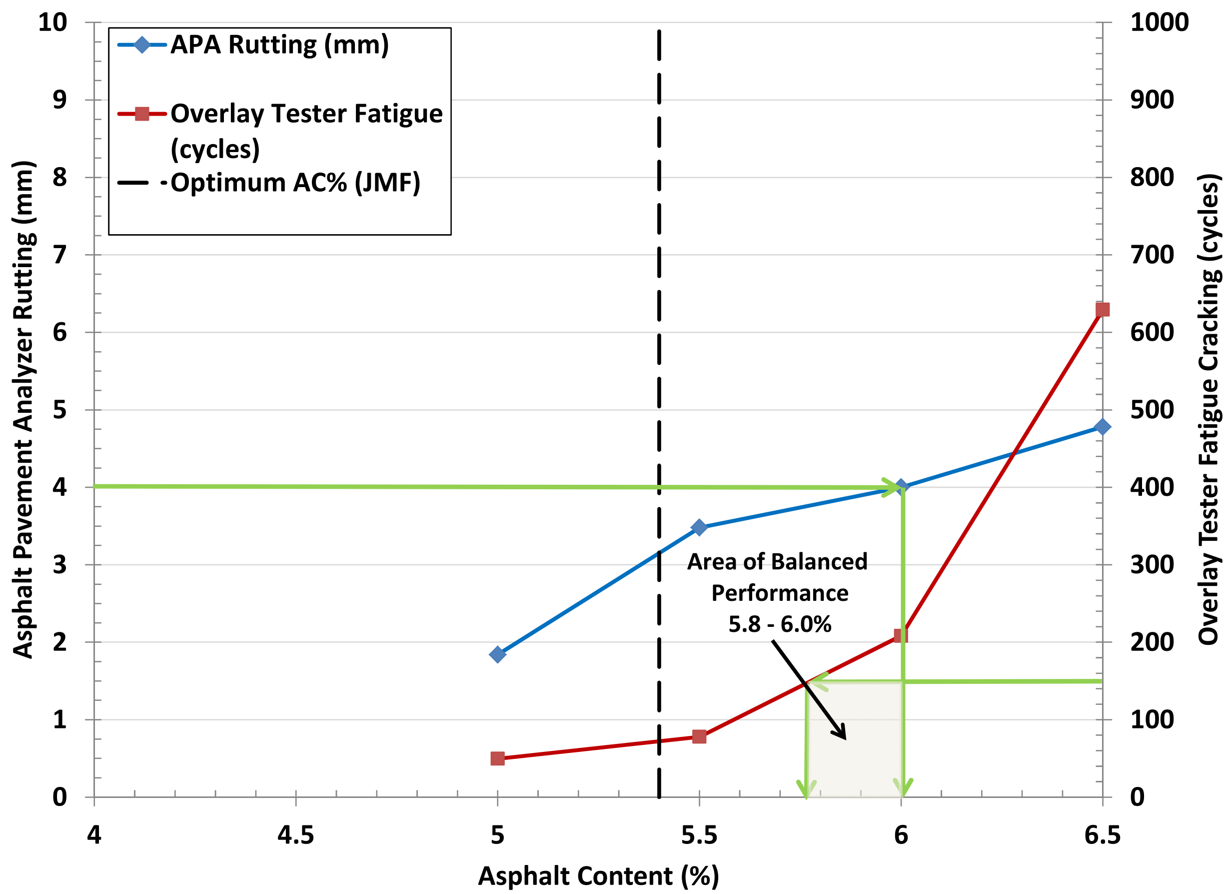


Figure 33 - Trap Rock Industries 9.5M76 Balanced Performance vs Asphalt Content

12.5 mm Nominal Maximum Aggregate Size (NMAS) Mixtures

Both the NJDOT approved PG64-22 and PG76-22 12.5M asphalt mixtures from Trap Rock Industries was evaluated for their volumetric and Balanced Blend performance properties. Figures 34 and 35 show the results for the 12.5M64 mixture from Trap Rock Industries 12.5M64 mixtures. The volumetric design shows that the addition of RAP in the mix design required a significant increase in asphalt content – approximately 1 percent. Meanwhile, the Balanced Design performance indicated that a range between 5.1 to 6.1 percent asphalt content. This was the widest range of potential asphalt contents found in the Balanced Blend analysis work.

Figures 36 and 37 present the test results for the Trap Rock Industries 12.5M76 asphalt mixture. Again, the 15 percent RAP asphalt mixture produced in the laboratory appears to require additional asphalt binder when compared to the same asphalt mixture when RAP is not present. The Balanced Design performance also shows that approximately 1 percent more asphalt binder is required to ensure both rutting and fatigue cracking performance is met.

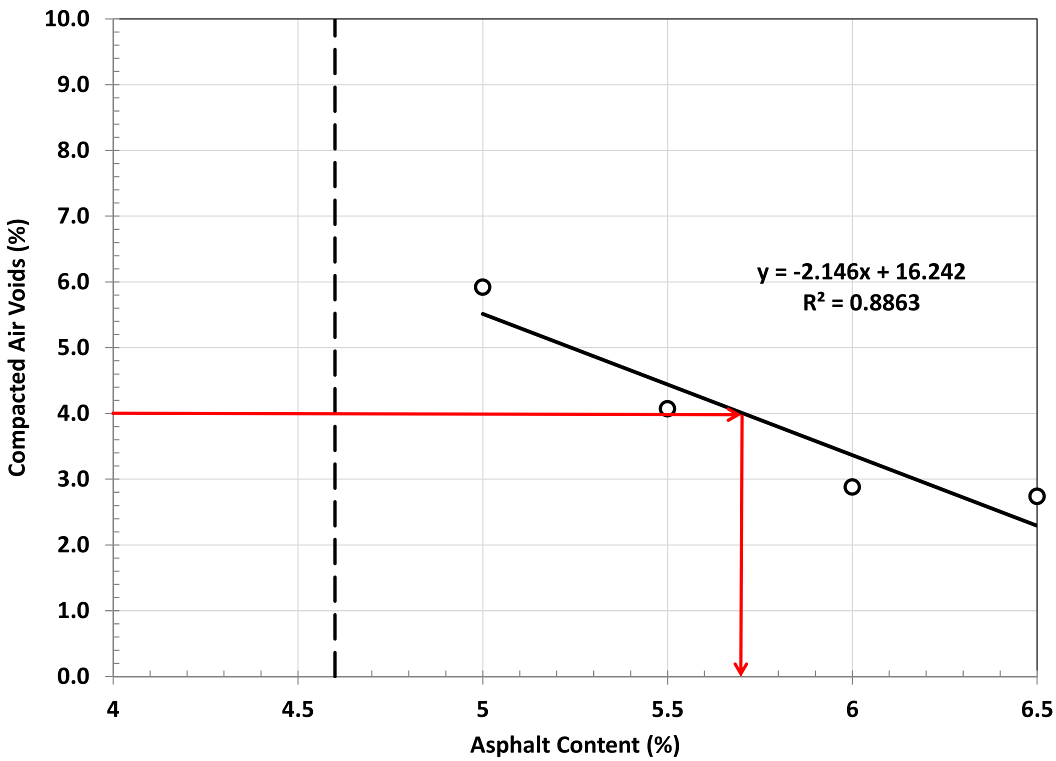


Figure 34 - Trap Rock Industries 12.5M64 Compacted Air Voids vs Asphalt Content

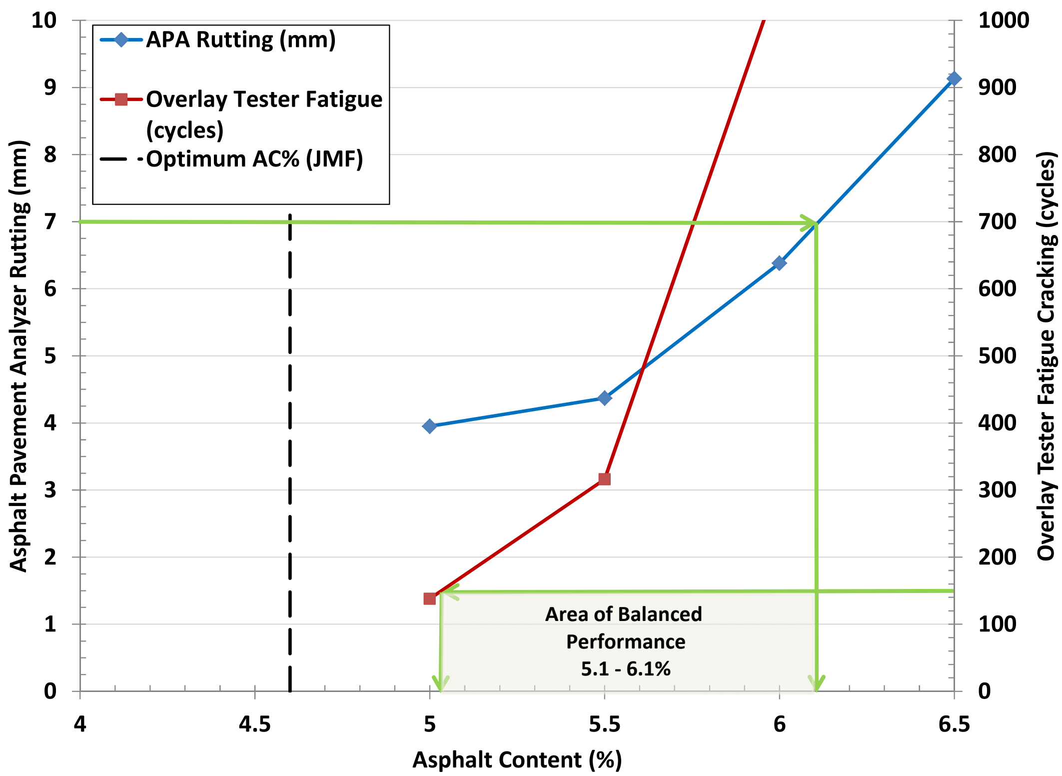


Figure 35 – Trap Rock Industries 12.5M64 Balanced Performance vs Asphalt Content

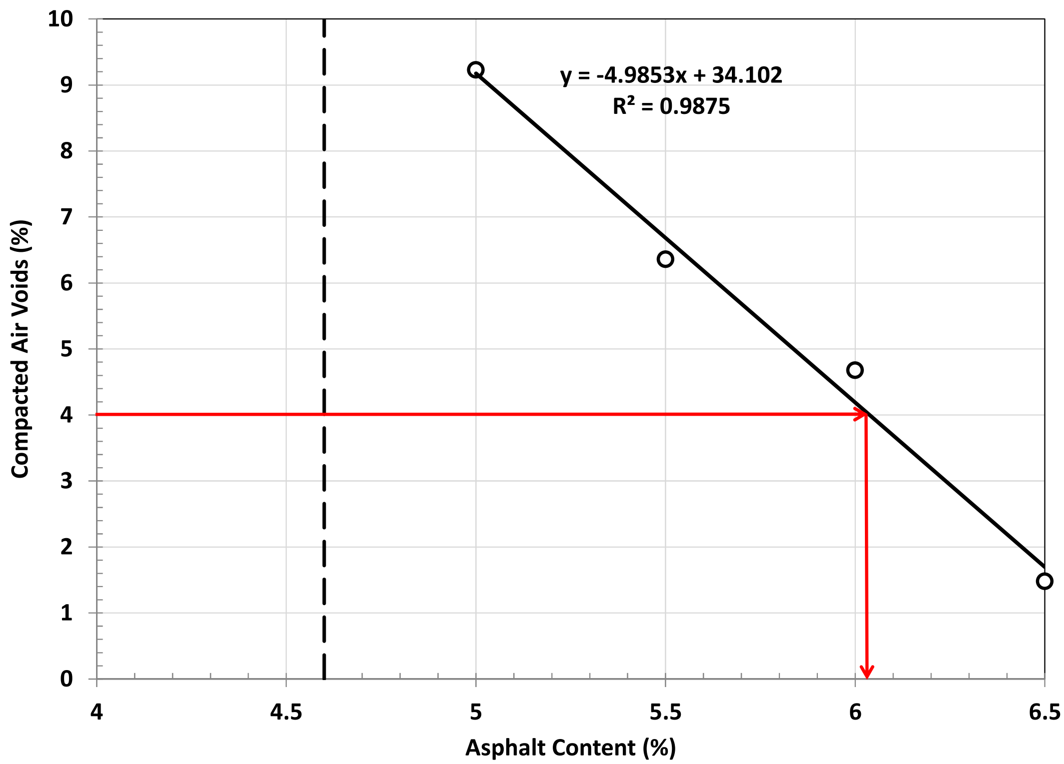


Figure 36 - Trap Rock Industries 12.5M76 Compacted Air Voids vs Asphalt Content

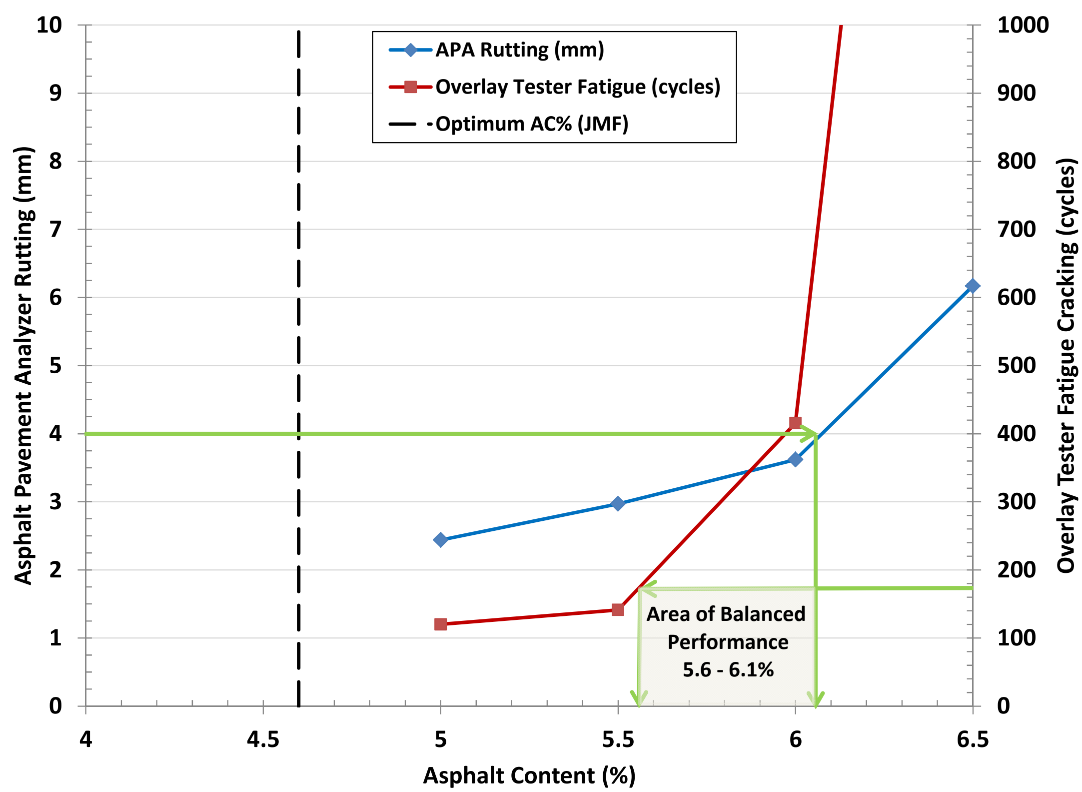


Figure 37 - Trap Rock Industries 12.5M76 Balanced Performance vs Asphalt Content

In summary, as shown earlier with the Tilcon Mt. Hope asphalt mixtures, an increase in asphalt content is required for each of the Trap Rock Industries mixtures when RAP is utilized during the mixture design and Balanced Design performance testing. However, unlike the Tilcon Mt. Hope mixtures, the amount of asphalt required in the Trap Rock Industries asphalt mixtures depended on the NMAS of the aggregate gradation. For the 9.5 mm mixtures, the current asphalt contents of the 0 percent RAP designed mixtures were relatively close to the 15 percent RAP designs generated during this study. However, the 12.5 mm NMAS mixtures differed by approximately 1 percent asphalt, where the current NJDOT approved mix designs, designed with 0 percent RAP, appeared to be highly under-asphalted and very prone to fatigue cracking. Table 16 shows the resultant asphalt contents of the Trap Rock Industries mixtures evaluated.

Table 16 – Summary of Determined Asphalt Contents for Trap Rock Industries Asphalt Mixtures

Mix Type	Optimum AC% (%)		Balanced Mix Design
	Virgin	15% RAP	Optimum AC% (%)
TRI 9.5M64	5.4	5.5	5.2 - 5.9 (5.5)
TRI 9.5M76	5.4	5.7	5.8 - 6.0 (5.9)
TRI 12.5M64	4.6	5.7	5.1 - 6.0 (5.6)
TRI 12.5M76	4.6	6.1	5.5 - 6.0 (5.7)

Improving Volumetrics to Achieve Better Fatigue Resistance

Durability in asphalt mixtures is a very broad characteristic, but it generally covers the asphalt mixtures' ability to resist cracking, raveling and brittle-type failures. For years, pavement engineers and asphalt material technicians have utilized the volumetric property Voids in Mineral Aggregate (VMA) as a general "durability index" parameter. In general, the higher the VMA at design, the greater the amount of effective asphalt (by volume), the better the durability of the asphalt mixture. Finer aggregate gradations, with increased surface area, require higher levels of VMA to ensure adequate asphalt film thickness around the aggregates occur. The current NJDOT volumetric requirements for asphalt mixture design are shown in Table 17. Unfortunately, since the VMA is comprised of both effective asphalt content and air voids, established criteria for VMA only have meaning during mixture design and asphalt plant QC testing. Therefore, instead of utilizing VMA as an indicator of durability, it was proposed in this study to look at the Effective Binder Content by Volume, EBCV (percent). Since the EBCV does not change like VMA due to varying air voids, the EBCV is a much more stable parameter.

Table 17 – NJDOT Asphalt Mixture Design Volumetric Requirements

Table 902.02.03-3 HMA Requirements for Design

Compaction Levels	Required Density(% of Theoretical Max. Specific Gravity)		Voids in Mineral Aggregate (VMA),% (minimum) Nominal Max. Aggregate Size, mm						Voids Filled With Asphalt (VFA)[1] %	Dust-to-Binder Ratio
	@N_{des}[2]	@N_{max}	37.5	25.0	19.0	12.5	9.5	4.75		
L	96.0	≤ 98.0	11.0	12.0	13.0	14.0	15.0	16.0	70 - 80	0.6 - 1.2
M	96.0	≤ 98.0	11.0	12.0	13.0	14.0	15.0	16.0	65 - 78	0.6 - 1.2
H	96.0	≤ 98.0	11.0	12.0	13.0	14.0	15.0	16.0	65 - 75	0.6 - 1.2

The Balanced Design performance test results for all eight asphalt mixtures evaluated are shown in Figure 38. The test results do show some scatter, which would be expected since the data is comprised of different PG grades, different NMAS, and different aggregate sources. However, the trend is relatively clear and shows that as the Effective Binder Content by Volume increases;

- The rutting potential increases as measured in the Asphalt Pavement Analyzer; and
- The fatigue cracking potential decreases as measured in the Overlay Tester.

