



Synthesis of Performance Testing of Asphalt Concrete

Minnesota
Department of
Transportation

**RESEARCH
SERVICES**

**Office of
Policy Analysis,
Research &
Innovation**

Eshan V. Dave, Principal Investigator
Department of Civil Engineering
University of Minnesota Duluth

September 2011

Research Project
Final Report 2011-22

Your Destination... Our Priority



All agencies, departments, divisions and units that develop, use and/or purchase written materials for distribution to the public must ensure that each document contain a statement indicating that the information is available in alternative formats to individuals with disabilities upon request. Include the following statement on each document that is distributed:

To request this document in an alternative format, call Bruce Lattu at 651-366-4718 or 1-800-657-3774 (Greater Minnesota); 711 or 1-800-627-3529 (Minnesota Relay). You may also send an e-mail to bruce.lattu@state.mn.us. (Please request at least one week in advance).

Technical Report Documentation Page

1. Report No. MN/RC 2011-22	2.	3. Recipients Accession No.	
4. Title and Subtitle Synthesis of Performance Testing of Asphalt Concrete		5. Report Date September 2011	
		6.	
7. Author(s) Eshan V. Dave, Philip Koktan		8. Performing Organization Report No.	
9. Performing Organization Name and Address Department of Civil Engineering University of Minnesota Duluth 1405 University Drive Duluth, MN 55812		10. Project/Task/Work Unit No. CTS Project #2011085	
		11. Contract (C) or Grant (G) No. (c) 89261 (wo) 269	
12. Sponsoring Organization Name and Address Minnesota Department of Transportation Research Services Section 395 John Ireland Boulevard, MS 330 St. Paul, MN 55455		13. Type of Report and Period Covered Final Report	
		14. Sponsoring Agency Code	
15. Supplementary Notes http://www.lrrb.org/pdf/201122.pdf			
16. Abstract (Limit: 250 words) At present, like many other agencies, the Minnesota Department of Transportation asphalt material specifications rely primarily on volumetric properties to ensure good field performance. There have been considerable amounts of research efforts to develop so called "asphalt performance tests" that can link laboratory-measured parameters to pavement performance. Research efforts are also undertaken to refine the asphalt mix-design method so that laboratory tests and procedures can be incorporated into material specification. This research project explored availability of such tests, their suitability, and their use by other agencies.			
17. Document Analysis/Descriptors Asphalt tests, Performance based specifications, Surveying, Survey of material specifications, State of the art, State of the practice.		18. Availability Statement No restrictions. Document available from: National Technical Information Services, Alexandria, Virginia 22312	
19. Security Class (this report) Unclassified	20. Security Class (this page) Unclassified	21. No. of Pages 90	22. Price

Synthesis of Performance Testing of Asphalt Concrete

Final Report

Prepared by:

Eshan V. Dave
Philip Koktan

Department of Civil Engineering
University of Minnesota Duluth

September 2011

Published by:

Minnesota Department of Transportation
Research Services Section
395 John Ireland Boulevard, MS 330
St. Paul, Minnesota 55155

This report represents the results of research conducted by the authors and does not necessarily represent the views or policies of the Minnesota Department of Transportation or the University of Minnesota Duluth. This report does not contain a standard or specified technique.

The authors, the Minnesota Department of Transportation, and the University of Minnesota Duluth do not endorse products or manufacturers. Any trade or manufacturers' names that may appear herein do so solely because they are considered essential to this report.

Acknowledgments

This research study, which was funded by the Minnesota Department of Transportation (MnDOT), would not have been possible without the contribution of a number of individuals. The authors would like to acknowledge the MnDOT (Office of Materials and Road Research), as the significant efforts from Tim Clyne (technical liaison for the project), Ben Worel, Maureen Jensen, Shongtao Dai, John Garrity, Jim McGraw, Eddie Johnson, Roger Olson, Melissa Cole, Jerry Geib, and Tom Wood are very much appreciated. Generous help from Tom Bennert at Rutgers University in providing the provisional performance-based specifications from the New Jersey Department of Transportation is acknowledged.