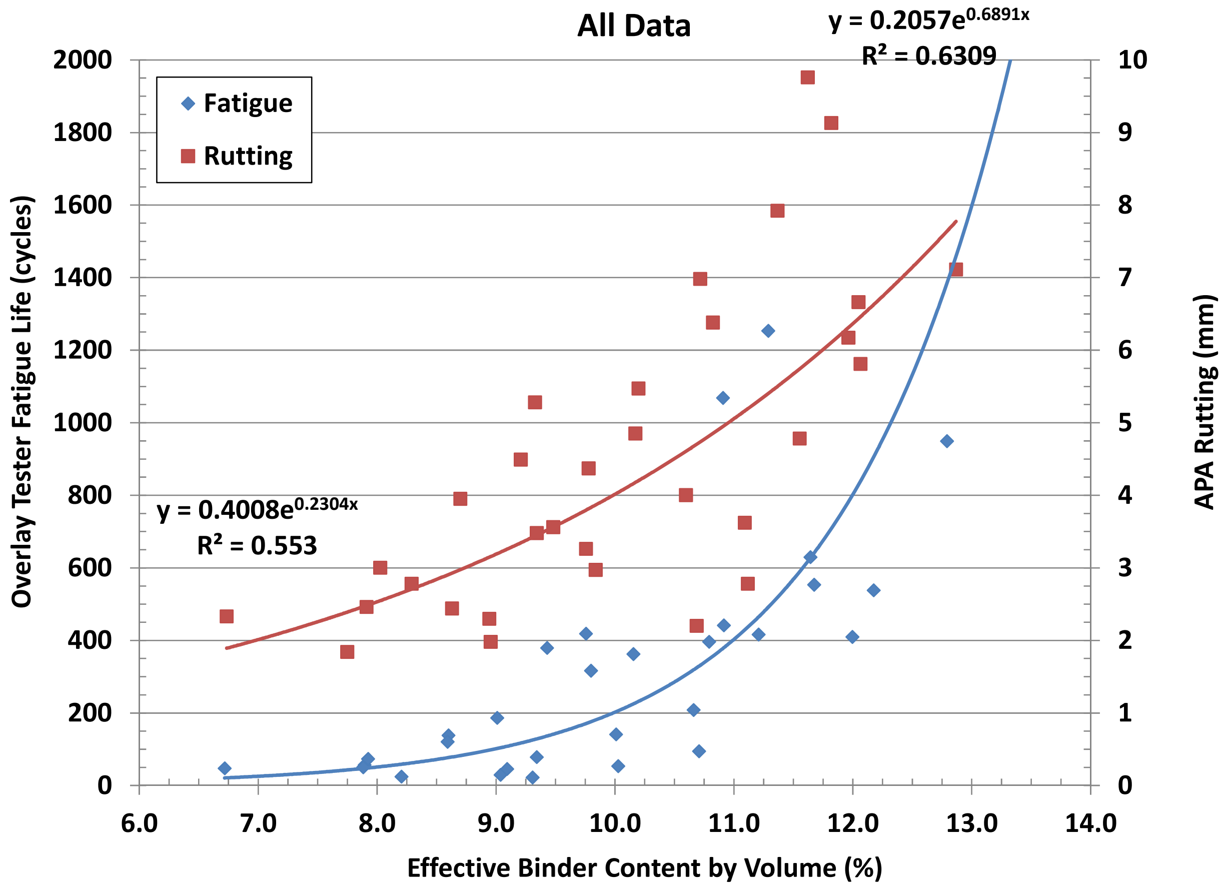


Figure 38 – Effective Binder Content by Volume (%) vs Balanced Design Performance - All Test Data

Both the 9.5 mm NMAS and 12.5 mm NMAS mixtures were separated out, along with the PG grade of the asphalt binder in Figures 39 and 40, to illustrate where the performance of the asphalt mixtures fit into the current design VMA specifications. Since VMA is the effective binder content by volume plus the air voids, simply subtracting 4 percent air voids from the VMA criteria results in the effective binder content by volume. For 9.5 mm asphalt mixtures evaluated, a design VMA of 15 percent (resulting in an effective binder content by volume of 11 percent), an average Overlay Tester value of approximately 225 cycles results. Figure 39 also shows that the 9.5 mm mixtures evaluated show good rutting resistance when compared to the proposed APA criteria.

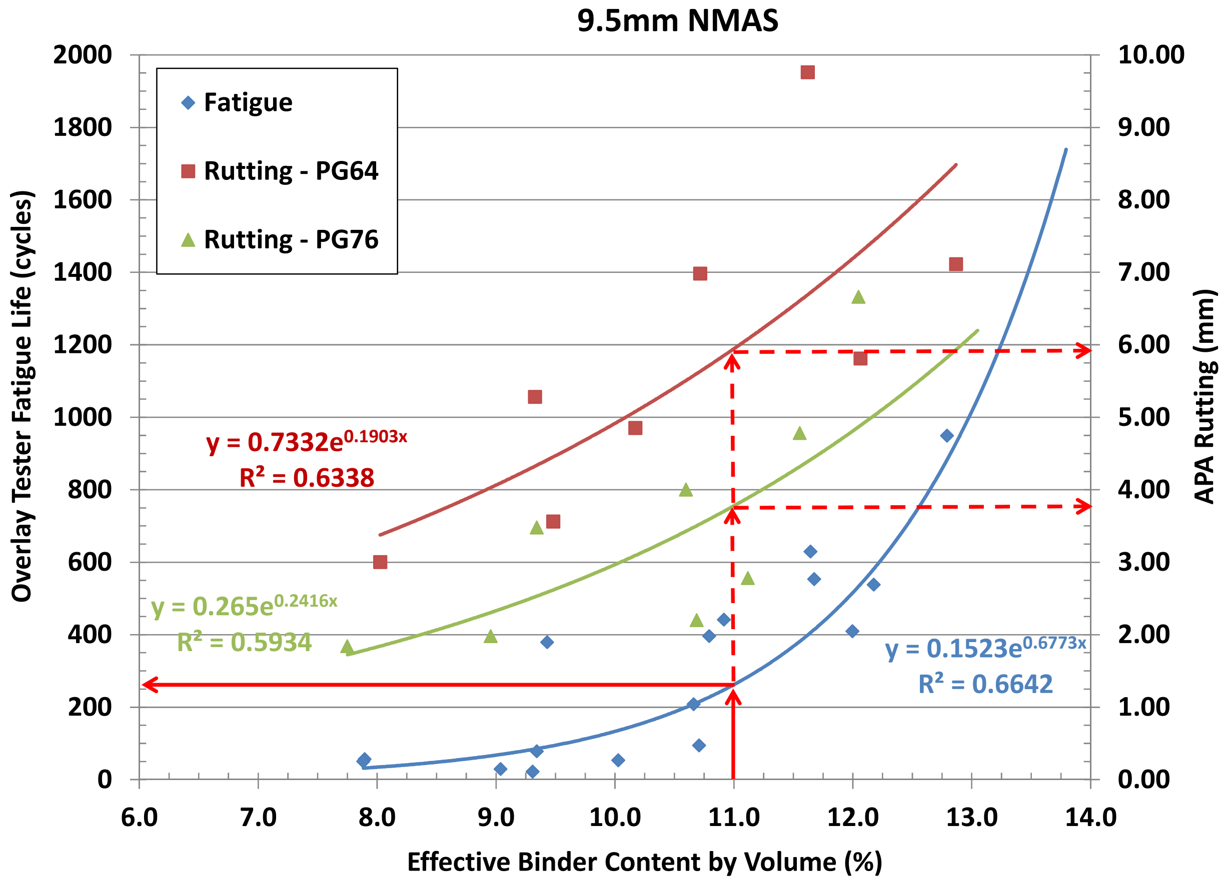


Figure 39 – Effective Binder Content by Volume (%) vs Balanced Design Performance – 9.5 mm NMAS with Current NJDOT Design VMA Criteria

Similar observations were made when looking at the results of the 12.5 mm NMAS mixtures evaluated (Figure 40). Both the PG64-22 and PG76-22 mixtures were found to meet the rutting requirement while the Overlay Tester was approximately 300 cycles.

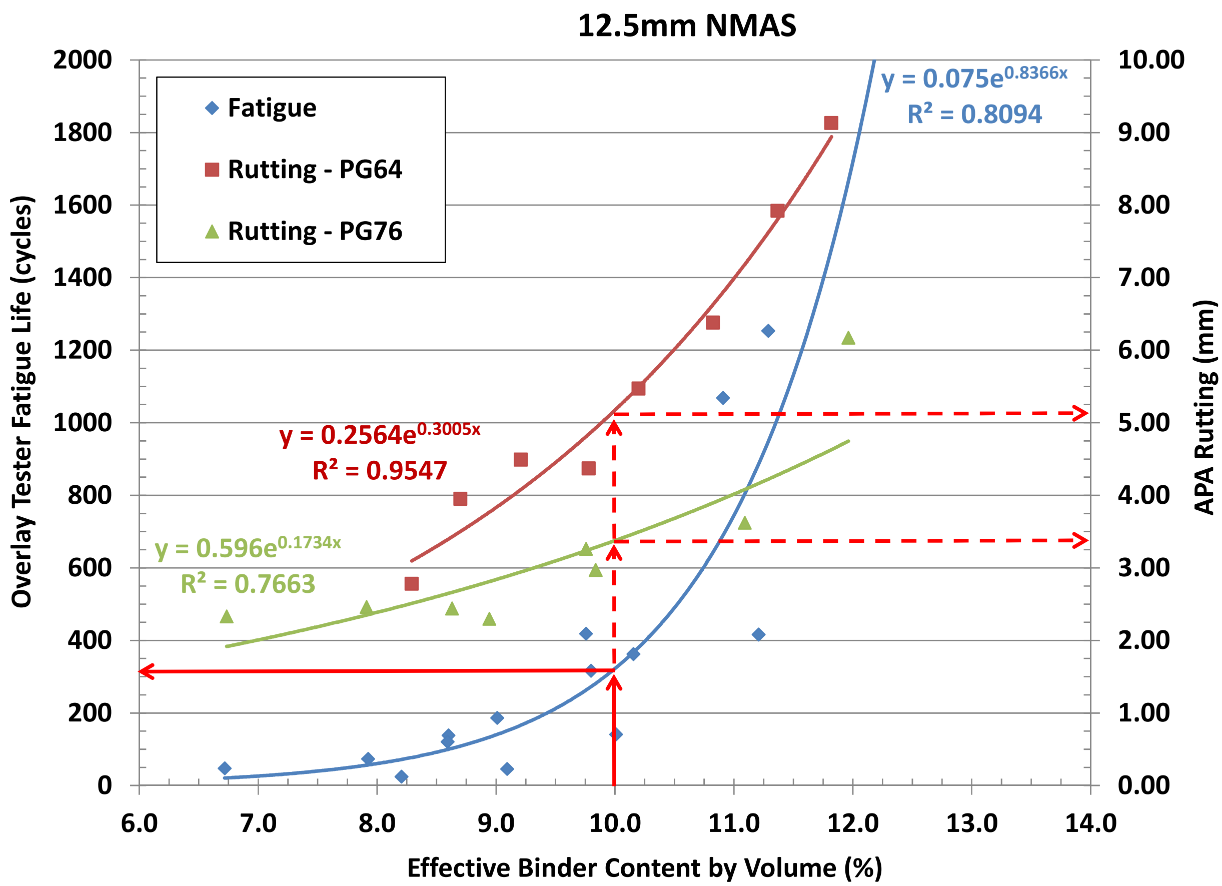


Figure 40 – Effective Binder Content by Volume (%) vs Balanced Design Performance – 12.5 mm NMAS with Current NJDOT Design VMA Criteria

Both the 9.5 mm and 12.5 mm asphalt mixtures were found to meet the minimum Overlay Tester requirements developed in this study while still meeting the rutting. However, with the current asphalt binder production tolerances, the effective asphalt content by volume would most likely decrease as asphalt suppliers are commonly producing asphalt mixtures towards the lower end of the allowable production tolerance. To help ensure enough asphalt binder is in the mixture to achieve higher effective asphalt content by volume values, it is proposed to look at increasing the design VMA by 1 percent. This would ultimately increase the effective asphalt content by volume by 1 percent as well. Figures 41 and 42 show the same data set generated during this study compared to the proposed 1 percent increase in the design VMA (resulting in a 1 percent increase in the effective binder content by volume). The proposed increase in effective binder content by volume shows:

- An average improvement in the Overlay Fatigue resistance of 58 percent when comparing the current design VMA spec to the proposed design VMA spec.
- An average increase in the APA rutting of 19 percent when comparing the current design VMA spec to the proposed design VMA spec. However, even though there was an increase in the APA rutting, only the 9.5 mm NMAS with PG76-22 asphalt binder exceeded the maximum recommended APA rutting (i.e. – 4.0 mm for a PG76-22 asphalt binder).

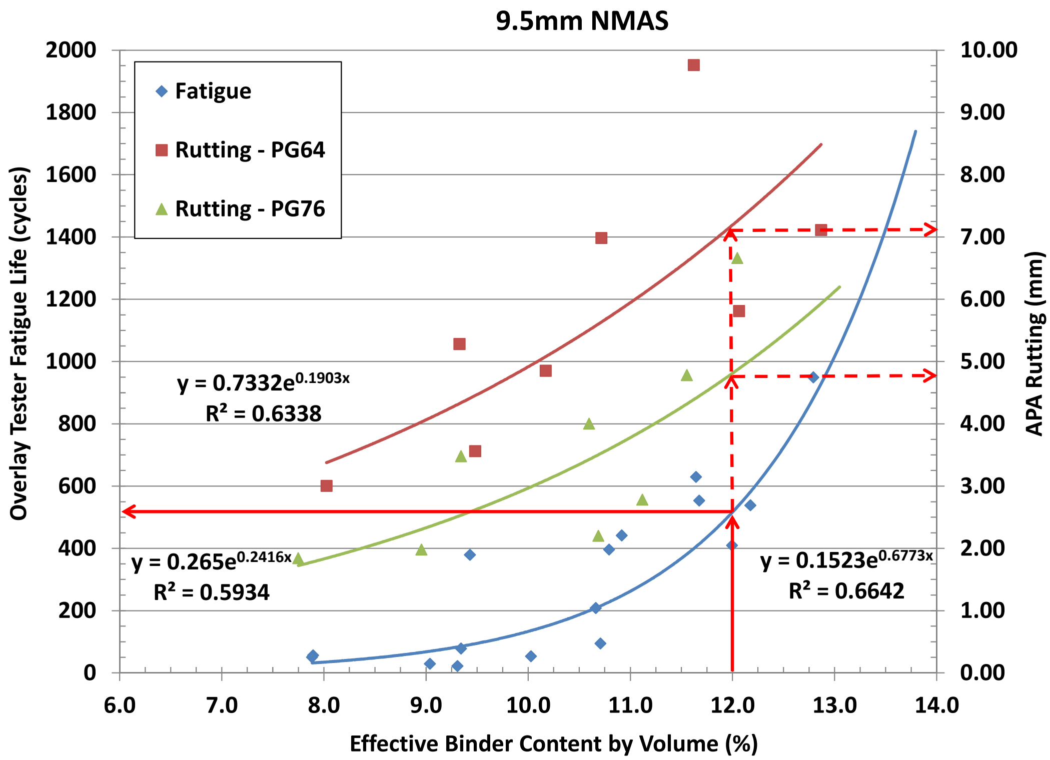


Figure 41 – Effective Binder Content by Volume (%) vs Balanced Design Performance – 9.5 mm NMAS with Proposed NJDOT Design VMA Criteria

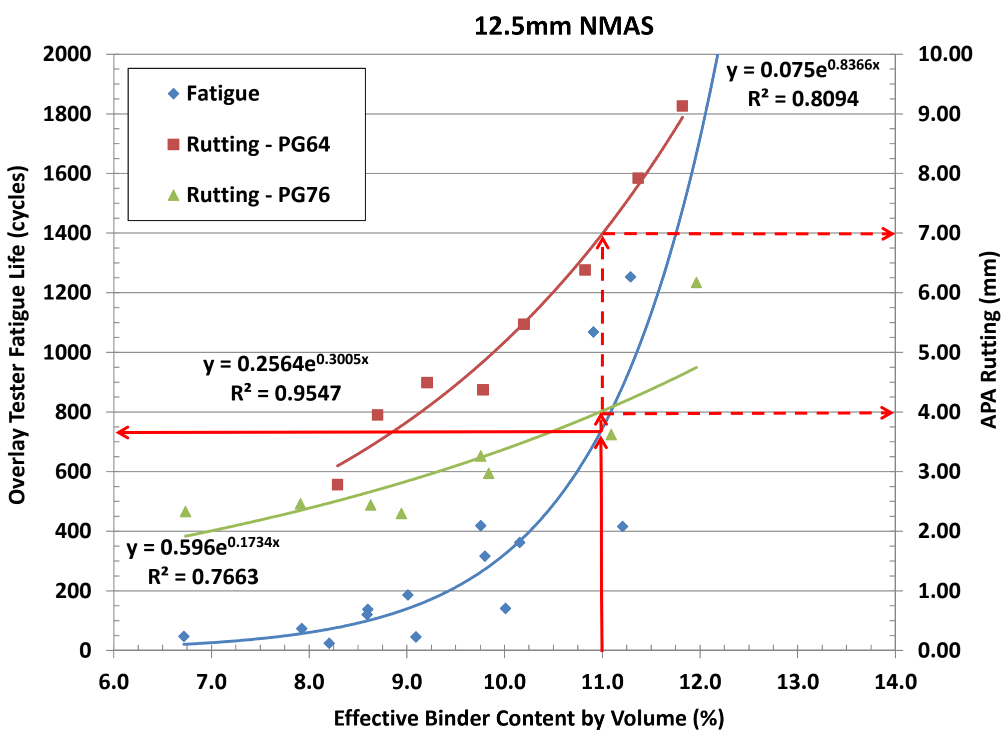


Figure 42 - Effective Binder Content by Volume (%) vs Balanced Design Performance – 12.5 mm NMAS with Proposed NJDOT Design VMA Criteria

Summary of Balanced Design Work

A new mixture approach was evaluated to determine its applicability to New Jersey asphalt mixtures. The methodology, called Balanced Mixture Design, incorporates an asphalt rutting and fatigue test to determine the appropriate asphalt content instead of the current volumetric procedure outlined in Superpave. And even though volumetric (air voids, VMA) are measured, ultimately the methodology relies on the performance (rutting and fatigue) of the asphalt mixture.

The results of the Balanced Mix Design demonstrated that for almost all mixtures evaluated, an increase in asphalt content was required over the current NJDOT approved mixture design. However, some of these results are confounding because the current approved mixture designs were conducted without RAP. Meanwhile, the Balanced Mix Design and accompanying volumetric analysis was conducted with 15 percent RAP. Regardless, it is apparent that asphalt mixtures produced with 15 percent RAP are under-asphalted, and based on the information generated in this study, the mixtures are under-asphalted on average by 0.6 percent.

The test results also allowed for the evaluation of the current NJDOT specification for design VMA (i.e. – VMA determined at 4 percent air voids). Historically, VMA has shown to be an indicator of durability (i.e. – the larger the VMA, the more effective asphalt, the more durable the asphalt mixture). However, it is recommended that the use of the Effective Binder Content by Volume be utilized instead of VMA. Currently, VMA is specified by nominal maximum aggregate size, but the criteria value only have "meaning" when the compacted mixture is at 4 percent (i.e. – typically at design). If a field core is evaluated and the in-place air voids differs from 4 percent, the VMA value of the core can not be compared to the VMA design criteria. However, since the effective binder content by volume is simply the difference of the VMA and air voids, this value should remain constant regardless of compacted air void level and only change with the volume of asphalt changes. Therefore, the effective binder content by volume is a more stable volumetric parameter that can be implemented during mixture design.

The Balanced Mix Design research results generated in this study also showed that the following effective binder content by volume values should result in asphalt mixtures with good rutting and fatigue cracking performance. A modification to the NJDOT specification to increase the Effective Asphalt Content by Volume would also result in an increase in the design Voids in Mineral Aggregate (VMA). The following changes to NJDOT's surface course mixture design volumetrics would then occur:

- 9.5 mm NMAS Mixtures: 12 percent Effective Binder Content by Volume
    - Results in 16 percent VMA at design air voids of 4 percent
- 12.5 mm NMAS Mixtures: 11 percent Effective Binder Content by Volume
    - Results in 15 percent VMA at design air voids of 4 percent

Determining Effective Asphalt Content by Volume during Production

Unfortunately, it is difficult to accurately measure the bulk gravity of the aggregate blend (G_{sb}) during production, especially when RAP is being used. If the Effective Binder Content by Volume was to be implemented during production and quality control testing, it is recommended that the asphalt plant develop a "correction factor" that relates the difference between design G_{sb} to the design G_{se}. The "correction factor" could then be applied to the production G_{se} to provide a reasonable estimate of the production G_{sb}. A preliminary procedure to determine the Production G_{sb}, and thereby the production Effective Binder Content by Volume, would then be as follows:

$$G_{sb}\ Correction\ Factor = \frac{G_{sb,Design}}{G_{se,Design}} \quad (1)$$

where,

$G_{sb,Design}$ = bulk specific gravity of aggregate blend determined during Design
$G_{se,Design}$ = effective specific gravity of aggregate blend determined during Design

$$G_{se,Prodcution} = \frac{100-P_b}{\frac{100}{G_{mm}}-\frac{P_b}{G_b}} \quad (2)$$

where,

$G_{se,Production}$ = effective specific gravity of aggregate blend determined during Production
P_b = asphalt content (%) determined during production
G_{mm} = maximum specific gravity determined during production
G_b = specific gravity of the asphalt binder

$$G_{sb,Production} = G_{se,Production}(G_{sb}\ Correction\ Factor) \quad (3)$$

where,

$G_{sb,Production}$ = estimated bulk specific gravity of the aggregate blend during Production

$$VMA = 100 - \frac{G_{mb}(P_s)}{G_{sb,Production}} \quad (4)$$

where,

VMA = Voids in Mineral Aggregate (%)
G_{mb} = bulk specific gravity of the compacted mix
P_s = percent of aggregate in the mix

$G_{sb,Production}$ = estimated bulk specific gravity of the aggregate blend during production

$$Effective\ Asphalt\ Content\ by\ Volume = VMA - Air\ Voids \tag{5}$$

OVERLAY TESTER ROUND ROBIN STUDY – SHEDWORKS VS TROXLER UNITS

With the NJDOT moving towards Performance-Based mixture designs, there is a need for the NJDOT to be capable of conducting the Quality Assurance testing currently on-going at Rutgers University. Through other funding sources, the NJDOT has already purchased an Asphalt Pavement Analyzer (APA) device used for rutting evaluations. However, with the recommendation to move forward with the implementation of the Overlay Tester to evaluate fatigue cracking on asphalt mixtures in New Jersey, the NJDOT needs to be capable of conducting the same testing that Rutgers University currently is responsible for. Unfortunately, the manufacturer that built the Rutgers University Overlay Tester, Shedworks, no longer is in business (at the time of this study). Troxler Electronics had purchased the intellectual rights for the Overlay Tester from Shedworks and began manufacturing the devices in 2012. However, the device being manufactured by Troxler Electronics differs from the Shedworks unit in a couple of different ways:

1. Specimen Heating and Cooling: The Shedworks device utilize the Pelletier Plate system currently adopted by most of the Dynamic Shear Rheometer (DSR) manufacturers. The test specimen is heated and cooled by the loading plates it is bolted down on. An external fan is used to circulate air through the small chamber, but the heating and cooling is conducted directly through the loading plates. Meanwhile, the Troxler device heats and cools through a temperature controlled fan. Instead of applying the temperature directly on the specimen via the loading platens, the Troxler unit heats and cools the entire chamber of the Overlay Tester.
2. On-Specimen Deformation Indicator: Although the strain-controlled test is controlled through the electronic LVDT, a dial gauge is mounted so the user can verify the actual deformation occurring between the two loading platens. This provides the user with some assurance that the specified horizontal deformation is actually being applied to the test specimen. Unfortunately, Troxler's Overlay Tester does not provide an external device to measure the deformation between the loading platens. Only the LVDT measurements are provided.
3. General Control Software: There are some differences between the general control software when comparing the Shedworks and Troxler Electronics Overlay Tester devices. Although this may sound minor, initial testing with the Troxler Electronics showed that the control software was inadequate to safely load the specimen, as well as general testing. Therefore, the Troxler Electronics software had to undergo a number of revisions prior to any Round Robin testing beginning. In fact, the first set of Round Robin testing had to be aborted due to extremely poor test results with the Troxler Electronics device.

Figures 43 and 44 show pictures of the inside and outside of the Shedworks and Troxler Electronics Overlay Tester devices.

(a) (b)

Figure 43 – Overlay Tester Devices; a) Shedworks and b) Troxler Electronics

(a) (b)

Figure 44 – Inside the Overlay Tester Devices; a) Shedworks and b) Troxler Electronics

The Round Robin testing consisted of compacting 10 gyratory specimens for four different asphalt mixtures. The asphalt mixtures were chosen to provide a range of fatigue life from low (approximately 200 cycles) to high (approximately 4000 cycles).

The asphalt mixtures chosen were plant produced from various projects Rutgers University has been involved with over the past year. After each gyratory specimen was compacted, the specimens were numbered and randomly selected for either the Shedworks unit or the Troxler Electronics unit. Test specimens were tested within 4 days after cutting and trimming took place.

Overlay Tester – Round Robin Results – Round #2

Three different Round Robin events were necessary for this Task. Originally, only one set of testing was scheduled. However, the first attempt at a Round Robin study had to be aborted due to issues with the control software of the Troxler Electronics Overlay Tester. After the software was fixed and updated on the machine at Rutgers University, Round Robin Trial #2 was initiated.

Round Robin Trial #2 utilized test specimens recently prepared for evaluation and did not utilize any previous compacted and prepared Overlay Tester specimens. A total of 40 test specimens were produced between the 4 different mixtures. Testing was conducted until complete failure of the test specimen, which is defined as a 93 percent load drop from the initial cycle load (i.e. – only 7 percent of the initial specimen strength remains).

Two different means of presenting the information were evaluated. In the first method, all of the test data is averaged and reported. This would encompass testing five test specimens and simply taking the average. The second approach is using a Trimmed Mean method. This procedure eliminates the highest and lowest values and averages the test results remaining. For the Overlay Tester, this would result in eliminating the highest and lowest recorded cycles and then averaging the middle three test results. The purpose of the Trimmed Mean is to decrease the variance of the reported test results. This is similar to the methodology proposed in AASHTO T314, *Determining the Fracture Properties of Asphalt Binder in Direct Tension*. In AASHTO T314, six test specimens are prepared and tested at each test temperature. Of the six specimens tested, the two lowest values of failure stress, strain, and energy are discarded. The four remaining failure values are used for reporting.

The test results for Round Robin #2 are shown in Figures 45 and 46 using all of the test data for reporting and the Trimmed Mean method for reporting, respectively. When using all of the test data for reporting, the coefficient of variation (COV) of the test devices are as follows:

- Reporting all test data:
    - Shedworks: 39.1 percent

    - Troxler: 78.5 percent

Meanwhile, when using the Trimmed Mean approach, the variance in the test data drops significantly for the test devices and are as follows:

- Trimmed Mean
    - Shedworks: 10.8 percent
    - Troxler: 23.7 percent

The use of the Trimmed Mean greatly reduces the variability and uncertainty in the test data. However, although the repeatability may be good, the question as to whether or not the results between the two devices are statistically equal or not is just as important. A statistical analysis was conducted on the Trimmed Mean test data of the two devices. At first, an *F-Test Two-Sample for Variances* was evaluated using the analysis tool in Excel©. This determines whether the variances found in the test data of the two datasets are statistically equal or not. The results of the F-Test provide an indication as to whether or not the two test devices provide the same level of repeatability (i.e. – variances). After the F-Test results are determined, a proper t-Test can be conducted. The t-Test determines whether two sets of data are statistically equal or not using either the *t-Test: Two-Sample Assuming Equal Variances* or *t-Test: Two-Sample Assuming Unequal Variances*. Both statistical analysis procedures were conducted using the data analysis tool in Excel©.

The F-test analysis indicated that of the four asphalt mixtures tested by both devices, only two of the mixtures resulted in statistically equal variances. This indicates that the two test devices may not be providing the same level of repeatability. However, it should also be noted that there are inherent sample variability simply due to the fundamental fracture properties of the asphalt mixtures themselves that may also play a role in the machine test variances.

The t-Test analysis indicated that of the four asphalt mixtures tested by both devices, only two of the mixtures resulted in statistically equal test results. This indicates that some of the asphalt mixtures are not performing the same in the test devices.

Focus was placed on the Troxler Overlay Tester as it was the newer of the two pieces of equipment and had several initial issues upon delivery. Upon further evaluation with the Troxler device, it was noticed that temperature fluctuations by as much as $3^{o}C$ were observed during extended testing. This was reported to Troxler and within 3 months a more heavily insulated environmental chamber was provided, as well as an upgraded heating/cooling fan.

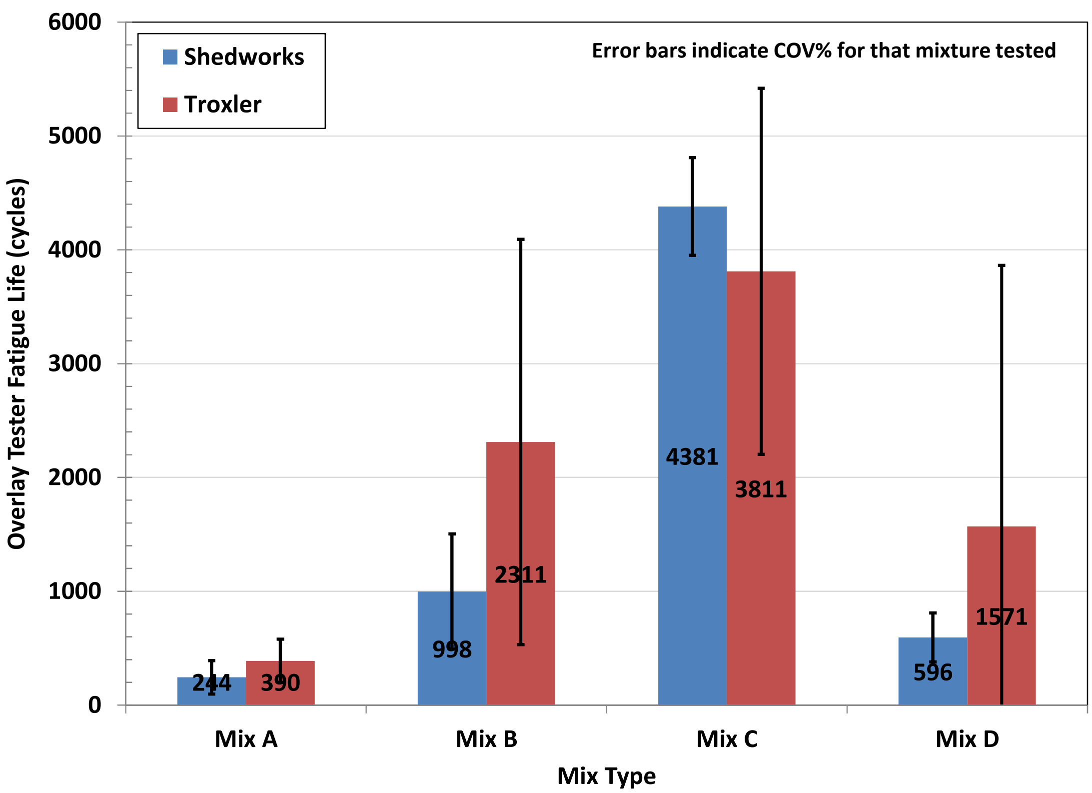


Figure 45 – Round Robin #2 Test Results – All Data Used for Reporting

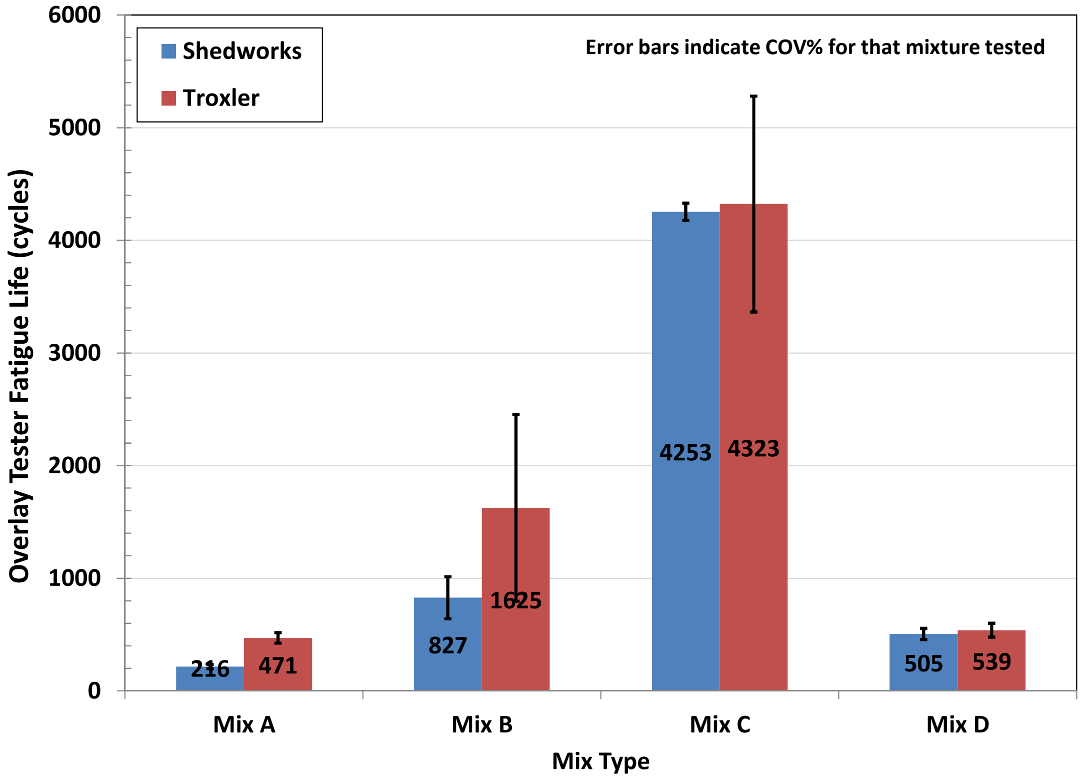


Figure 46 – Round Robin #2 Test Results – Trimmed Mean Method Used for Reporting

Overlay Tester – Round Robin Results – Round #3

After the environmental chamber modifications made by Troxler Electronics, the third and final Round Robin testing program was conducted to evaluate the repeatability of the Shedworks and Troxler Electronics Overlay Tester devices. Once again, four different asphalt mixtures ranging in expected Overlay Tester performance were produced. Loose mix, sampled from various plant produced projects, were utilized to produce ten gyratory compacted specimens per mixture. The gyratory specimens were numbered 1 to 10 and then randomly distributed among the two different test devices.

Figure 47 presents the test results using the entire set of test data as an average (i.e. – all five specimens). The coefficient of variation for the two machines was:

- Reporting all test data:
    - Shedworks: 39.5 percent
    - Troxler: 40.6 percent

The Shedworks unit resulted in almost the identical coefficient of variation (COV) as determined during Round Robin #2. Meanwhile, the COV determined from the Troxler Electronics machine greatly improved to 40.6 percent from the previously determined 78.5 percent.

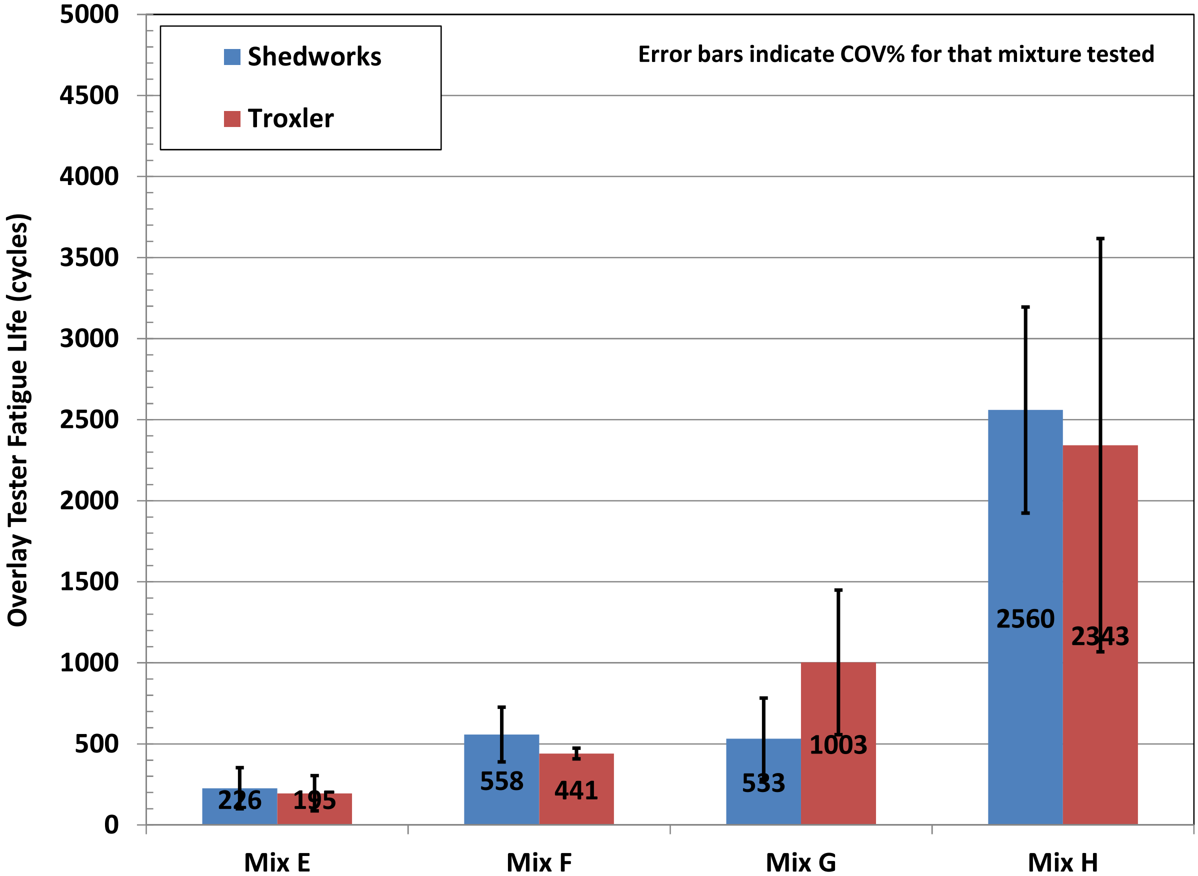


Figure 47 – Round Robin #3 Test Results – All Data Used for Reporting

Figure 48 shows the Round Robin #3 test results using the recommended Trimmed Mean method. When using this procedure, the coefficient of variation was:

- Trimmed Mean
  - Shedworks: 27.7 percent
  - Troxler: 24.0 percent

The variance in the Shedworks unit slightly increased from the Round Robin #2 testing, while the Troxler Electronics device resulted in a very similar COV. Overall, the repeatability of the testing was found to be acceptable considering that most intermediate temperature fatigue testing inherently has variability.