We would also like thank the MnDOT Research Services Section for their help in the administration of this project, especially Alan Rindels (administrative liaison for the project). Finally we would like to thank the staff at University of Minnesota's Center for Transportation Studies (CTS) for all their help during the course of the project.

Table of Contents

1	Introduction.....	1
1.1	Background.....	1
1.2	Research Goals.....	1
1.3	Research Approach.....	1
1.4	Report Organization.....	1
2	State of the Practice for Asphalt Performance Tests.....	3
2.1	Introduction.....	3
2.2	Asphalt Concrete Material Specification Methodologies.....	3
2.3	Superpave Mix Design Procedure.....	4
2.4	Review of State Department of Transportation Material Specifications.....	6
2.4.1	Methodology.....	6
2.4.2	Presentation of Review Results.....	6
2.4.3	Summary of Findings.....	9
2.5	Use of Performance-Based Specifications for Cracking Distresses.....	10
2.5.1	New Jersey DOT Performance-Based Specification Study.....	10
2.5.2	Performance Based Specifications for Reflective Cracking.....	11
2.5.3	European Asphalt Concrete Specifications.....	11
2.6	Synthesis of the Current State of Practice for Asphalt Performance Tests.....	11
3	State of the Art for Asphalt Performance Tests.....	12
3.1	Introduction.....	12
3.2	Review Methodology.....	12
3.3	Review of Asphalt Performance Tests.....	12
3.3.1	Bulk Behavior Tests.....	12
3.3.2	Damage and Fracture Tests.....	15
3.4	Synthesis of the Current State of the Art for Asphalt Performance Tests.....	22
4	Review of Previous MnDOT Projects on Asphalt Performance Testing.....	24
4.1	Introduction and Motivation.....	24
4.2	Methodology.....	24
4.3	Review of Previous Projects.....	24
4.3.1	Diametral Compression Test.....	24
4.3.2	Evaluation of Asphalt Pavement Analyzer.....	25

4.3.3	Study of Low Temperature Cracking	25
4.3.4	Complex (Dynamic) and Resilient Modulus Testing	26
4.4	<i>Findings from Previous MnDOT Research</i>	26
5	Summary, Conclusions and Recommendations.....	28
5.1	<i>Project Summary</i>	28
5.2	<i>Conclusions</i>	28
5.3	<i>Recommendations</i>	29
	References.....	30
	Appendix A : Review of State Department of Transportation Specifications	
	Appendix B: Provisional Performance Based Specifications from NJDOT Study	

List of Tables

Table 3.1 Comparison of Bulk Behavior Asphalt Performance Tests.....	15
Table 3.2 Comparison of Fracture and Damage Tests.....	22
Table 4.1 Asphalt Performance Test Findings from Previous MnDOT Research	27

List of Figures

Figure 2.1 Evolution of Asphalt Material Specifications (from Gallivan, 2001)	4
Figure 2.2 Mechanical Testing Requirements by DOTs	7
Figure 2.3 Break-Down of the Performance Testing Requirements by DOTs.....	8
Figure 2.4 Rutting Performance Tests Used by DOTs	9
Figure 2.5 Cracking Performance Tests Used by DOTs.....	9

Executive Summary

The current asphalt concrete material specifications for the Minnesota Department of Transportation do not require a laboratory performance test as part of acceptance criteria. Extensive research has been conducted on the topic of asphalt performance testing which has demonstrated that use of such laboratory tests can improve the longevity of asphalt pavements and reduce risk of early deterioration. The goal of this project was to synthesize the research and implementation efforts that have been undertaken for asphalt performance tests. This is an important first step in the process of identifying a suitable test that can be included in future material specifications. In order to achieve this project goal, a three-pronged approach was undertaken whereby the state of the practice and the state of the art for asphalt performance testing were determined, as well as brief review of previous MnDOT research on performance tests was conducted.

The current state of the practice for asphalt performance tests was determined through a review of various State Highway Agency (SHA) material specifications. The key findings from this review were:

- The performance test requirement in the standard material specifications has been routinely used by many agencies.
- The majority of routinely used performance tests are conducted for evaluation of potential for moisture induced damage or rutting distress.
- Few demonstrative studies have shown that use of performance testing-based material specifications is feasible, especially to tackle cracking distresses.