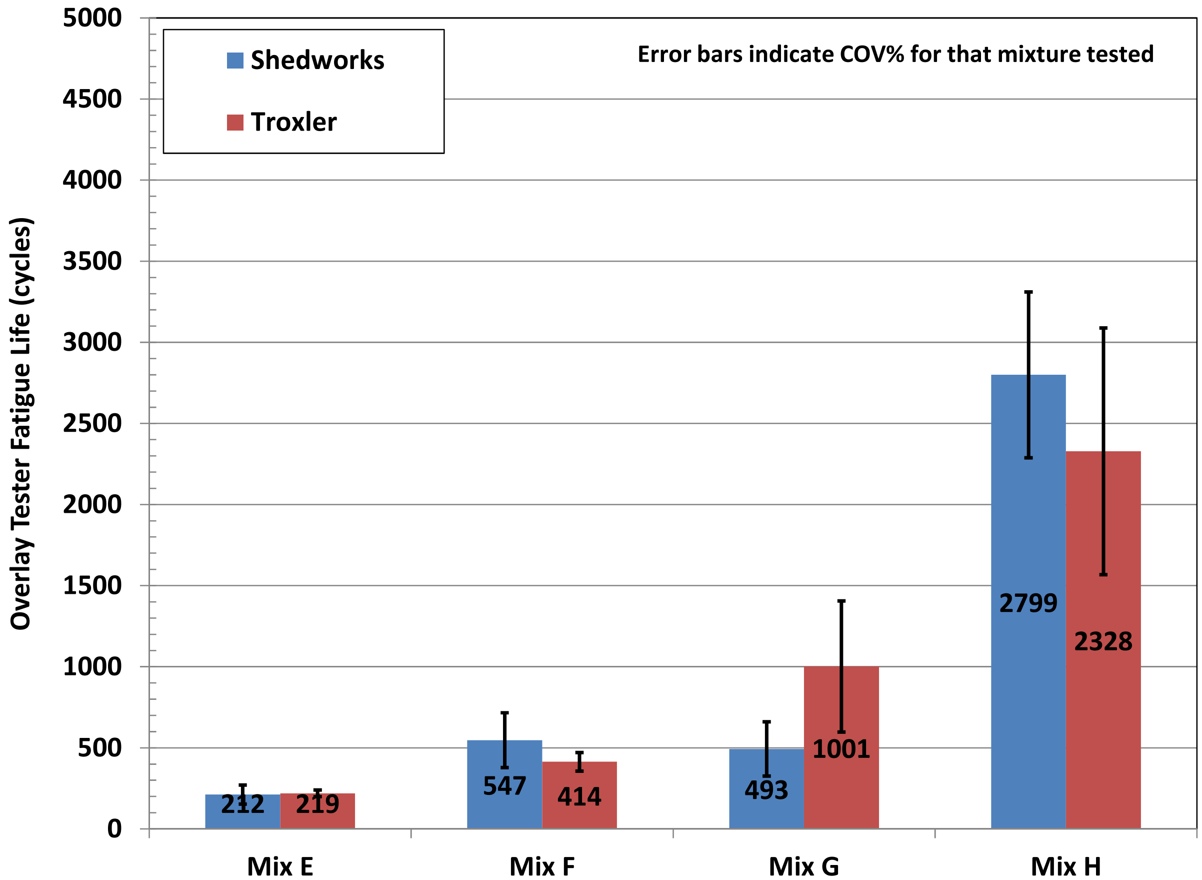


Figure 48 – Round Robin #3 Test Results – Trimmed Mean Method Used for Reporting

Similar to the Round Robin #2 test results, a statistical analysis was conducted on the Trimmed Mean test data of the two devices. At first, an *F-Test Two-Sample for Variances* was evaluated using the analysis tool in Excel©. This determines whether the variances found in the test data of the two datasets are statistical equal or not. The results of the F-Test provide an indication as to whether or not the two test devices provide the same level of repeatability (i.e. – variances). After the F-Test results are determined, a proper t-Test can be conducted. The t-Test determines whether two sets of data are statistically equal or not using either the *t-Test: Two-Sample Assuming Equal Variances* or *t-Test: Two-Sample Assuming Unequal Variances*. Both statistical analysis procedures were conducted using the data analysis tool in Excel©.

The F-Test analysis indicated that of the four asphalt mixtures tested by both Overlay Tester machines, only 1 of the 4 mixtures resulted in the measured variances to be "Statistically Not Equal". This indicates that the Troxler Electronics machine's repeatability improved with the modification of the environmental control system and chamber, and that the variability of generated test data of the two machines is generally equivalent.

The t-Test analysis indicated for all four of the respective mixtures, the Shedworks and Troxler Electronic resulted in performance that was “Statistically Equal”. This indicates that both of the test devices are providing the same test results for the given asphalt mixture tested in this study.

Conclusions of the Round Robin Testing Program

A total of three different Round Robin studies were conducted using one operator and two Overlay Tester machines. Due to equipment issues with the Troxler Electronics device, the first Round Robin study was stopped mid-way through testing. Therefore, the only meaningful test results came from the second and third Round Robin studies.

In the testing, the Shedworks unit was considered “the true” test results, as the unit has been used in New Jersey since 2006, utilized to generate a large database of test results, and had continued to be properly calibrated and mechanically and electronically maintained throughout the past 8 years. Also, the Troxler Electronics Overlay Tester device was one of the first units built by Troxler Electronics, who historically has not been involved with building asphalt mixture equipment used for performance testing.

The results of the Round Robin #2 indicated that there were differences between the two manufacturers’ devices as 2 of the 4 mixtures tested in each of the machines were Statistically Not Equal when comparing their averages, as well as showing that there were differences in the resultant variability when testing a set of mixtures. Upon redesigning the environmental chamber, as well as improving the cooling fan system, the test results generated from the Round Robin #3 showed that both machines were resulting in very similar variances when testing the same mixture, as well as providing Statistically Equal test results.

On a side note, the Round Robin testing program also showed that a Trimmed Mean approach needs to be conducted when utilizing the Overlay Tester. Therefore, it is recommended that 5 test samples be tested per mixture. The highest and lowest value obtained out of the 5 test samples should be eliminated and the middle three test results averaged for reporting purposes.

CONCLUSIONS

An extensive research effort was conducted to evaluate performance-based asphalt mixture design concepts for the New Jersey Department of Transportation (NJDOT). The NJDOT has been utilized performance-based design procedures for their “Specialty” asphalt mixtures since 2006. However, performance criteria had not yet been developed for NJ’s “Conventional” asphalt mixtures, which includes dense-graded, stone matrix asphalt (SMA) and open-graded friction course (OGFC) mixtures. The research study also looked at the proposed method of “Balanced Mixture Design”, which does not utilize air voids as the determinate for optimum asphalt content.

Instead, the procedure determines the range of asphalt contents where both rutting and fatigue cracking performance is satisfied and recommends the middle of that range as the optimum asphalt content. Lastly, the study evaluated the Overlay Tester equipment from a second manufacturer, Troxler Electronics, and how well this new unit compared to the original device manufactured by Shedworks, Inc. A mini Round Robin study was conducted to compare the two pieces of equipment and a brief statistical analysis comparing the test data was conducted. Based on the information generated during this work, the following conclusions can be drawn:

- Utilizing laboratory data conducted on New Jersey specific asphalt mixtures, as well as conversations with TxDOT regarding their implementation of performance-based asphalt mixture designs, Rutgers University and the NJDOT developed a set of performance criteria for use in “Conventional” asphalt mixtures. “Conventional” asphalt mixtures includes dense-grade mixes, SMA mixes and OGFC mixes. The criteria are sensitive to both traffic level and location in the pavement (i.e. – surface, intermediate, or base). Traffic level is incorporated through the specification of asphalt binder grade. For high volume traffic, a PG76-22 is selected. Meanwhile, lower volume traffic requires a PG64-22. At the moment, the NJDOT differentiates High and Low volume traffic at a level of 10 million ESAL’s (MESAL’s) – greater than 10 MESAL’s requires a PG76-22 and less than 10 MESAL’s requires a PG64-22. The criteria also attempts to maintain consistency across other NJDOT performance-based specifications, such as the NJDOT HRAP specification. The proposed specification limits can be found in Table 12.

Table 12 – Proposed Performance-Based Specifications for NJDOT's Asphalt Mixtures

Test Procedure	Dense-graded Hot Mix Asphalt (HMA)						Open-graded Friction Course (OGFC) & Stone Matrix Asphalt (SMA)
	Surface Course		Intermediate Course		Base Course		
	PG64-22	PG76-22	PG64-22	PG76-22	PG64-22	PG76-22	
APA @ 8,000 Cycles & 64°C (AASHTO T340)	< 7.0 mm	< 4.0 mm	< 7.0 mm	< 4.0 mm	< 7.0 mm	< 4.0 mm	< 4.0 mm
Overlay Tester (NJDOT B-10)	> 150 Cycles	> 175 Cycles	> 100 Cycles	> 125 Cycles	> 50 Cycles		> 300 Cycles

- The Balanced Mix Design approach seems to have potential with respect to determining an appropriate asphalt content that would meet both the rutting and fatigue cracking requirement on NJDOT's typical surface course mixtures. Also the test methodology may be more time consuming, the laboratory exercise noted that an increase in the current design VMA may help in the achieving greater fatigue resistance in dense-graded asphalt mixtures. Based on the data generated in this study, a 1 percent increase is recommended for both 9.5 and 12.5 mm nominal maximum aggregate size mixtures. The 1 percent increase resulted in only a slight increase in rutting potential, while greatly improving the fatigue resistance of the asphalt mixtures.
- The asphalt mixture performance generated during the Balanced Mix Design phase showed that the Effective Binder Content by Volume parameter may be more appropriate, and easier, to specify. The VMA parameter directly changes with changes in air voids, making it a difficult parameter to specify during production. However, Effective Binder Content by Volume remains constant, during mix design and production, as it is the difference between the measured VMA and compacted air voids. This provides a stable value that can be used during volumetric design and plant production quality control.
- The Robin Round exercise validated the Troxler Electronics Overlay Tester as an alternative test device to the Shedworks Overlay Tester at Rutgers University. Three different sets of test specimens were produced and tested. In the final round robin, the student t-Test indicated that the test results of four different asphalt mixtures were statistically equal at a 95 percent confidence interval between the two pieces of equipment. After completion of the study, the Troxler Electronics device was delivered to the NJDOT and a 2-day training activity took place. The training encompassed sample preparation, gluing, testing and data analysis.

IMPLEMENTATION RECOMMENDATIONS/PLAN

There are a number of areas where the information generated during the study can be implemented.

Modification to Current NJDOT Specifications

The research study illustrated that an increase in the Voids in Mineral Aggregate (VMA) by 1 percent greatly improved the fatigue resistance of the asphalt mixtures, while minimally changing the rutting resistance of the asphalt mixtures. Therefore, it is recommended that the NJDOT increase the VMA of their dense graded asphalt mixtures 1 percent for all nominal maximum aggregate size mixtures.

The research study also suggests that implementing the use of the volumetric parameter, Effective Asphalt Content by Volume, is more appropriate and consistent for mixture design and production specification. VMA by definition will change with the compacted air void level, making it difficult to use as a specification during production. However, Effective Asphalt Content by Volume remains constant, thereby lending itself easier to specify and enforce for both mixture design and quality control. Also, even though it was not directly part of the research study, implementing the Effective Asphalt Content by Volume requires the asphalt plant to maintain a certain level of film thickness in the asphalt mixture. This is a more appropriate approach then specifying a minimum asphalt content. The Effective Asphalt Content by Volume is a volumetric parameter, while minimum asphalt content is a mass-weight parameter. Since the Superpave mixture design is volumetric-based, it is more appropriate to use the Effective Asphalt Content by Volume than minimum asphalt content by weight of the mixture.

Pilot Study

The second area for implementation would be the detailed evaluation of a pilot study. Two types of pilot studies could be evaluated based on the finding from the study.

Increased VMA Specification

The first recommended pilot study would be to evaluate the mixture production and performance of asphalt mixtures with the 1 percent increase in VMA. Asphalt mixtures should be produced with and without the increased VMA, allowing for a direct comparison of the laboratory performance, as well as field performance.

The second recommended pilot study would be to conduct a Balanced Mix Design for a selected asphalt mixture to be placed on a project. The Balanced Mix Design mixture would be produced alongside the current NJDOT approved asphalt mixture to once again compare the laboratory performance, as well as the field performance.

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APPENDIX A – HIGH PERFORMANCE THIN OVERLAY (HPTO)

Section 406 – High Performance Thin Overlay (HPTO)

406.01 DESCRIPTION

This Section describes the requirements for constructing high performance thin overlay (HPTO).

406.02 MATERIALS

406.02.01 Materials

Provide materials as specified:

Tack Coat:
Emulsified Asphalt, Grade RS-1, SS-1, SS-1h, Grade CSS-1 or CSS-1h 902.01.03
HPTO 902.08

406.02.02 Equipment

Provide equipment as specified:

Materials Transfer Vehicle (MTV) 1003.01
HMA Paver 1003.03
Ultra-Thin Paver 1003.04
HMA Compactor 1003.05
HMA Plant 1009.01
HMA Trucks 1009.02

406.03 CONSTRUCTION

406.03.01 High Performance Thin Overlay (HPTO)

A. Paving Plan. At least 20 days before the start of placing the HPTO, submit a detailed plan of operation to the RE for approval as specified in 401.03.03.A.

B. Weather Limitations. If within the 3 hours before paving the National Weather Service locally forecasts a 50 percent chance or greater of precipitation during the scheduled placement, postpone the placement of HPTO. Do not place HPTO if it is precipitating and do not allow trucks to leave the plant when precipitation is imminent. The Contractor may resume paving operations when the chance of precipitation is less than 50 percent and the surface is dry.

Do not pave if the surface temperature of the underlying pavement is below 50°F.

C. Test Strip. At least 14 days prior to production of the HPTO, construct a test strip as specified in 401.03.03.C except for the allowance to continue paving. Submit test strip results to the RE. The RE will analyze the test strip results in conjunction with the ME's results from the HMA plant to approve the test strip. Do not proceed with production paving until receiving written permission from the RE.

If paving HPTO only on a bridge deck, then the test strip is not required.

D. Transportation and Delivery of HMA. Transport and deliver HMA as specified in 401.03.03.D.

E. Spreading and Grading. Do not start paving of the HPTO until the RE has approved the underlying surface. Apply tack coat as specified in 401.03.02. Place HPTO at the laydown temperature recommended by the supplier of the asphalt binder or the supplier of the asphalt modifier without exceeding 330ºF maximum discharge temperature. Spread and grade HPTO as specified in 401.03.03.E. Do not exceed the maximum lift thickness of 1 ¼".

F. Compacting. Compact as specified in 401.03.03.F. If vibratory compaction causes aggregate breakdown, forces liquid asphalt to the surface or creates a surface with undesirable ride quality, then operate rollers in static mode only. If compacting HPTO on a bridge deck, then operate rollers in static mode only.

G. Opening to Traffic. Remove loose material from the traveled way before opening to traffic. Do not allow construction equipment or traffic on the HPTO until the mat cools to a temperature of less than 140 °F.

H. Air Void Requirements on Roadway. Mainline lots are defined as the area covered by a day's paving production of the same job mixed formula between 500 and 2000 tons for the traveled way and auxiliary lanes. The RE will combine daily production areas less than 500 tons with previous or subsequent production areas to meet the minimum lot requirements. When the maximum lot requirement is exceeded in a day's production, the RE may divide the area of HMA placed into 2 lots with approximately equal areas.

Ramp pavement lots are defined as approximately 10,000 square yards of pavement in ramps. The RE may combine ramps with less than the minimum area into a single lot. If 2 or more ramps are included in a single lot, the RE will require additional cores to ensure that at least 1 core is taken from each ramp.

Other pavement lots are defined as approximately 10,000 square yards of pavement in shoulders and other undefined areas.

The ME will calculate the percent defective (PD) as the percentage of the lot outside the acceptable range of 2 percent air voids to 7 percent air voids. The acceptable quality limit is 10 percent defective. For lots in which PD < 10, the Department will award a positive pay adjustment. For lots in which PD > 10, the Department will assess a negative pay adjustment.

The ME will determine air voids from 5 cores taken from each lot in random locations. The ME will determine air voids of cores from the values for the maximum specific gravity of the mix and the bulk specific gravity of the core. The ME will determine the maximum specific gravity of the mix according to NJDOT B-3 and AASHTO T 209, except that minimum sample size may be waived in order to use a 6-inch diameter core sample. The ME will determine the bulk specific gravity of the compacted mixture by testing each core according to AASHTO T 166.

The ME will calculate pay adjustments based on the following:

1. Sample Mean ($\overline{X}$) and Standard Deviation (S) of the N Test Results (X1, X2,..., XN).

$$\overline{X} = \frac{(X_1 + X_2 + ... + X_N)}{N}$$

$$S = \sqrt{\frac{(X_1 - \overline{X})^2 + (X_2 - \overline{X})^2 + ... + (X_N - \overline{X})^2}{N - 1}}$$

2. Quality Index (Q).

$$Q_L = \frac{(\overline{X} - 2.0)}{S}$$

$$Q_U = \frac{(7.0 - \overline{X})}{S}$$

3. Percent Defective (PD). Using NJDOT ST for the appropriate sample size, the Department will determine PD_L and PD_U associated with Q_L and Q_U, respectively. $PD = PD_L + PD_U$

4. **Percent Pay Adjustment (PPA).** Calculate the PPA for traveled way and ramp lots as specified in Table 401.03.03-3.

Table 406.03.03-3 PPA for Mainline Lots and Ramp Lots

	Quality	PPA
Surface	PD < 10	PPA = 4 − (0.4 PD)
	10 ≤ PD < 30	PPA = 1 − (0.1 PD)
	PD ≥ 30	PPA = 40 − (1.4 PD)
Intermediate and Base	PD < 30	PPA = 1 − (0.1 PD)
	PD ≥ 30	PPA = 40 − (1.4 PD)

Calculate the PPA for other pavement lots as specified in Table 401.03.03-4.

Table 406.03.03-4 PPA for Other Pavement Lots

	Quality	PPA
All Courses	PD < 50	PPA = 1 − (0.1 PD)
	PD ≥ 50	PPA = 92 − (1.92 PD)

5. **Outlier Detection.** The ME will screen all acceptance cores for outliers using a statistically valid procedure. If an outlier is detected, replace that core by taking an additional core at the same offset and within 5 feet of the original station. The following procedure applies only for a sample size of 5.

    1. The ME will arrange the 5 core results in ascending order, in which X1 represents the smallest value and X5 represents the largest value.
    2. If X5 is suspected of being an outlier, the ME will calculate:

    $$R = \frac{X_5 - X_4}{X_5 - X_1}$$

    3. If X1 is suspected of being an outlier, the ME will calculate:

    $$R = \frac{X_2 - X_1}{X_5 - X_1}$$

    4. If R > 0.642, the value is judged to be statistically significant and the core is excluded.

6. **Retest.** If the initial series of 5 cores produces a percent defective value of PD ≥ 30 for mainline or ramp lots, or PD ≥ 50 for other pavement lots, the Contractor may elect to take an additional set of 5 cores at random locations chosen by the ME. Take the additional cores within 15 days of receipt of the initial core results. If the additional cores are not taken within the 15 days, the ME will use the initial core results to determine the PPA. If the additional cores are taken, the ME will recalculate the PPA using the combined results from the 10 cores.

7. **Removal and Replacement.** If the final lot PD ≥ 75 (based on the combined set of 10 cores or 5 cores if the Contractor does not take additional cores), remove and replace the lot and all overlying work. The replacement work is subject to the same requirements as the initial work.

I. **Air Void Requirements on Bridge Deck.** The RE may waive the coring of HPTO constructed on a bridge deck or may require that the Contractor to test bridge decks with the thin lift nuclear density gauge. If required by RE, perform nuclear density gauge testing according to ASTM D 2950 at 5 random locations per bridge deck. Use the maximum specific gravity determined at the HMA plant according to AASHTO T 209 to determine percent air voids. If the average air voids for the bridge deck are 8 percent or greater, the RE will require a revised paving plan for any subsequent bridge deck placement of HPTO and may require the HPTO to be removed and replaced.

J. Ride Quality Requirements. The Department will evaluate the HPTO as specified in 401.03.03.J.

406.04 MEASUREMENT AND PAYMENT

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

Item	*Pay Unit*
HIGH PERFORMANCE THIN OVERLAY	TON

The Department will measure HIGH PERFORMANCE THIN OVERLAY by the ton as indicated on the certified weigh tickets, excluding unused material.

The Department will make payment for TACK COAT as specified in 401.04.

The Department will make payment for CORE SAMPLES, HOT MIX ASPHALT as specified in 401.04.

902.08 HIGH PERFORMANCE THIN OVERLAY (HPTO)

902.08.01 Composition of Mixture.

Mix HPTO in a plant that is listed on the QPL and conforms to the requirements for HMA Plants as specified in 1009.01. The composition of the mixture for HPTO is coarse aggregate, fine aggregate, and asphalt binder, and may also include mineral filler. Do not use Reclaimed Asphalt Pavement (RAP), Ground Bituminous Shingle Material, Remediated Petroleum Contaminated Soil Aggregate, or Crushed Recycled Container Glass (CRCG). Use asphalt binder and aggregates that meet the following requirements:

1. For the asphalt binder, use PG 76-22 as specified in 902.01.01.
2. Use coarse aggregate that is argillite, gneiss, granite, quartzite, or trap rock and conforms to 901.05.01.
3. For fine aggregate, use stone sand conforming to 901.05.02 and has an uncompacted void content of at least 45 percent when tested according to AASHTO T 304, Method A. In addition, the minimum sand equivalent is 45 percent when tested according to AASHTO T 176.
4. If necessary, use mineral filler as specified in 901.05.03.

902.08.02 Mix Design.

At least 45 days before initial production, submit a job mix formula for the HPTO on forms supplied by the Department. Include a statement naming the source of each component and a report showing the results meet the criteria specified in Tables 902.08.03-1 and 902.08.03-2.

For the job mix formula for the HPTO mixture, establish the percentage of dry weight of aggregate passing each required sieve size and an optimum percentage of asphalt binder based upon the weight of the total mix. Determine the optimum percentage of asphalt binder according to AASHTO R 35 and M 323 with an Ndes of 50 gyrations. Before maximum specific gravity testing or compaction of specimens, condition the mix for 2 hours according to the requirements for conditioning for volumetric mix design in AASHTO R 30, Section 7.1. If the absorption of the combined aggregate is more than 1.5 percent according to AASHTO T 84 and T 85, condition the mix for 4 hours according to AASHTO R 30, Section 7.2 prior to compaction of specimens (AASHTO T 312) and determination of maximum specific gravity (AASHTO T 209). Ensure that the job mix formula is within the master range specified in, Table 902.08.03-1.

Ensure that the job mix formula provides a mixture that meets a minimum tensile strength ratio (TSR) of 85 percent when prepared according to AASTHO T 312 and tested according to AASHTO T 283 with the following exceptions:

1. Before compaction, condition the mixture for 2 hours according to AASHTO R 30 Section 7.1.

2. Compact specimens with 40 gyrations.
3. Extrude specimens as soon as possible without damaging.
4. Use AASHTO T 269 to determine void content.
5. Record the void content of the specimens.
6. If less than 55 percent saturation is achieved, the procedure does not need to be repeated, unless the difference in tensile strength between duplicate specimens is greater than 25 pounds per square inch.
7. If visual stripping is detected, modify or readjust the mix.

For each mix design, submit three gyratory specimens and one loose sample corresponding to the composition of the job mix formula, including the design asphalt content. The ME will use these samples for verification of the properties of the job mix formula. Compact the specimens to the design number of gyrations (Ndes). To be acceptable all three gyratory specimens must comply with the gradation and asphalt content requirements in Table 902.08.03-1 and with the control requirements in Table 902.08.03-2. The ME reserves the right to be present at the time of molding the gyratory specimens.

In addition, submit 6 gyratory specimens and a 5 gallon bucket of loose mix to the ME. Compact the additional gyratory specimens according to AASHTO T 312. Ensure that the 6 gyratory specimens are 77 millimeters high and have an air void content of 5.0 ± 0.5 percent. The ME will use the additional samples for performance testing of the HPTO mix. The ME will test the specimens using an Asphalt Pavement Analyzer according to AASHTO TP 63 at 64°C, 100 pounds per square inch hose pressure, and 100 pound wheel load. The ME will approve the job mix formula if the average rut depth for the 6 specimens in the asphalt pavement analyzer testing is not more than 4 millimeters in 8,000 loading cycles. If the job mix formula does not meet the APA criteria, redesign the HPTO mix.

If unsatisfactory results for any specified characteristic of the work make it necessary, establish a new job mix formula for approval. In such instances, if corrective action is not taken, the ME may require an appropriate adjustment.

If a change in sources is made or a change in the properties of materials occurs, the ME will require that a new job mix formula be established and approved before production can continue.

902.08.03 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.

Ensure that the temperature of the HPTO at discharge from the plant or surge and storage bins is maintained between 300 and 330 °F.

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.

B. Sampling. The ME will take 5 stratified random samples of HPTO for volumetric acceptance testing from each lot of approximately 3500 tons of a mix. When a lot of HPTO 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 composition testing, unless composition is determined by hot bin analysis. If using hot bin analysis at a fully automated batch plant, take 5 samples from each lot corresponding to the volumetric acceptance samples, under the supervision of the ME.

C. Quality Control Testing. The HMA producer is required to 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 is required to perform sampling and testing according to the approved quality control plan, to keep the mix within the limits specified for the HPTO 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 fully automated plants, the QC technician may determine composition using hot bin analysis according to NJDOT B-5. Use only one method for determining composition within a lot.

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.

D. Acceptance Testing and Requirements. The ME will determine volumetric properties at Ndes for acceptance from samples taken, compacted, and tested at the HMA plant. The ME will compact HPTO to 50 gyrations, 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 HPTO.

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

Ensure that the HMA mixture conforms to the requirements specified in Table 902.08.03-2, and to the gradation requirements in Table 902.08.03-1. 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.

E. Performance Testing. Provide 6 gyratory specimens and a 5 gallon bucket of loose mix to the ME. Compact the additional gyratory specimens according to AASHTO T 312. Ensure that the 6 gyratory specimens are 77 millimeters high and have an air void content of 5.0 ± 0.5 percent. The first sample is required to be taken in the first lot of production. Thereafter, every third lot is required to be sampled. The ME will use the samples for performance testing of the HPTO mix. The ME will test the specimens using an Asphalt Pavement Analyzer according to AASHTO TP 63 at 64°C, 100 pounds per square inch hose pressure, and 100 pounds wheel load. If the HPTO mix exceeds the APA criteria of 4 mm in 8000 loading cycles, the ME may stop production until corrective action is taken. If the HPTO mix exceeds the APA criteria of 12 mm in 8000 loading cycles, the RE may require removal and replacement of the lot of HPTO.

Table 902.08.03-1 HPTO Grading of Total Aggregate

Sieve Size	Percent Passing by Mass
3/8”	100
#4	65-85
#8	33-55
#16	20-35
#30	15-30
#50	20-Oct
#100	15-May
#200	5.0-8.0
Minimum Percent Asphalt by Mass of Total Mix	7

Table 902.08.03-2 Volumetric Requirements for Design and Control of HPTO					
	Required Density (% of Max. Sp. Gr.)		**Voids in Mineral Aggregate**	**Dust to Binder Ratio**	**Draindown AASHTO T 305**
	N_{des} (50 gyrations)	**N_{max} (100 gyrations)**	**(VMA)**		
Design Requirements	**96.5**	**≤ 99.0**	**≥ 18.0 %**	**0.6 - 1.2**	**≤ 0.1 %**
Control Requirements	**95.5 - 97.5**	**≤ 99.0**	**≥ 18.0 %**	**0.6 – 1.3**	**≤ 0.1 %**

APPENDIX B – BITUMINOUS RICH INTERMEDIATE COURSE (BRIC)

Section 408- Binder Rich Intermediate Course

408.01 DESCRIPTION

This Section describes the requirements for constructing binder rich intermediate course (BRIC).

408.02 MATERIALS

408.02.01 Materials

Provide materials as specified:

BRIC……………………….....…………. …………………………………………….…902.09

Use an approved HMA surface course to fill core holes, maintaining the material hot enough to compact. The Contractor may use a commercial type of cold mixture as patching material for filling core holes if HMA surface course is not being produced when coring.

408.02.02 Equipment

Provide equipment as specified:

Materials Transfer Vehicle (MTV) …………....……………………………...…………….1003.01
HMA Paver………………………………………………………………….………....1003.03
HMA Compactor……………………………………………………………...………….1003.05
Bituminous Material Distributor ..……………………………………………………….1003.07
HMA Plant…………………………………………………………………….……..1009.01
HMA Trucks …………………………………………………………………..……..……1009.02

Provide a thin-lift nuclear density gauge according to ASTM D 2950

Install a paver hopper insert with a minimum capacity of 14 tons in the hopper of the HMA Paver.

408.03 CONSTRUCTION

408.03.01 Preparing Existing Pavement

Prepare existing pavement as specified in 401.03.01.

408.03.02 Tack Coat and Prime Coat

Apply tack coat as specified in 401.03.02.

408.03.03 BRIC

A. Paving Plan. At least 20 days before the start of placing the BRIC, submit to the RE for approval a detailed plan of operation as specified in 401.03.03.A. If multiple plants are producing the BRIC, determine how material will be separated for testing and acceptance. Include in the paving plan a proposed location for the test strip.

B. Weather Limitations. If within the 12 hours before paving the National Weather Service locally forecasts a 40 percent chance or greater of precipitation during the scheduled placement, postpone the placement of BRIC. Do not place BRIC if it is precipitating and do not allow trucks to leave the plant when precipitation is imminent. The Contractor may resume paving operations when the chance of precipitation is less than 40 percent and the surface is dry.

Do not pave if the base temperature is below 50 °F.

C. Test Strip. At least two weeks prior to production of the BRIC, construct a test strip as specified in 401.03.03.C except for the allowance to continue paving. Submit test strip results to the RE. The RE will analyze the test strip results in conjunction with the ME's results from the HMA plant to approve the test strip. Do not proceed with production paving until receiving written permission from the RE.

D. Transportation and Delivery of HMA. Transport and deliver BRIC as specified in 401.03.03.D.

E. Spreading and Grading. Do not start paving of the BRIC until the RE has approved the underlying surface. Place BRIC at the laydown temperature recommended by the supplier of the asphalt binder or the supplier of the asphalt modifier without exceeding 330ºF maximum discharge temperature at the HMA plant. Spread and grade BRIC as specified in 401.03.03.E.

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

G. Opening to Traffic. Remove loose material from the traveled way, shoulder, and auxiliary lanes before opening to traffic. Do not allow traffic or construction equipment on the BRIC until the surface temperature is less than 120 °F. Ensure that traffic is not allowed on the BRIC for more than 7 days.

H. Air Void Requirements. Mainline lots are defined as the area covered by a day's paving production of the same job mixed formula between 1000 and 4000 tons for the traveled way and auxiliary lanes. The RE will combine daily production areas less than 1000 tons with previous or subsequent production areas to meet the minimum lot requirements. When the maximum lot requirement is exceeded in a day's production, the RE will divide the area of HMA placed into 2 lots with approximately equal areas. The RE may increase the maximum lot size to cover one day's paving production. If multiple plants produce the BRIC, ensure production is kept separate so that separate lots can be designated by the RE.

Ramp pavement lots are defined as approximately 10,000 square yards of pavement in ramps. The RE may combine ramps with less than the minimum area into a single lot. If 2 or more ramps are included in a single lot, the RE will require additional cores to ensure that at least 1 core is taken from each ramp.

Other pavement lots are defined as approximately 10,000 square yards of pavement in shoulders and other undefined areas.

The ME will calculate the percent defective (PD) as the percentage of the lot outside the acceptable range of 1 percent air voids to 6 percent air voids. The acceptable quality limit is 10 percent defective. For lots in which PD < 10, the Department will award a positive pay adjustment. For lots in which PD > 10, the Department will assess a negative pay adjustment.

The ME will determine air voids from 5 cores taken from each lot in random locations. The ME will determine air voids of cores from the values for the maximum specific gravity of the mix and the bulk specific gravity of the core. The ME will determine the maximum specific gravity of the mix according to NJDOT B3 and AASHTO T 209, except that minimum sample size may be waived in order to use a 6-inch diameter core sample. The ME will determine the bulk specific gravity of the compacted mixture by testing each core according to AASHTO T 166.

The ME will calculate pay adjustments based on the following:

1. **Sample Mean ($\overline{X}$) and Standard Deviation (S) of the N Test Results ($X_1, X_2, \ldots, X_N$).**

$$\overline{X} = \frac{(X_1 + X_2 + \ldots + X_N)}{N}$$

$$S = \sqrt{\frac{(X_1 - \overline{X})^2 + (X_2 - \overline{X})^2 + \ldots + (X_N - \overline{X})^2}{N - 1}}$$

2. **Quality Index (Q).**

$$Q_L = \frac{(\overline{X} - 1.0)}{S}$$

$$Q_U = \frac{(6.0 - \overline{X})}{S}$$

3. **Percent Defective (PD).** Using NJDOT ST for the appropriate sample size, the Department will determine PD_L and PD_U associated with Q_L and Q_U, respectively. $PD = PD_L + PD_U$

4. **Percent Pay Adjustment (PPA).** Calculate the PPA for traveled way and ramp lots as specified in Table 408.03.03-1.

Table 408.03.03-1 PPA for BRIC Lots

	Quality	PPA
BRIC	PD < 30	PPA = 1 − (0.1 PD)
	PD ≥ 30	PPA = 40 − (1.4 PD)

Calculate the PPA for other pavement lots as specified in Table 401.03.03-4.

5. **Outlier Detection.** The ME will screen all acceptance cores for outliers using a statistically valid procedure. If an outlier is detected, replace that core by taking an additional core at the same offset and within 5 feet of the original station. The following procedure applies only for a sample size of 5.

    1. The ME will arrange the 5 core results in ascending order, in which X_1 represents the smallest value and X_5 represents the largest value.
    2. If X_5 is suspected of being an outlier, the ME will calculate:

$$R = \frac{X_5 - X_4}{X_5 - X_1}$$

    3. If X_1 is suspected of being an outlier, the ME will calculate:

$$R = \frac{X_2 - X_1}{X_5 - X_1}$$

    4. If R > 0.642, the value is judged to be statistically significant and the core is excluded.

6. **Retest.** If the initial series of 5 cores produces a percent defective value of PD ≥ 30 for mainline or ramp lots, or PD ≥ 50 for other pavement lots, the Contractor may elect to take an additional set of 5 cores at random locations chosen by the ME. Take the additional cores within 15 days of receipt of the initial core results. If the additional cores are not taken within the 15 days, the ME will use the initial core results to determine the PPA. If the additional cores are taken, the ME will recalculate the PPA using the combined results from the 10 cores.

7. **Removal and Replacement.** If the final lot PD ≥ 75 (based on the combined set of 10 cores or 5 cores if the Contractor does not take additional cores), remove and replace the lot and all overlying work. The replacement work is subject to the same requirements as the initial work.

I. **Thickness Requirements.** When required for thickness determination, drill core holes as specified in 401.03.05. The Department will evaluate thickness as specified in 401.03.03.I.

408.04 MEASUREMENT AND PAYMENT

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

Item	*Pay Unit*
BINDER RICH INTERMEDIATE COURSE, 4.75MM	TON

The Department will measure BINDER RICH INTERMEDIATE COURSE, 4.75MM by the ton as indicated on the certified weigh tickets, excluding unused material.

The Department will make payment for CORE SAMPLES, HOT MIX ASPHALT as specified in 401.04

The Department will make payment for TACK COAT as specified in 401.04.

THE FOLLOWING SECTION IS ADDED TO DIVISION 900:

902.09 BINDER RICH INTERMEDIATE COURSE (BRIC)

902.09.01 Composition of Mixture.

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

The composition of the BRIC mixture is coarse aggregate, fine aggregate, polymer modified asphalt binder, and may also include mineral filler, and crumb rubber. Do not add RAP, CRCG, GBSM, or RPCSA. Ensure that the combination meets the aggregate grading and minimum binder content in Table 902.09.03-1 and meets the volumetric requirements in Table 902.09.03-2.

Use an asphalt binder that is storage-stable, pre-blended, homogeneous, polymer modified asphalt binder using Styrene-Butadiene (SB), Styrene-Butadiene-Styrene (SBS), or Styrene-Butadiene-Rubber (SBR) formulations. Modified binders that graded out as a PG 70-28 were found to be adequate to produce mixtures that meet the design criteria for performance testing as specified in Table 902.09.03-3. Similar modified asphalts that are at least a PG 70-28 and that produce mixtures that meet the mixture performance tests are permitted. Consult with the asphalt binder producer during the mix design process to produce a mixture that meets the design criteria for performance testing. .

For coarse aggregate in BRIC, use crushed stone conforming to 901.05.01.

For fine aggregate, use stone sand conforming to 901.05.02. Ensure that the combined fine aggregate in the mixture conforms to the requirements for compaction level M as specified in Table 902.02.02-2.