Technical literature pertinent to laboratory tests and their relationship to pavement performance was extensively reviewed to determine the current state of the art on the topic. The highlights of this review can be summarized as:

- The list of laboratory tests proposed for prediction of field performance is exhaustive. Very few tests from this list have undergone a satisfactory validation, and fewer are simple enough to be used on routine basis. Most tests tackle one or more asphalt pavement distress, however none can be used as a global performance indicator. The availability of vetted tests that satisfy the requirements for use as simple cracking performance test is quite limited.
- Majority of national level research effort has been on development of the asphalt mixture performance test (AMPT). Very good agreement is observed between results from this test and the pavement rutting distress. Some work has shown that this test can be used to successfully predict pavement cracking distress, however it requires use of mechanistic models.
- Tests that show greatest potential for use in performance based-material specifications in Minnesota are fracture energy tests (disk-shaped compact tension and semi-circular bend tests). Other prospective tests include, indirect tensile strength, especially from moisture damage evaluation tests; fracture tests such as semi-circular bend tests or disk-shaped compact tension test; Texas overlay tester; and four-point bending-beam fatigue test.

The fracture energy tests have shown very good correlation with cracking in field. Particularly, thermal and reflective cracking, which are prominent distresses on flexible and composite

pavements in Minnesota. There is need to explore simplification of fracture test procedures to make them well suited for routine usage in performance based specifications. The indirect tensile strength property for asphalt mixes are currently determined as part of the mix design process. The current specifications do not require mixes to meet this property and focus only on the ratio of tensile strengths from dry and moisture conditioned specimens to determine the moisture damage susceptibility. Use of this parameter as performance indicator will require no additional implementation on part of MnDOT or contractors. While the suitability of using this parameter as performance indicator is not known, large data set of results are already available, thus this test should be one of the starting point for future research efforts.

The review of previous research at MnDOT informed that there is large amount of performance test results and field data available, efforts are needed to combine data from various projects. This should be one of the first steps in moving forward with the current research. Such dataset and recommendations from the present study will enable identification of candidate tests that may be selected for validation and implementation studies.

1 Introduction

1.1 Background

At present, like many other agencies, the Minnesota Department of Transportation (MnDOT) asphalt material specifications rely primarily on volumetric properties to ensure good field performance. The current asphalt material specifications do not put emphasis on need for mechanical testing of asphalt concrete. There have been considerable amounts of research efforts to develop so called “Asphalt Performance Tests” that can link laboratory measured parameters to actual pavement performance. Some research efforts are also undertaken to refine the asphalt mix design method so that laboratory tests and procedures can be incorporated as part of material specification. Research efforts are needed to explore availability of such “asphalt performance tests”, their suitability and their use by other agencies. This research project focuses on answering these questions and developing plans for future research on this topic.

1.2 Research Goals

The goal of this research is to synthesize the state of the practice and state of the art for asphalt concrete performance tests. This includes review of other State Department of Transportation (DOT) material specifications as well as review of technical literature on asphalt concrete performance tests. The summary of these reviews were prepared and are presented in this report. Research efforts were also undertaken to find previous research from MnDOT that shows links between asphalt performance tests and actual field performance. Summary of findings from those previous research are also included herein.

1.3 Research Approach

As described in the research goals, this study primarily focuses on review of literature and material specifications. The project was approached in a three pronged manner, the efforts included:

- (1) Review of material specifications from various departments of transportation (DOTs);
- (2) Review of technical literature on asphalt performance tests; and
- (3) Preliminary review of previous research projects conducted or funded by MnDOT that dealt with asphalt performance tests.

Through above shown efforts the available information was synthesized to make variety of recommendations. These include suitability of including mechanical test in material specifications, identification potential laboratory tests that have been used by other DOTs as performance indicators, and recommendations for future studies that can be undertaken to evaluate suitability of a performance test and develop implementation plans.