Use mineral filler, if necessary, that conforms to 901.05.03.

902.09.02 Mix Design

At least 45 days before initial production, submit a job mix formula for the BRIC on forms supplied by the Department, to include a statement naming the source of each component and a report showing that the results meet the criteria specified in Tables 902.09.03-1 and 902.09.03-2.

The job mix formula for the BRIC mixture establishes the percentage of dry weight of aggregate passing each required sieve size and an optimum percentage of asphalt binder based upon the weight of the total mix. Determine the optimum percentage of asphalt binder according to AASHTO R 35 and M 323 with an N_{des} of 50 gyrations. Before maximum specific gravity testing or compaction of specimens, condition the mix for 2 hours according to the requirements for conditioning for volumetric mix design in AASHTO R 30, Section 7.1. If the absorption of the combined aggregate is more than 1.5 percent according to AASHTO T 84 and T 85, ensure that the mix is short term conditioned for 4 hours according to AASHTO R 30, Section 7.2 prior to compaction of specimens (AASHTO T 312) and determination of maximum specific gravity (AASHTO T 209). Ensure that the job mix formula is within the master range specified in Table 902.09.03-1.

Ensure that the job mix formula provides a mixture that meets a minimum tensile strength ratio (TSR) of 85% when prepared according to AASTHO T 312 and tested according to AASHTO T 283 with the following exceptions:

1. Before compaction, condition the mixture for 2 hours according to AASHTO R 30 Section 7.1.
2. Compact specimens with 40 gyrations.
3. Extrude specimens as soon as possible without damaging.
4. Use AASHTO T 269 to determine void content.
5. Record the void content of the specimens.
6. If less than 55% saturation is achieved, the procedure does not need to be repeated, unless the difference in tensile strength between duplicate specimens is greater than 25 pounds per square inch.
7. Report any visual stripping in accordance with AASHTO T 283 Section 11.3, modify or readjust the mix if stripping is evident.

For each mix design, submit with the mix design forms 3 gyratory specimens and 1 loose sample corresponding to the composition of the JMF. 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 Tables 902.09.03-1 and 902.09.03-2. The ME reserves the right to be present at the time the gyratory specimens are molded.

In addition, submit nine gyratory specimens and five 5-gallon buckets of loose mix to the ME. The ME will use these additional samples for performance testing of the BRIC mix. The ME reserves the right to be present at the time of molding the gyratory specimens. Ensure that the additional gyratory specimens are compacted according to AASHTO T 312, are 77 mm high, and have an air void content of 3.5 ± 0.5 percent. The ME will test six (6) specimens using an Asphalt Pavement Analyzer (APA) according to AASHTO TP 63 at 64°C, 100 psi hose pressure, and 100 lb. wheel load. The ME will use the remaining three (3) specimens to test using an Overlay Tester (NJDOT B-10) at 25°C and a joint opening of 0.025 inch.

The ME will approve the JMF if the average rut depth for the 6 specimens in the asphalt pavement analyzer testing is not more than 6 mm in 8,000 loading cycles and the number of cycles to failure in the Overlay Tester is greater than 700. If the JMF does not meet the APA and Overlay Tester criteria, redesign the BRIC mix and submit for retesting. The JMF for the BRIC mixture is in effect until modification is approved by the ME.

When unsatisfactory results for any specified characteristic of the work make it necessary, the Contractor may establish a new JMF for approval. In such instances, if corrective action is not taken, the ME may require an appropriate adjustment to the JMF.

Should a change in sources be made or any changes in the properties of materials occur, the ME will require that a new JMF be established and approved before production can continue.

The ME may verify a mix on an annual basis rather than on a project-to-project basis if the properties and proportions of the materials do not change. If written verification is submitted by the HMA supplier that the same source and character of materials are to be used, the ME may waive the requirement for the design and verification of previously approved mixes.

902.09.03 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 BRIC, ensure that the temperature of the mixture at discharge from the plant or surge and storage bins is at least 10 °F above the manufacturer's recommended laydown temperature. Do not allow the mixture temperature to exceed 330 °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.

B. Sampling. The ME will take 5 stratified random samples of HMA for volumetric acceptance testing from each lot of approximately 3500 tons of a mix. When a lot of HMA 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, unless composition is determined by hot bin analysis. If using hot bin analysis at a fully automated batch plant, take 5 samples from each lot corresponding to the volumetric acceptance samples, under the supervision of the ME.

C. Quality Control Testing. The HMA 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 in Tables 902.09.03-1, 902.09.03-2, and 902.09.03-3. 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 fully automated plants, the QC technician may determine composition using hot bin analysis according to NJDOT B-5. Use only one method for determining composition within a lot.

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, and mineral filler, according to the approved quality control plan for the plant.

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 HMA to the number of design gyrations (N_{des}) of 50 gyrations, 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 HMA.

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

Ensure that the HMA mixture conforms to the requirements specified in Table 902.09.03-2, and to the gradation requirements in Table 902.09.03-1. 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.

E. Performance Testing. Provide five (5) 5-gallon buckets of loose mix to the ME for testing in the Asphalt Pavement Analyzer (APA) and the Overlay Tester device. Ensure that the first sample is taken during the construction of the test strip as specified in 408.03.01.C. Thereafter, sample every second lot or as directed by the ME. If a sample does not meet the design criteria for performance testing as specified in Table 902.09.03-3, the ME may stop production of BRIC until corrective action is taken. If the BRIC mix exceeds the APA criteria of 12 mm in 8000 loading cycles, the RE may require removal and replacement of the lot of BRIC.

Table 902.09.03-1 BRIC Grading of Total Aggregate

Sieve Size	Percent Passing by Mass	
	minimum	**maximum**
3/8”	100	--
#4	90	100
#8	55	90
#30	20	55
#200	4.0	10.0
Minimum Percent Asphalt Binder by Mass of Total Mix	7.0	

Table 902.09.03-2 Volumetric Requirements for Design and Control of BRIC

	Required Density (% of Max Sp. Gr.)	Voids in Mineral Aggregate	Dust to Binder Ratio	Draindown AASHTO T 305

	@ N_{des} (50 gyrations)	@ N_{max} (100 gyrations)	(VMA)		
Design Requirements	97.5	≤ 99.0	≥ 18.0 %	0.6 – 1.2	≤ 0.1 %
Control Requirements	96.5 – 98.5	≤ 99.0	≥ 18.0 %	0.6 – 1.3	≤ 0.1 %

Table 902.09.03-3 Performance Testing Requirements for BRIC	
Test	**Requirement**
Asphalt Pavement Analyzer (AASHTO TP 63)	< 6 mm@ 8,000 loading cycles
Overlay Tester (NJDOT B-10)	> 700 cycles

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 temperature 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°F (0 to 35°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°F (15°C) or 77°F (25°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.

APPENDIX C – BRIDGE DECK WATER-PROOFING WEARING COURSE (BDWSC)

Section 555 - Bridge Deck WaterProof Surface Course

555.01 DESCRIPTION

This Section describes the requirements for constructing bridge deck waterproof surface course (BDWSC).

555.02 MATERIALS

555.02.01 Materials

Provide materials as specified:

Tack Coat 64-22, PG 64-22 .... 902.01.01
Tack Coat:
Cut-Back Asphalt, Grade RC-70 .... 902.01.02
Emulsified Asphalt, Grade RS-1, SS-1, SS-1h, Grade CSS-1 or CSS-1h 902.01.03
Joint Sealer, Hot Poured 914.02
Polymerized Joint Adhesive 914.03

A. BDWSC. Provide BDWSC mixture that is produced at an HMA plant that is listed on the QPL and meets the requirements specified in 1009.01. Ensure that the BDWSC mixture meets the following requirements:

1. **Composition of Mixtures.** Composition of the mixture for BDWSC is coarse aggregate, fine aggregate, and asphalt binder, and may also include mineral filler and crumb rubber. Do not use Reclaimed Asphalt Pavement (RAP), Ground Bituminous Shingle Material, Remediated Petroleum Contaminated Soil Aggregate, or Crushed Recycled Container Glass (CRCG) in BDWSC.

   Use an asphalt binder that is storage-stable, pre-blended, homogeneous, polymer modified asphalt cement using Styrene-Butadiene (SB), Styrene-Butadiene-Styrene (SBS), or Styrene-Butadiene-Rubber (SBR) formulations. Modified binders that graded out as a PG 82-34 were found to be adequate to produce mixtures that pass the mixture performance tests. Similar modified asphalts that are at least a PG 76-28 and that produce mixtures that meet the mixture performance tests are permitted. Alternately, the Contractor may use a concentrated thermoplastic polymeric asphalt modifier, integrated during the hot mix asphalt mixing process.

   Use coarse aggregate that conforms to 901.05.01 and is classified as argillite, gneiss, granite, quartzite, or trap rock as defined in 901.03.01. Use fine aggregate that is stone sand as specified in 901.05.02 and has an uncompacted void content of at least 45 percent when tested according to AASHTO T 304, Method A. In addition, ensure that the minimum sand equivalent is 45 percent when tested according to AASHTO T 176. Ensure that mineral filler, if used, conforms to 901.05.03.

2. **Mix Design.** At least 45 days before initial production, submit a JMF for the BDWSC on forms supplied by the Department. Include a statement naming the source of each component and a report confirming the results meet the criteria specified in Tables 555.02.01-1 and 555.02.01-2.

   Establish the percentage of dry weight of aggregate passing each required sieve size and an optimum percentage of asphalt binder based upon the weight of the total mix. Determine the optimum percentage of asphalt binder according to AASHTO R 35 and M 323 with an N_{des} of 50 gyrations. Before maximum specific gravity testing or compaction of specimens, condition the mix for 2 hours according to the requirements for conditioning for volumetric mix design in AASHTO R 30, Section 7.1. If the absorption of the combined aggregate is more than 1.5 percent according to AASHTO T 84 and T 85, short term condition the mix for 4 hours according to AASHTO R 30, Section 7.2 prior to compaction of specimens (AASHTO T 312) and determination of maximum specific gravity (AASHTO T 209). Ensure that the JMF is within the master range specified in, Table 555.02.01-1.

   Ensure that the mixture meets a minimum tensile strength ratio (TSR) of 90 percent when tested according to AASHTO T 283 with the following exceptions:

   1. Before compaction, condition the mixture for 2 hours according to AASHTO R 30 Section 7.1.
   2. Compact specimens with 40 gyrations according to AASHTO T 312.
   3. Extrude specimens as soon as possible without damaging.

4. Use AASHTO T 269 to determine void content.
5. Record the void content of the specimens.
6. If less than 55 percent saturation is achieved, the procedure does not need to be repeated, unless the difference in tensile strength between duplicate specimens is greater than 25 pounds per square inch.
7. If visual stripping is detected, modify or readjust the mix.

For each mix design, submit 3 gyratory specimens and one loose sample corresponding to the composition of the JMF, including the design asphalt content, with the mix design forms. The ME will use these samples for verification of the properties of the job mix formula. Compact the specimens to the design number of gyrations (N_{des}). To be acceptable, all three gyratory specimens must comply with the gradation and asphalt content requirements in Table 555.02.01-1 and with the control requirements in Table 555.02.01-2. The ME reserves the right to be present at the time of molding the gyratory specimens.

In addition, submit 6 gyratory specimens and two (2) 5-gallon buckets of loose mix to the ME. The ME will use these additional samples for performance testing of the BDWSC mix. Ensure that the additional gyratory specimens are compacted according to AASHTO T 312, are 77 mm high, and have an air void content of 1.5 ± 0.5 percent. The ME will test the specimens using an Asphalt Pavement Analyzer according to AASHTO TP 63 at 64°C, 100 psi hose pressure, and 100 lb. wheel load. The ME will use the supplied loose mix to compact two (2) samples to an air void content of 1.5 ± 0.5 percent for Flexural Beam Fatigue testing. The ME will test the fatigue specimens according to AASHTO T 321 at 15°C, 10 Hz loading frequency, and 1,500 micro-strains. The ME will approve the JMF if the average rut depth for the 6 specimens in the asphalt pavement analyzer testing is not more than 3 mm in 8,000 loading cycles and the fatigue life, as determined by AASHTO T 321, is greater than 100,000 cycles. If the JMF does not meet the APA and Flexural Beam Fatigue criteria, redesign the BDWSC mix and submit for retesting.

The JMF for the BDWSC mixture is in effect until modification is approved.

When unsatisfactory results for any specified characteristic of the work make it necessary, the Contractor may establish a new JMF for approval. In such instances, if corrective action is not taken, the ME may require an appropriate adjustment to the JMF.

Should a change in sources be made or a change in the properties of materials occur, the ME will require that a new JMF be established and approved before production can continue.

Table 555.02.01-1 Job Mix Formula Requirements for BDWSC

Sieve Size	Percent Passing by Mass
½”	100
3/8”	80-100
#4	55-85
#8	32-42
#16	20-30
#30	12-22
#50	7-16
#100	3-12
#200	2.0-6.0
Minimum Percent Asphalt Binder by Mass of Total Mix	7.0

Table 555.02.01-2 Volumetric Requirements for Design and Control of BDWSC

	Required Density (% of Max Sp. Gr.)	Voids Filled with Asphalt	Voids in Mineral Aggregate	Dust to Binder Ratio	Draindown AASHTO T 305
	N_{des} (50 gyrations)	(VFA)	(VMA)		
Design	99	90 - 100	≥ 18.0 %	0.3 – 0.9	≤ 0.1 %

Requirements					
Control Requirements	98 - 100	90 - 100	≥ 18.0 %	0.3 – 0.9	≤ 0.1 %

Table 555.02.01-3 Performance Testing Requirements for BDWSC	
Test	**Requirement**
APA @ 8,000 loading cycles (AASHTO TP 63)	< 3 mm
Flexural Fatigue Life (AASHTO T 321)	> 100,000 cycles

3. 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.

Ensure that the temperature of the mix at discharge from the plant or storage silo meets the recommendation of the supplier of the asphalt binder or supplier of the asphalt modifier.

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.

b. Sampling. Perform sampling as specified in 902.02.04.B.

c. Quality Control Testing. Perform quality control testing as specified in 902.02.04.C.

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 HMA to the 50 design gyrations (N_{des}), 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 BDWSC.

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

Ensure that the HMA mixture conforms to the requirements specified in Table 555.02.01-1 and 555.02.01-2. 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.

e. Performance Testing. Provide five (5) 5-gallon buckets of loose mix to the ME for testing in the Asphalt Pavement Analyzer (APA) and the Flexural Beam Fatigue device. Ensure that the first sample is taken in the first lot of production. Thereafter, sample every second lot. The ME may stop production of BDWSC if a sample does not meet the design criteria for performance testing as detailed in Table 555.02.01-3.

B. Asphaltic Plug Joint System. Use one of the following asphaltic plug joint systems:

Deery FBJ-6297 Flexible Asphaltic Plug Joint System as supplied by

Deery American Corporation
P.O. Box 4099
Grand Junction, CO 81502
Telephone: 970-858-3678

Thorma-Joint as supplied by
Dynamic Surface Applications, Ltd.
373 Village Road
Pennsdale, PA 17756
Telephone: 800-491-5663

Ensure that the asphaltic plug joint conforms with ASTM D 6297.

Use closure plates that are mild steel plate and minimum 1/8 inch thick by eight (8) inch wide by 3 foot in length with pre-drilled holes at 1 (one) foot on center for the locating pins.

For the open joints in barrier curbs, parapets and sidewalks adjacent to asphaltic plug joints, use a cold applied silicone joint sealer conforming to ASTM D 5893, Type NS.

C. **Retrofit Strip Seal Joint System.** Use a strip seal joint system that builds up the joint using elastomeric or polymer concrete and seals the joint using a strip seal expansion joint. Ensure that the joint system includes a method for securing the strip seal with the elastomeric or polymer concrete.

Ensure that the strip seal joint system is capable of being constructed within the allowable lane closure hours for the project and compatible with installation in an asphalt overlay.

Use strip seal gland that is a neoprene strip seal gland according to 914.04.02.B or a preformed silicon strip seal meeting the criteria in Table 555.02.01-4.

Table 555.02.01-4 Requirements for Preformed Silicon Strip Seal

Property	Test Method	Requirement
Durometer (Shore A)	ASTM D 2240	55 ± 5
Tensile (psi)	ASTM D 412	550 minimum
Elongation	ASTM D 412	350% minimum
Tear (die B ppi)	ASTM D 624	80 minimum
Compression Set @ 350°F, 22 hrs.	ASTM D 395	30% maximum
Operating Temperature Range[1]		– 60°F to + 450°F
Specific Gravity		1.51
Color		Black

1. The heat age data at temperatures above 300°F does not apply in this application but in general, tested at 302°F and 437°F, no degradation occurs causing functional concern. The operating temperature range indicates the material remains elastomeric in nature at the above temperatures.

555.02.02 Equipment

Provide equipment as specified:

HMA Paver 1003.03
HMA Compactor 1003.05
Bituminous Material Distributor 1003.07
Sealer Application System 1003.08
Mechanical Sweeper 1008.03
Hot-Air Lance 1008.06
HMA Plant 1009.01
HMA Trucks 1009.02

Provide a thin-lift nuclear density gauge according to ASTM D 2950.

For the asphaltic plug joint, provide a single unit equipped with thermostatic controls and continuous reading of the temperature of both the asphaltic material and the heat transfer medium. Ensure that material vat is oil jacketed, double walled with the space between the inner and outer shells filled with oil or other heat transfer medium. Ensure that unit has full sweep, horizontal agitation that lifts the material from the bottom of the reservoir and turns the material over. Agitation shall be capable of mixing and suspending aggregate filled materials having a specific gravity as high as 3.0.

555.03 CONSTRUCTION

555.03.01 BDWSC

A. Paving Plan. At least 20 days before the start of placing the BDWSC, submit to the RE for approval a detailed plan of operation as specified in 401.03.03.A. Include in the paving plan a proposed location for the test strip.

B. Weather Limitations. Do not place BDWSC if it is precipitating. Do not allow trucks to leave the plant when precipitation is imminent. The Contractor may resume operations when the precipitation has stopped and the surface is free of water.

Do not pave if the base temperature is below 50 °F.

C. Test Strip. Construct a test strip of the BDWSC at a location agreed upon with the RE. Ensure that the tack coat or prime coat has been placed as specified in 555.03.01.D, before placing BDWSC. Transport and deliver, spread and grade, and compact as specified in 555.03.01.E, 555.03.01.F, and 555.03.01.G, respectively, and according to the approved paving plan. Construct a test strip of at least 60 Tons. While constructing the test strip, record the following information and submit to the RE:

1. **Ambient Temperature.** Measure ambient temperature at the beginning and end of each day's paving operation.

2. **Base Temperature.** Measure the surface temperature of the existing base before paving.

3. **HMA Temperature.** Measure the temperature of the HMA immediately after placement.

4. **Roller Pattern.** Provide details on the number of rollers, type, and number of passes used on the test strip.

5. **Nuclear Density Gauge Readings.** Obtain the maximum density from the plant, and input it into the nuclear density gauge. Use the nuclear density gauge to read the bulk density and percent air voids.

6. **Quality Control Core Density Test Results.** Take 5 randomly selected quality control cores to test for the bulk specific gravity and the maximum specific gravity.

   Use drilling equipment with a water-cooled, diamond-tipped, masonry drill bit that shall produce 6-inch nominal diameter cores for the full depth of the pavement. Remove the core from the pavement without damaging it. After removing the core, remove all water from the hole. Fill the hole with HMA or cold patching material, and compact the material so that it is 1/4 inch above the surrounding pavement surface.

   Compare the nuclear density gauge readings and the core test results to establish a correlation. Use this correlation as a guide for the continued use of the nuclear density gauge for density control.

If the test strip does not meet requirements, make adjustments and construct a second test strip. If the second test strip does not meet requirements, suspend paving operations until written approval to proceed is received.

Before making adjustments to the paving operations, notify the RE in writing.

D. Tack Coat. Clean the surface and apply tack coat as specified in 401.03.02. Use the same tack coat material as required for adjacent roadway paving on the Project. Ensure that the tack coat is full cured prior to placing the BDWSC. Apply a 1/8-inch thick, uniform coating of polymerized joint adhesive to vertical contact surfaces of curbing, gutters, scuppers, parapets and other structures before the placing of the BDWSC against them. Apply the polymerized joint adhesive slowly to ensure an even coating thickness.

E. Transportation and Delivery of HMA. Transport and deliver BDWSC as specified in 401.03.03.D except that the use of an MTV is not required.

F. **Spreading and Grading.** Ensure that required deck repairs have been completed before placing the BDWSC. Place BDWSC at the laydown temperature recommended by the supplier of the asphalt binder or the supplier of the asphalt modifier if the dry mix modified process is used. Spread and grade BDWSC as specified in 401.03.03.E.

G. **Compacting.** Compact as specified in 401.03.03.F. Operate rollers in static mode only.

H. **Opening to Traffic.** Remove loose material from the traveled way, shoulder, and auxiliary lanes before opening to traffic. Do not allow traffic or construction equipment on the BDWSC until the surface temperature is less than 170 °F.

I. **Air Void Requirements.** Use a thin-lift nuclear density gauge to measure in-place bulk specific gravity. Correct the reading using correction factor developed during the test strip. Calculate the air voids using the maximum specific gravity supplied by the QC technician at the HMA plant. Compact the mixture so that the air voids are a maximum of 3 percent.

J. **Ride Quality Requirements.** The Department may evaluate the surface course placed in the traveled way as specified in 401.03.03.J using the equations for ramps and shoulders in Table 401.03.03-7.

K. **Treatment of Fixed-End Deck Joints**. Verify that the fixed-end joint and the type of header.

1. If the joint is an armored joint, affix a 1/8 inch thick galvanized steel plate over the open joint using intermittent welding of at least 1 inch in every 12 inches on the leading edge just before placing the BDWSC. Ensure that the plate is wide enough to extend at least 2 inches over the opening of the armored joint. After the BDWSC is installed, saw and seal over the trailing edge of the plate. Perform the sawcutting and sealing according to 401.03.04 except make the width of cut 1/2 inch and the depth of cut 1 1/2 inches.
2. If the joint is not armored, repair the concrete header and end of the deck, if necessary. Use Hilti gun or some other means to attach plate to concrete header or deck on the leading edge. Ensure that the plate is wide enough to extend at least 2 inches over the opening of the joint. After the BDWSC is installed, saw and seal over the trailing edge of the plate. Perform the sawcutting and sealing according to 401.03.04 except make the width of cut 1/2 inch and the depth of cut 1 1/2 inches.
3. If there is no header, repair the end of the deck before the BDWSC overlay. After the BDWSC overlay, saw and seal the overlay over the joint interface between the end of the deck and the roadway HMA. Perform the sawcutting and sealing according to 401.03.04 except make the width of cut 1/2 inch and the depth of cut 1 1/2 inches.

555.03.02 Asphaltic Plug Joint System

A. **Manufacturer's Representative and Recommendations.** Submit two copies of written installation procedures and material certifications two weeks prior to the first scheduled installation to the RE. Arrange with the manufacturer of the joint system to assign a representative who is completely knowledgeable and competent in all aspects with the joint systems materials and installation procedures.

Ensure that the representative is present during each joint system installation to assure proper construction, material preparation, installation and curing. The representative is responsible to advise the RE and the Contractor that the correct installation methods are being followed, to train assigned personnel in the correct methods of installation, and to verify proper installation of the joint in writing to the RE.

B. **Weather Limitations.** Do not install the asphaltic plug joints when wet conditions exist or frost planes are present on the surrounding structure. If within the 12 hours before placement the National Weather Service locally forecasts a 60 percent chance or greater of precipitation during the scheduled placement, postpone the placement of asphaltic plug joint. Do not place asphaltic plug joints if there is precipitation or when precipitation is imminent. Resume installation operations when the chance of precipitation is less than 60 percent and the surface is dry.

Do not place asphaltic plug joints if the surface temperature of the pavement is below 50 ˚F.

C. **Preparation.** Center the joint installation over the existing expansion joint gap and to the width determined by the manufacturer. Variation in the width of the joint may be necessary to accommodate site conditions.

Saw cut the pavement transversely at the determined width along the joint to a two (2) inch minimum depth. To permit the new joint system to be installed, remove all material, including wearing surface, masking or covering material, waterproofing membrane, concrete header, and old joint material between the saw cuts. This will form the blockout for the asphaltic plug joint. Ensure that the bottom surface of the blockout, is parallel with the plane of the roadway surface (true and flat). If it is necessary to remove concrete, use only hand held tools. Remove existing materials without damaging existing sound concrete that is to remain. Repair any damage to sound concrete in accordance with Subsection 551.03.01.

Grit blast all joint surfaces, dry and free of dust, dirt, grease, loose materials and any other matter that will inhibit bonding. Clean the concrete surface to the satisfaction of the manufacturer's representative. Remove all dust and dry the area and at least 6 inches on either side of the area using a hot air lance.

D. Installation of Backer Rod and Closure Plate. If joint material is missing, place backer rod into the joint opening at a minimum depth of one (1) inch, followed by an application of asphaltic mastic material as recommended by the manufacturer. Apply the asphaltic mastic onto the blockout. Avoid filling the bridge joint if elastomeric compression seal is in place.

Center and place the closure plate over the entire length of the joint opening into the asphaltic mastic. Sit the closure plate flush on the bottom of the joint blockout to prevent asphaltic plug joint material from entering the joint opening. Butt the plates together and do not overlap them. Secure the plates by placing centering pins through pre-stamped holes into the backer rod, unless recommended otherwise by the manufacturer. Ensure that the closure plate follows the deck at grade breaks by bending the plate or butting two plates at the grade break. If field cuts are required to accommodate grade breaks, repair hot dipped galvanized coating according to ASTM A 780.

Immediately coat the bridging plates with asphaltic mastic making sure that they are encapsulated by the adhesive. Coat all exposed areas of the blockout area on the horizontal, vertical and closure plate surfaces with asphaltic mastic to form a monolithic waterproofing membrane.

E. Heating, Mixing, and Applying Asphaltic Plug Joint Material. Do not use dry radiant or direct flame heating on the asphaltic binder. Mix the asphalt binder and aggregates according to manufacturer's recommendations. Heat the material to the manufacturer's recommended application temperature (minimum of 350 ºF). Determine temperature at the discharge chute with infrared thermometer.

Install the asphaltic bridge joint material according to manufacturer's recommendations. Compact the asphaltic bridge joint material according to the manufacturer's recommendations.

F. Opening to Traffic. Open the asphaltic plug joint after it has cooled sufficiently and according to the manufacturer's recommendation.

555.03.03 Retrofit Strip Seal Joint System

A. Working Drawings. Submit working drawings for certification for the retrofit strip seal joint system as per section 105.05. As a minimum include the following information of the working drawings:

1. Manufacturer's requirements for materials in the joint system.
2. Method of installation including sequence of installation, temperature restrictions, materials handling requirements.
3. Ensure that the removal and reinstallation of the strip seal can be accomplished from above the joint without full closure of the roadway.
4. Method to be used to ensure that the strip seal does not protrude above the top of the joint.

B Manufacturer's Representative and Recommendations. Submit two copies of written installation procedures and material certifications two weeks prior to the first scheduled installation to the RE. Arrange with the manufacturer of the joint system to assign a representative who is completely knowledgeable and competent in all aspects with the joint systems materials and installation procedures.

Ensure that the representative is present during each joint system installation to assure proper construction, material preparation, installation and curing. The representative is responsible to advise the RE and the Contractor that the correct installation methods are being followed, to train assigned personnel in the correct methods of installation, and to verify proper installation of the joint in writing to the RE.

C. Weather Limitations. Follow the manufacturer's recommendations regarding weather limitations.

D. Preparation. Center the joint installation over the existing expansion joint gap and to the width determined by the manufacturer. Variation in the width of the joint may be necessary to accommodate site conditions.

Saw cut the pavement transversely at the determined width along the joint to a two (2) inch minimum depth. To permit the new joint system to be installed, remove all material, including wearing surface, masking or covering material, waterproofing membrane, concrete header, and old joint material between the saw cuts. If it is necessary to remove concrete, use only hand held tools. Remove existing materials without damaging existing sound concrete that is to remain. Use elastomeric or polymer concrete to repair any damage to sound concrete.

Grit blast all joint surfaces, dry and free of dust, dirt, grease, loose materials and any other matter that will inhibit bonding. Clean the concrete surface to the satisfaction of the manufacturer's representative.

E. Installation Elastomeric or Polymer Concrete. Form the joint and install hardware, if necessary. If hardware is installed to mechanically hold the strip seal gland, ensure that it is placed at the proper depth for the joint. Mix and place the elastomeric or polymer concrete according to the manufacturer's recommendations. Open to traffic according to the manufacturer's recommendations.

F. Installation Strip Seal Gland. Prepare the surfaces and the strip seal gland according to manufacturer's recommendations. Install the strip seal gland according to manufacturer's recommendations. Ensure that the strip seal gland is installed to the proper depth and does not protrude above the top of the joint. Open to traffic according to the manufacturer's recommendations.

555.04 MEASUREMENT AND PAYMENT

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

Item	*Pay Unit*
BRIDGE DECK WATERPROOF SURFACE COURSE	TON
ASPHALTIC BRIDGE JOINT SYSTEM	LINEAR FOOT
RETROFIT STRIP SEAL JOINT SYSTEM	LINEAR FOOT

The Department will measure BRIDGE DECK WATERPROOF SURFACE COURSE by the ton as indicated on the certified weigh tickets, excluding unused material.

The Department will make payment for TACK COAT or TACK COAT 64-22 as specified in 401.04.

The Department will make payment for POLYMERIZED JOINT ADHESIVE as specified in 401.04.

The Department will measure ASPHALTIC BRIDGE JOINT SYSTEM and RETROFIT STRIP SEAL JOINT SYSTEM in linear feet from curb to curb along the bridge deck joint.

APPENDIX D – BITUMINOUS RICH BASE COURSE (BRBC)

Section 407- Bottom Rich Base Course

407.01 DESCRIPTION

This Section describes the requirements for constructing bottom rich base course (BRBC).

407.02 MATERIALS

407.02.01 Materials

Provide materials as specified:

BRBC…………………………...…………. ……………………………………………….…902.10

Use an approved HMA surface course to fill core holes, maintaining the material hot enough to compact. The Contractor may use a commercial type of cold mixture as patching material for filling core holes if HMA surface course is not being produced when coring.

407.02.02 Equipment

Provide equipment as specified:

Materials Transfer Vehicle (MTV) …………...……………………………...…………….1003.01
HMA Paver………………………………………………………………………..……....1003.03
HMA Compactor……………………………………………………………...………….1003.05
Bituminous Material Distributor ..……………………………………………………….1003.07
HMA Plant………………………………………………………………………..……..1009.01
HMA Trucks ………………………………………………………………..……..……1009.02

Provide a thin-lift nuclear density gauge according to ASTM D 2950

Install a paver hopper insert with a minimum capacity of 14 tons in the hopper of the HMA Paver.

407.03 CONSTRUCTION

407.03.01 BRBC

A. **Paving Plan.** At least 20 days before the start of placing the BRBC, submit to the RE for approval a detailed plan of operation as specified in 401.03.03.A. If multiple plants are producing the BRBC, determine how material will be separated for testing and acceptance. Include in the paving plan a proposed location for the test strip.

B. **Weather Limitations.** Do not place BRBC if it is precipitating. Do not allow trucks to leave the plant when precipitation is imminent. The Contractor may resume operations when the precipitation has stopped and the surface is free of water.

Do not pave if the base temperature is below 40 °F.

C. **Test Strip.** At least two weeks prior to production of the BRBC, construct a test strip as specified in 401.03.03.C except for the allowance to continue paving. Submit test strip results to the RE. The RE will analyze the test strip results in conjunction with the ME’s results from the HMA plant to approve the test strip. Do not proceed with production paving until receiving written permission from the RE.

D. **Transportation and Delivery of HMA.** Transport and deliver BRBC as specified in 401.03.03.D.

E. **Spreading and Grading.** Ensure that required compaction and grading of the underlying material has been completed before placing the BRBC. Do not start paving of the BRBC until the RE has approved the underlying surface. Place BRBC at the laydown temperature recommended by the supplier of the asphalt binder or the supplier of the asphalt modifier. Spread and grade BRBC as specified in 401.03.03.E.

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

G. Opening to Traffic. Remove loose material from the traveled way, shoulder, and auxiliary lanes before opening to traffic. Do not allow traffic or construction equipment on the BRBC until the surface temperature is less than 120 °F.

H. Air Void Requirements. Mainline lots are defined as the area covered by a day's paving production of the same job mixed formula between 1000 and 4000 tons for the traveled way and auxiliary lanes. The RE will combine daily production areas less than 1000 tons with previous or subsequent production areas to meet the minimum lot requirements. When the maximum lot requirement is exceeded in a day's production, the RE will divide the area of HMA placed into 2 lots with approximately equal areas. The RE may increase the maximum lot size to cover one day's paving production. If multiple plants produce the BRBC, ensure production is kept separate so that separate lots can be designated by the RE.

Ramp pavement lots are defined as approximately 10,000 square yards of pavement in ramps. The RE may combine ramps with less than the minimum area into a single lot. If 2 or more ramps are included in a single lot, the RE will require additional cores to ensure that at least 1 core is taken from each ramp.

Other pavement lots are defined as approximately 10,000 square yards of pavement in shoulders and other undefined areas.

The ME will calculate the percent defective (PD) as the percentage of the lot outside the acceptable range of 1 percent air voids to 8 percent air voids. The acceptable quality limit is 10 percent defective. For lots in which PD < 10, the Department will award a positive pay adjustment. For lots in which PD > 10, the Department will assess a negative pay adjustment.

The ME will determine air voids from 5 cores taken from each lot in random locations. The ME will determine air voids of cores from the values for the maximum specific gravity of the mix and the bulk specific gravity of the core. The ME will determine the maximum specific gravity of the mix according to NJDOT B3 and AASHTO T 209, except that minimum sample size may be waived in order to use a 6-inch diameter core sample. The ME will determine the bulk specific gravity of the compacted mixture by testing each core according to AASHTO T 166.

The ME will calculate pay adjustments based on the following:

1. **Sample Mean ($\overline{X}$) and Standard Deviation (S) of the N Test Results ($X_1, X_2, \ldots, X_N$).**

$$\overline{X} = \frac{(X_1 + X_2 + \ldots + X_N)}{N}$$

$$S = \sqrt{\frac{(X_1 - \overline{X})^2 + (X_2 - \overline{X})^2 + \ldots + (X_N - \overline{X})^2}{N - 1}}$$

2. **Quality Index (Q).**

$$Q_L = \frac{(\overline{X} - 1.0)}{S}$$

$$Q_U = \frac{(8.0 - \overline{X})}{S}$$

3. **Percent Defective (PD).** Using NJDOT ST for the appropriate sample size, the Department will determine PD_L and PD_U associated with Q_L and Q_U, respectively. $PD = PD_L + PD_U$

4. **Percent Pay Adjustment (PPA).** Calculate the PPA for traveled way and ramp lots as specified in Table 401.03.03-3.

Table 401.03.03-3 PPA for BRBC Lots		
	Quality	**PPA**
BRBC	PD < 30	PPA = 1 − (0.1 PD)
	PD ≥ 30	PPA = 40 − (1.4 PD)

Calculate the PPA for other pavement lots as specified in Table 401.03.03-4.

5. **Outlier Detection.** The ME will screen all acceptance cores for outliers using a statistically valid procedure. If an outlier is detected, replace that core by taking an additional core at the same offset and within 5 feet of the original station. The following procedure applies only for a sample size of 5.
   1. The ME will arrange the 5 core results in ascending order, in which X_1 represents the smallest value and X_5 represents the largest value.
   2. If X_5 is suspected of being an outlier, the ME will calculate:

$$R = \frac{X_5 - X_4}{X_5 - X_1}$$

   3. If X_1 is suspected of being an outlier, the ME will calculate:

$$R = \frac{X_2 - X_1}{X_5 - X_1}$$

   4. If R > 0.642, the value is judged to be statistically significant and the core is excluded.

6. **Retest.** If the initial series of 5 cores produces a percent defective value of PD ≥ 30 for mainline or ramp lots, or PD ≥ 50 for other pavement lots, the Contractor may elect to take an additional set of 5 cores at random locations chosen by the ME. Take the additional cores within 15 days of receipt of the initial core results. If the additional cores are not taken within the 15 days, the ME will use the initial core results to determine the PPA. If the additional cores are taken, the ME will recalculate the PPA using the combined results from the 10 cores.

7. **Removal and Replacement.** If the final lot PD ≥ 75 (based on the combined set of 10 cores or 5 cores if the Contractor does not take additional cores), remove and replace the lot and all overlying work. The replacement work is subject to the same requirements as the initial work.

I. **Thickness Requirements.** When required for thickness determination, drill core holes as specified in 401.03.05. The Department will evaluate thickness as specified in 401.03.03.I.

407.04 MEASUREMENT AND PAYMENT

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

Item	*Pay Unit*
BOTTOM RICH BASE COURSE, 19MM	TON

The Department will measure BOTTOM RICH BASE COURSE, 19MM by the ton as indicated on the certified weigh tickets, excluding unused material.

The Department will make payment for CORE SAMPLES, HOT MIX ASPHALT as specified in 401.04

The Department will make payment for PRIME COAT or TACK COAT as specified in 401.04.

THE FOLLOWING SECTION IS ADDED TO DIVISION 900:

902.10 BOTTOM RICH BASE COURSE (BRBC)

902.10.01 Composition of Mixture.

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

The composition of the BRBC mixture is coarse aggregate, fine aggregate, polymer modified asphalt binder, and may also include mineral filler, and crumb rubber. Do not add RAP, CRCG, GBSM, or RPCSA. Ensure that the combination meets the aggregate grading and minimum binder content in Table 902.10.03-1.

Use asphalt binder for BRBC that is PG 76-28 as specified in AASHTO M 320, Table 1. Use PG 76-28 asphalt binder that is a storage-stable, pre-blended, homogeneous, polymer modified asphalt binder using styrene-butadiene or styrene-butadiene-styrene formulations. Ensure that the binder's rolling thin film oven test (AASHTO T 240) residue has a minimum elastic recovery (ASTM D 6084, Procedure A) of 75 percent when tested for at 25 °C. Adjust the mix design as necessary to meet the requirements of 902.10.02. Similar modified asphalts that produce mixtures that meet the mixture performance tests are permitted.