1.4 Report Organization

This report is organized into five main chapters. An overview of performance tests in context of Superpave asphalt mix design process is presented in Chapter 2 along with results from review of other State DOT material specifications. Chapter 3 presents review of asphalt performance

tests, comments are made regarding suitability of these tests as evaluated by their capability in predicting field performance and the amount of equipment and specimen preparation needs. Chapter 4 describes brief overview of previous research undertaken at MnDOT that has availability of lab test and field performance data. Finally Chapter 5 summarizes the research project, presents the condensed findings and makes recommendations based on those findings.

2 State of the Practice for Asphalt Performance Tests

2.1 Introduction

This chapter presents the review of the state of the practice of asphalt performance tests. The state of the practice for the context of this project was determined by conducting review of material specifications from various State Departments of Transportation (DOTs). Prior to presentation of results from the review, brief comments are made regarding the material specification processes as well as the original recommendations of AASHTO Superpave asphalt mix design process. Description of Superpave process is important, as most DOTs utilize a variant of this process for their asphalt specifications.

2.2 Asphalt Concrete Material Specification Methodologies

Over the period of years the specification of asphalt concrete by State highway agencies has varied significantly. A review of asphalt specification development can be found elsewhere (Anderson and Russell, 2001, Gallivan, 2011). The evolution of asphalt material specifications as visualized by Gallivan (2011) is shown in Figure 2.1. The most common categories which describe various agency specifications are as follows:

- **Method Specifications:** These are usually highly prescriptive in nature and describe the asphalt mix design, manufacture and paving processes. The major short-coming of this approach is that a majority of performance risk is placed on the mix design and manufacture. At present, the most commonly adopted mix design procedure is Level I Superpave volumetric asphalt mix design method. This methodology does not require any major mechanical test to evaluate in field performance of the mix.
- **Quality Control and Quality Assurance (QC/QA) Specifications:** This type of specification approach improves upon the method specifications by ensuring the quality of final product. Typically these involve quality tests for as constructed asphalt concrete lift. Typical quality parameters include, mix laydown temperature, mix volumetrics (air void, asphalt content etc.), and as-built thicknesses of asphalt lifts. In case of QC/QA specifications the risk of inadequate field performance is still undertaken by the agency, as assumption is made that the quality indication parameters will assure good field performance. Once again the most commonly used quality indicators are linked to mix volumetrics and not a mechanical test procedure.
- **End Result Specifications (ERS) and Performance Related Specifications (PRS):** The use of ERS build upon the QC/QA methodology by inclusion of risk assessment (Buttlar and Manik, 2007). While, the assessment of risk inherently links the pavement performance end-result to commonly measured QC/QA quantities, usually a mechanical test for performance evaluation is not included in this type of specifications. In some cases, such as California DOT's PRS system (Deacon et al., 1997), the material volumetric and structural properties are jointly used to means for pavement specifications. Typically these types of specifications rely on well-established links between mix volumetrics and layers thicknesses and commonly anticipated pavement distresses.
- **Performance Based Specifications (PBS):** These type of specification procedures commonly utilize results from a mechanical test or series of mechanical tests commonly referred to as performance tests. Such performance test results allow for agencies to predict the field

performance of the pavement. By specifying a limit on the performance test result agencies can ensure good pavement life. The key hindrance in wide-spread usage of this type of specification method is lack of widely accepted and proven asphalt performance test. Several research studies have been conducted to develop performance based specifications for asphalt concrete for example, study by Williams et al. (2004) developed trial specifications for Michigan DOT. It is worthwhile to notice that the review of various DOT material specifications from United States showed that PBS is not currently in routine practice. Furthermore, from perspective of research, a major thrust has been on the rutting distress with limited to no research conducted on use of PBS that is focused on thermal cracking distress.

- **Warranty Based Projects:** These types of projects are commonly specified to minimize the performance related risks to the agency. Usually in case of warranty projects, the final field performance goal is established by the agencies and contractors are given greater freedom over the choice of pavement structure and materials to meet those performance goals. Due to greater risk on part of contractor, usually these types of projects are associated with higher costs.