For coarse aggregate in BRBC, use crushed stone conforming to 901.05.01.

For fine aggregate, use stone sand conforming to 901.05.02. Ensure that the combined fine aggregate in the mixture conforms to the requirements for compaction level L as specified in Table 902.02.02-2.

Use mineral filler, if necessary, that conforms to 901.05.03.

902.10.02 Mix Design

At least 45 days before initial production, submit a job mix formula for the BRBC on forms supplied by the Department, to include a statement naming the source of each component and a report showing that the results meet the criteria specified in Tables 902.10.03-1 and 902.10.03-2.

The job mix formula for the BRBC mixture establishes the percentage of dry weight of aggregate passing each required sieve size and an optimum percentage of asphalt binder based upon the weight of the total mix. Determine the optimum percentage of asphalt binder according to AASHTO R 35 and M 323 with an N_{des} of 50 gyrations. Before maximum specific gravity testing or compaction of specimens, condition the mix for 2 hours according to the requirements for conditioning for volumetric mix design in AASHTO R 30, Section 7.1. If the absorption of the combined aggregate is more than 1.5 percent according to AASHTO T 84 and T 85, ensure that the mix is short term conditioned for 4 hours according to AASHTO R 30, Section 7.2 prior to compaction of specimens (AASHTO T 312) and determination of maximum specific gravity (AASHTO T 209). Ensure that the job mix formula is within the master range specified in Table 902.10.03-1.

Ensure that the job mix formula provides a mixture that meets a minimum tensile strength ratio (TSR) of 85% when prepared according to AASTHO T 312 and tested according to AASHTO T 283 with the following exceptions:

1. Before compaction, condition the mixture for 2 hours according to AASHTO R 30 Section 7.1.
2. Compact specimens with 40 gyrations.
3. Extrude specimens as soon as possible without damaging.
4. Use AASHTO T 269 to determine void content.
5. Record the void content of the specimens.
6. If less than 55% saturation is achieved, the procedure does not need to be repeated, unless the difference in tensile strength between duplicate specimens is greater than 25 pounds per square inch.
7. Report any visual stripping in accordance with AASHTO T 283 Section 11.3, modify or readjust the mix if stripping is evident.

For each mix design, submit with the mix design forms 2 gyratory specimens and 1 loose sample corresponding to the composition of the JMF. 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 Tables 902.10.03-1 and 902.10.03-2. The ME reserves the right to be present at the time the gyratory specimens are molded.

In addition, submit six gyratory specimens and four 5-gallon buckets of loose mix to the ME. The ME will use these additional samples for performance testing of the BRBC mix. The ME reserves the right to be present at the time of molding the gyratory specimens. Ensure that the additional gyratory specimens are compacted according to AASHTO T 312, are 77 mm high, and have an air void content of 5.5 ± 0.5 percent. The ME will test the specimens using an Asphalt Pavement Analyzer according to AASHTO TP 63 at 64°C, 100 psi hose pressure, and 100 lb. wheel load. The ME will use the supplied loose mix to compact six (6) samples to an air void content of 5.5 ± 0.5 percent for Flexural Beam Fatigue testing. The ME will test the fatigue specimens according to AASHTO T 321 at 15°C, and 10 Hz loading frequency. Three (3) of the compacted specimens will be tested at 400 microstrains and three (3) of the compacted specimens will be tested at 800 microstrains. The ME will predict the endurance limit of the asphalt mixture in accordance to the methodology proposed in Section 9.3 of NCHRP Project 9-38 document, Proposed Standard Practice for Predicting the Endurance Limit of Hot Mix Asphalt (HMA) for Long-Life Pavement Design, with the exception that endurance limit is defined as 100,000,000 cycles at 100 microstrains.

The ME will approve the JMF if the average rut depth for the 6 specimens in the asphalt pavement analyzer testing is not more than 5 mm in 8,000 loading cycles and the fatigue life, as determined by Section 9.3 of NCHRP Project 9-38 document, is greater than 100,000,000 cycles. If the JMF does not meet the APA and Flexural Beam Fatigue criteria, redesign the BRBC mix and submit for retesting. The JMF for the BRBC mixture is in effect until modification is approved by the ME.

When unsatisfactory results for any specified characteristic of the work make it necessary, the Contractor may establish a new JMF for approval. In such instances, if corrective action is not taken, the ME may require an appropriate adjustment to the JMF.

Should a change in sources be made or a change in the properties of materials occur, the ME will require that a new JMF be established and approved before production can continue.

The ME may verify a mix on an annual basis rather than on a project-to-project basis if the properties and proportions of the materials do not change. If written verification is submitted by the HMA supplier that the same source and character of materials are to be used, the ME may waive the requirement for the design and verification of previously approved mixes.

902.10.03 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 BRBC, ensure that the temperature of the mixture at discharge from the plant or surge and storage bins is at least 10 °F above the manufacturer's recommended laydown temperature. Do not allow the mixture temperature to exceed 330 °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.

B. Sampling. The ME will take 5 stratified random samples of HMA for volumetric acceptance testing from each lot of approximately 3500 tons of a mix. When a lot of HMA 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, unless composition is determined by hot bin analysis. If using hot bin analysis at a fully automated batch plant, take 5 samples from each lot corresponding to the volumetric acceptance samples, under the supervision of the ME.

C. **Quality Control Testing.** The HMA 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 in Tables 902.10.03-1, 902.10.03-2, and 902.10.03-3. 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 fully automated plants, the QC technician may determine composition using hot bin analysis according to NJDOT B-5. Use only one method for determining composition within a lot.

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 HMA to the number of design gyrations (N_{des}) of 50 gyrations, 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 HMA.

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

Ensure that the HMA mixture conforms to the requirements specified in Table 902.10.03-2, 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.

E. **Performance Testing.** Provide five (5) 5-gallon buckets of loose mix to the ME for testing in the Asphalt Pavement Analyzer (APA) and the Flexural Beam Fatigue device. Ensure that the first sample is taken during the construction of the test strip as specified in 407.03.01.C. Thereafter, sample every fifth lot or as directed by the ME. The ME may stop production of BRBC if a sample does not meet the design criteria for performance testing as specified in Table 902.10.03-3.

Table 902.10.03-1 BRBC Grading of Total Aggregate

Sieve Size	**Percent Passing by Mass**	
	minimum	**maximum**
1”	100	--
¾”	90	100
½”	--	90
#8	23	49
#200	2.0	8.0
Minimum Percent Asphalt Binder by Mass of Total Mix	5.0	

Table 902.10.03-2 Volumetric Requirements for Design and Control of BRBC					
	Required Density (% of Max Sp. Gr.)	**Voids Filled with Asphalt**	**Voids in Mineral Aggregate**	**Dust to Binder Ratio**	**Draindown AASHTO T 305**
	@ N_{des} (50 gyrations)	**(VFA)**	**(VMA)**		
Design Requirements	96.5	70 - 80	≥ 13.5 %	0.6 – 1.2	≤ 0.1 %
Control Requirements	95.5 – 97.5	70 - 80	≥ 13.5 %	0.6 – 1.3	≤ 0.1 %

Table 902.10.03-3 Performance Testing Requirements for BRBC	
Test	**Requirement**
Asphalt Pavement Analyzer (AASHTO TP 63)	< 5 mm@ 8,000 loading cycles
Flexural Fatigue Life of HMA (AASHTO T 321)	> 100,000,000 cycles@ 100 microstrains

HIGH RECYCLED ASPHALT PAVEMENT MIX (HRAP)

Section 401 – Hot Mix Asphalt (HMA) Courses

ADD THE FOLLOWING TO 401.01:

401.01 DESCRIPTION

This Section also describes the requirements for constructing a Hot Mix Asphalt (HMA) course with required minimum amounts of Reclaimed Asphalt Pavement (RAP).

ADD THE FOLLOWING TO 401.02.01:

401.02.01 Materials

Hot Mix Asphalt HIGH RAP 902.11

ADD THE FOLLOWING SUBSECTION TO 401.03:

401.03.07 Hot Mix Asphalt (HMA) HIGH RAP

A. Paving Plan. At least 20 days before beginning placing the HMA HIGH RAP, submit a detailed plan of operation as specified in 401.03.03.A to the RE for approval. Include in the paving plan a proposed location for the test strip. Submit for Department approval a plan of the location for the HMA HIGH RAP on the project.

B. Weather Limitations. Place HMA HIGH RAP 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 HMA HIGH RAP as specified in 401.03.03.D.

E. Spreading and Grading. Spread and grade HMA HIGH RAP 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 HMA HIGH RAP.

F. Compacting. Compact HMA HIGH RAP as specified in 401.03.03.F.

G. Opening to Traffic. Follow the requirements of 401.03.03.G for opening HMA HIGH RAP to traffic.

H. Air Void Requirements. Ensure that the HMA HIGH RAP is compacted to meet the air void requirements as specified in 401.03.03.H.

I. Thickness Requirements. Ensure that the HMA HIGH RAP is paved to meet the thickness requirements as specified in 401.03.03.I.

J. Ride Quality Requirements. Ensure that the HMA HIGH RAP 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*
HOT MIX ASPHALT ___ ___ ___ SURFACE COURSE HIGH RAP	TON
HOT MIX ASPHALT ___ ___ ___ INTERMEDIATE COURSE HIGH RAP	TON
HOT MIX ASPHALT ___ ___ ___ BASE COURSE HIGH RAP	TON

ADD THE FOLLOWING TO 902:

902.11 HOT MIX ASPHALT RAP

902.11.01 Mix Designations

The requirements for specific HMA mixtures with required minimum amounts of RAP are identified by the abbreviated fields in the Item description as defined as follows:

HOT MIX ASPHALT 12.5H64 SURFACE COURSE HIGH RAP

1. "HOT MIX ASPHALT" "Hot 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 902.02.03-2 (levels are L=low, M=medium, and H=high).
4. "64" The fourth field in the Item description normally designates the high temperature (in °C) of the performance-graded binder (options are 64, 70, and 76 °C). In the High RAP mixes this field will designate the mix performance requirements.
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).
6. "HIGH RAP" This additional field designates that there will be a minimum percentage of RAP required for the mixture in 902.011.02.

902.11.02 Composition of Mixture

Provide materials as specified:

Aggregates for Hot Mix Asphalt 901.05

Use a virgin asphalt binder that will result in a mix that meets the performance requirements specified in Table 902.11.03-2. Ensure that the virgin asphalt binder meets the requirements of 902.01.01 except the performance grade. Use a performance grade of asphalt binder as determined by the mix design and mix performance testing.

Mix HMA HIGH RAP 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 HMA HIGH RAP surface course is coarse aggregate, fine aggregate, asphalt binder, and a minimum of 20 percent Reclaimed Asphalt Pavement (RAP), and may also include mineral filler, asphalt rejuvenator and Warm Mix Asphalt (WMA) additives or processes as specified in 902.01.05. When WMA is used it must meet the requirements as specified in 902.10. 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 HMA HIGH RAP base or intermediate course is coarse aggregate, fine aggregate, asphalt binder, and a minimum of 30 percent Reclaimed Asphalt Pavement (RAP), and may also include mineral filler, up to 10 percent of additional recycled materials, asphalt rejuvenator, and Warm Mix Asphalt (WMA) additives or processes as specified in 902.01.05. When WMA is used it must meet the requirements as specified in 902.10. The recycled materials may consist of a combination of RAP, CRCG, Ground Bituminous Shingle Material (GBSM), and RPCSA, with the following individual limits:

Table 902.11.02-1 Use of Recycled Materials in Base or Intermediate Course		
Recycled Material	**Minimum Percentage**	**Maximum Percentage**
RAP	30	
CRCG		10
GBSM		5
RPCSA		20

Combine the aggregates to ensure that the resulting mixture meets the grading requirements specified in Table 902.02.03-1. 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 902.02.02-2. Ensure that the material passing the No. 40 sieve is non-plastic when tested according to AASHTO T 90.

902.11.03 Mix Design

At least 45 days before initial production, submit a job mix formula for the HMA HIGH RAP on forms supplied by the Department, to include a statement naming the source of each component and a report showing that the results meet the criteria specified in Tables 902.02.03-1 and 902.11.03-1.

Include in the mix design the following based on the weight of the total mixture:

1. Percentage of RAP or GBSM.
2. Percentage of asphalt binder in the RAP or GBSM.
3. Percentage of new asphalt binder.
4. Total percentage of asphalt binder.
5. Percentage of each type of virgin aggregate.

Table 902.11.03-1 HMA HIGH RAP Requirements for Design

Compaction Levels	Required Density (% of Theoretical Max. Specific Gravity)		Voids in Mineral Aggregate (VMA)², % (minimum) — Nominal Max. Aggregate Size, mm					Voids Filled With Asphalt (VFA) %	Dust-to-Binder Ratio
	@N_{des}¹	@N_{max}	25.0	19.0	12.5	9.5	4.75		
L	96.0	≤ 98.0	13.0	14.0	15.0	16.0	17.0	70 - 85	0.6 - 1.2
M	96.0	≤ 98.0	13.0	14.0	15.0	16.0	17.0	65 - 85	0.6 - 1.2

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. For verification, specimens must be between 95.0 and 97.0 percent of maximum specific gravity at N_{des}.
2. For calculation of VMA, use bulk specific gravity of the combined aggregate including aggregate extracted from the RAP.

The job mix formula for the HMA HIGH RAP mixture establishes the percentage of dry weight of aggregate, including the aggregate from the RAP, passing each required sieve size and an optimum percentage of asphalt binder based upon the weight of the total mix. Determine the optimum percentage of asphalt binder according to AASHTO R 35 and M 323 with an N_{des} as required in Table 902.02.03-2. Before maximum specific gravity testing or compaction of specimens, condition the mix for 2 hours according to the requirements for conditioning for volumetric mix design in AASHTO R 30, Section 7.1. If the absorption of the combined aggregate is more than 1.5 percent according to AASHTO T 84 and T 85, ensure that the mix is short term conditioned for 4 hours according to AASHTO R 30, Section 7.2 prior to compaction of specimens (AASHTO T 312) and determination of maximum specific gravity (AASHTO T 209). Ensure that the job mix formula is within the master range specified in Table 902.02.03-1.

Ensure that the job mix formula provides a mixture that meets a minimum tensile strength ratio (TSR) of 80% when prepared according to AASHTO T 312 and tested according to AASHTO T 283. Submit the TSR results with the mix design.

Determine the correction factor of the mix including the RAP by using extracted aggregate from the RAP in the proposed proportions when testing is done to determine the correction factor as specified in AASHTO T 308. Use extracted aggregate from the RAP in determining the bulk specific gravity of the aggregate blend for the mix design.

For each mix design, submit with the mix design forms 3 gyratory specimens and 1 loose sample corresponding to the composition of the JMF. Ensure that the samples include the percentage of RAP that is being proposed for the mix. 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 Tables 902.02.03-1 and 902.11.03-1. The ME reserves the right to be present at the time the gyratory specimens are molded.

In addition, submit nine gyratory specimens and five 5-gallon buckets of loose mix to the ME. The ME will use these additional samples for performance testing of the HMA HIGH RAP mix. The ME reserves the right to be present at the time of molding the gyratory specimens. Ensure that the additional gyratory specimens are compacted according to AASHTO T 312, are 77 mm high, and have an air void content of 6.5 ± 0.5 percent. The ME will test six (6) specimens using an Asphalt Pavement Analyzer (APA) according to AASHTO T 340 at 64°C, 100 psi hose pressure, and 100 lb. wheel load. The ME will use the remaining three (3) specimens to test using an Overlay Tester (NJDOT B-10) at 25°C and a joint opening of 0.025 inch.

The ME will approve the JMF if the results meet the criteria in Table 902.11.03-2.

Table 902.11.03-2 Performance Testing Requirements for HMA HIGH RAP Design

	Requirement			
	Surface Course		Intermediate Course	
Test	**PG 64-22**	**PG 76-22**	**PG 64-22**	**PG 76-22**
APA @ 8,000 loading cycles (AASHTO T 340)	< 7 mm	< 4 mm	< 7 mm	< 4 mm
Overlay Tester (NJDOT B-10)	> 150 cycles	> 175 cycles	> 100 cycles	> 125 cycles

If the JMF does not meet the APA and Overlay Tester criteria, redesign the HMA HIGH RAP mix and submit for retesting. The JMF for the HMA HIGH RAP mixture is in effect until modification is approved by the ME.

When unsatisfactory results for any specified characteristic of the work make it necessary, the Contractor may establish a new JMF for approval. In such instances, if corrective action is not taken, the ME may require an appropriate adjustment to the JMF.

Should a change in sources be made or any changes in the properties of materials occur, the ME will require that a new JMF be established and approved before production can continue.

902.11.04 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.

Ensure that the temperature of the mix at discharge from the plant or storage silo meets the recommendation of the supplier of the asphalt binder, supplier of the asphalt modifier and WMA manufacturer. For HMA, do not allow the mixture temperature to exceed 330°F at discharge from the plant. For WMA, 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.

B. Sampling. The ME will take 5 stratified random samples of HMA HIGH RAP for volumetric acceptance testing from each lot of approximately 3500 tons of a mix. When a lot of HMA HIGH RAP 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 HMA HIGH RAP 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.

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 HMA HIGH RAP to the number of design gyrations (N_{des}) specified in Table 902.02.03-2, 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 HMA HIGH RAP.

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

Ensure that the HMA HIGH RAP mixture conforms to the requirements specified in Table 902.11.04-1, and to the gradation requirements in Table 902.02.03-1. 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 902.11.04-1 HMA HIGH RAP 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]	25.0	19.0	12.5	9.5	4.75	
L, M	95.0 – 98.5	13.0	14.0	15.0	16.0	17.0	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 HMA HIGH RAP. Provide five (5) 5-gallon buckets of loose mix to the ME for testing in the Asphalt Pavement Analyzer (APA) and the Overlay Tester device. Ensure that the first sample is taken during the construction of the test strip as specified in 401.03.07.C. Thereafter, sample every lot or as directed by the ME. If a sample does not meet the design criteria for performance testing as specified in Table 902.11.03-2, the Department will assess a pay adjustment as specified in Table 902.11.04-2. If a lot fails to meet requirements for both APA and Overlay Tester, the Department will assess pay adjustments for both parameters. The Department will calculate the pay adjustment by multiplying the percent pay adjustment (PPA) by the quantity in the lot and the bid price for the HMA High RAP item.

Table 902.11.04-2 Performance Testing Pay Adjustments for HMA HIGH RAP					
	Surface Course		Intermediate Course		PPA
	PG 64-22	PG 76-22	PG 64-22	PG 76-22	
APA @ 8,000 loading cycles, mm (AASHTO T 340)	$t \le 7$ $7 > t > 10$ $t \ge 10$	$t \le 4$ $4 > t > 7$ $t \ge 7$	$t \le 7$ $7 > t > 10$ $t \ge 10$	$t \le 4$ $4 > t > 7$ $t \ge 7$	0 – 1 – 5
Overlay Tester, cycles (NJDOT B-10)	$t \ge 150$ $150 > t > 100$ $t \le 100$	$t \ge 175$ $175 > t > 125$ $t \le 125$	$t \ge 100$ $100 > t > 75$ $t \le 75$	$t \ge 125$ $125 > t > 90$ $t \le 90$	0 – 1 – 5