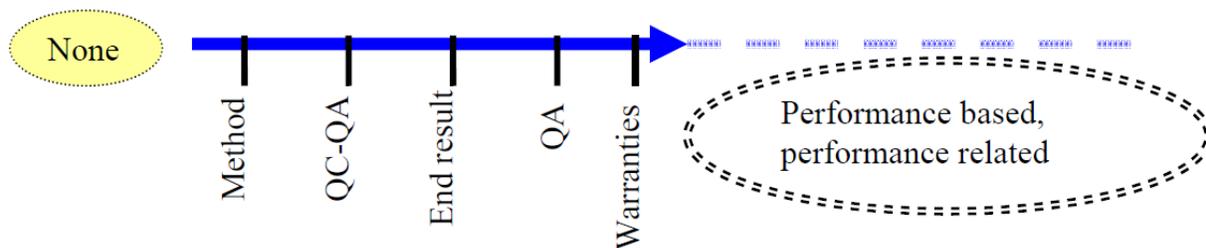


Figure 2.1 Evolution of Asphalt Material Specifications (from Gallivan, 2001)

From the perspective of the material specification process, the tasks of this study fall most closely to the PBS. This is mainly due to a requirement of a robust, validated and simple mechanical test in the PBS system to link laboratory measured properties to anticipated field performance. There are some implications to ERS, PRS and warranty projects, as all of these also require some link between the asphalt material and field performance.

2.3 Superpave Mix Design Procedure

The Strategic Highway Research Program (SHRP) was established in 1988 with goal of improving the asphalt material specifications and mix design procedures. At its conclusion in mid-1990s the goals of SHRP were realized through development of the Superior Performing Asphalt Pavement System or Superpave. The Superpave system includes the performance graded (PG) asphalt binder specifications as well as the asphalt concrete mix design procedure. The asphalt mix design procedure was developed as a performance based specification (Roberts et al., 2009). The mix designs specifications are divided into tiered system with three different design reliability levels (Cominsky et al., 1994). The lowest reliability or Level I is typically recommended for pavements with life-time design traffic of less than 10 million ESALs. The Level II and Level III typically correspond to design traffic levels of 10 – 100 million and above

100 million ESALs. The basic premise with different design levels is that Level 1 relies primarily on the volumetric properties to get good field performance, Level 2 requires volumetric and performance test to improve upon the reliability and finally, Level 3 includes proof tests in addition to volumetric and performance tests to yield the greatest level of reliability. The requirements of various levels of Superpave mix design procedure are presented in the following discussion. More details on these can be found in the SHRP project report by Cominsky et al. (1994).

The design approach for Superpave Level I mix design procedure can be summarized as,

- Use of suitable asphalt binder according to the Superpave PG grading system;
- Use of good aggregate structure as dictated by the aggregate source and consensus properties, and gradation control zones;
- Selection of optimal asphalt content using various volumetric measures;
- Use of Superpave gyratory compactor to simulate field compaction; and
- Determining moisture damage sensitivity of the mix by use of AASHTO T-283 test procedure to determine the tensile strength ratio.

For the Superpave Level II mix design, in addition to the above requirements, a series of performance tests and performance models are utilized to improve upon the reliability of good field performance. The performance tests and models were developed for each of the three popular asphalt distresses, rutting or permanent deformation, fatigue cracking and thermal or low temperature cracking. The required performance tests for Superpave Level II mix design are as follows,

- Permanent Deformation Distress: Series of tests conducted using the Superpave Shear tester (SST). Tests include: repeated shear as constant stress ratio, simple shear at constant height and frequency sweep test at one temperature.
- Fatigue Cracking Distress: Tests conducted using SST include: simple shear at constant height and frequency sweep test at one temperature. Indirect tensile strength measured using the indirect tensile test (IDT) is also required.
- Low Temperature Cracking Distress: A series of IDT tests include: indirect tensile creep at three temperatures and indirect tensile strength at one temperature. The creep stiffness and slope parameters from the bending beam rheometer (BBR) testing of asphalt binder is also required.

The test results from above shown list are used as inputs to three performance models, one for each primary distress. The design process recommends that each set of tests be conducted at three asphalt binder contents, thus giving designer a full picture of the effect of binder content on the predicted performance of pavement.

The Superpave Level III mix design procedure recommends the performance tests of Level II design with greater extent of test parameters (test temperatures, loading frequencies etc.) as well as adds few additional testing requirements. The added requirements for Level III performance tests are following:

- Permanent Deformation Distress: Using the SST device, uniaxial strain tests at three temperatures, frequency sweep at three temperatures and simple shear at constant height at three temperatures. Additionally, mix volumetric measurements are required to be taken at three temperatures.
- Fatigue Cracking Distress: Frequency sweep using SST at three temperatures and indirect tensile strength using IDT at three temperatures.
- Low Temperature Cracking Distress: Both indirect tensile creep and indirect tensile strength at three temperatures using IDT.

Once again, the performance test results were used as inputs to the performance prediction models which were used to finalize the mix design. The level III design procedure also recommends a series of proof tests as means to validate the performance of mix. The recommended proof tests are as follows,

- Permanent Deformation Distress: Wheel tracking test.
- Fatigue Cracking Distress: Flexural beam fatigue test.
- Low Temperature Cracking Distress: Thermal stress restrain specimen test (TSRST).

More details on the various test procedures described in the preceding section is presented in the next chapter.

2.4 Review of State Department of Transportation Material Specifications

2.4.1 Methodology

One of the primary tasks of this research project is to determine the current state of the practice by State highway agencies in use of performance tests in routine usage. In order to conduct this evaluation a comprehensive review of the Standard Bridge and Road Construction Specification manuals was conducted for 51 agencies. The review included DOTs from all 50 United States as well as the District of Columbia. Following set of conditions were focused upon in order to conduct the review in timely fashion:

- The most current version of the standard specifications was reviewed. Older versions were referred in some instances, such as, citation in a reviewed literature.
- Unless otherwise indicated in this report, the thrust was on the standard specifications and not the provisional specifications. Again, if other literature indicated that provisional specifications are requiring performance test then those were reviewed.
- Testing requirements were focused for plant produced asphalt concrete. Other asphaltic materials such as surface treatments or emulsified tack-coats were not focused upon in this project.

2.4.2 Presentation of Review Results

The information collected from review was converted into numerical data. This section presents the numerical results in form of plots and the data is summarized into key points. Appendix A contains the raw data collected from the review.

The first key observation from this review is that most standard specifications describe method and QC/QA specifications and very few uses the terminology “performance related specifications (PRS)”. No standard specification was found to explicitly use the term “Performance Based Specifications (PBS)”. Other observation is that all 51 specifications broadly follow Superpave Level I volumetric mix design requirements. The Level II or Level III type requirements are not present in any instances.

In terms of the testing necessity, 47 DOTs have at least one mechanical test requirement. Only Delaware, Maine, Massachusetts, and New Mexico DOTs are exception. Majority of this testing requirement is to evaluate the moisture damage susceptibility of the asphalt mixture. The requirements span across variety of tests such as, tensile strength ratio (TSR), tensile strength, Hamburg wheel tracking test, asphalt pavement analyzer (APA), Marshall flow and stability tests, and others. Figure 2.2 shows the break-down of various testing requirements. As evident from this figure, a majority of DOTs require testing to evaluate the moisture damage susceptibility (total of 57%). Majority of the DOTs use TSR as the moisture damage test. While the testing procedures for TSR vary in small amounts between various agencies, in broader sense they follow the AASHTO T-283 specifications. Other than moisture damage tests, the APA testing for rutting performance is the next prevalent test, with a 10% share.

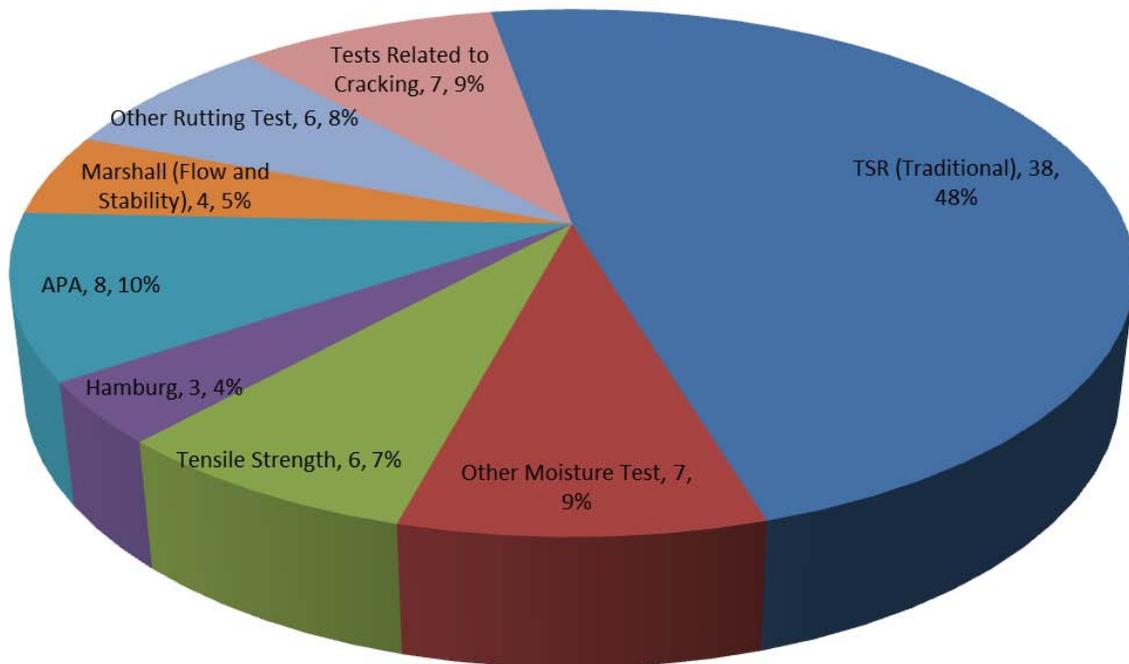


Figure 2.2 Mechanical Testing Requirements by DOTs

The break-down of the remaining 21 mechanical testing requirements other than the traditional moisture damage tests is shown in Figure 2.3. Since these tests are usually required to evaluate the potential field performance of the pavement, these are referred to as performance test requirements from here onwards in this section. Of these 21 requirements:

- 6 are tensile strength limits (Determined and reported along with TSR)

- 15 are rutting or rutting and stripping testing requirements, with break-down of:
- 3 for Hamburg wheel tracking test,
- 8 for asphalt pavement analyzer (APA) test, and
- 4 Marshall flow and stability requirements.
- 6 DOTs require other non-rutting and non-moisture damage mechanical tests, these are usually cracking related performance tests.

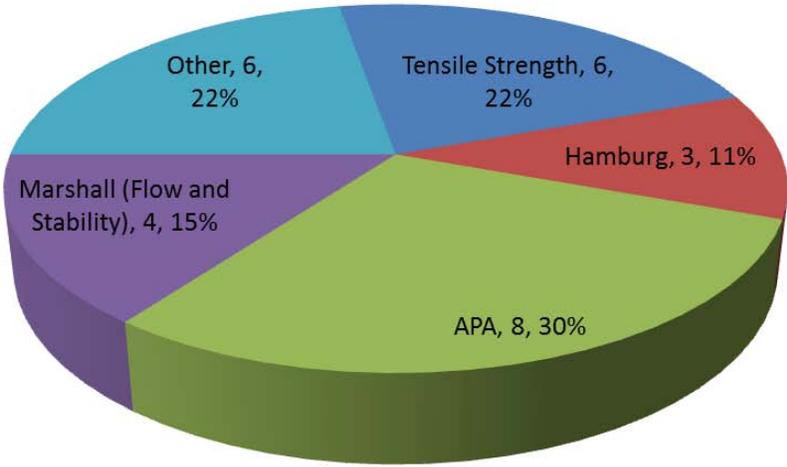


Figure 2.3 Break-Down of the Performance Testing Requirements by DOTs

The performance tests requirements can be further divided by the type of pavement distress that they are applicable to and in broader sense this division is done as: rutting or permanent deformation related tests and cracking related tests. The breakdown of 18 rutting test requirements is presented in Figure 2.4 and the 7 cracking related tests in Figure 2.5. Majority of cracking performance requirement is in form tensile strength, it should be noted that this tensile strength is usually available from the TSR test and does not require additional testing and specimen procurement and preparation. The other two cracking tests described in the DOTs specifications are the flexural beam fatigue test and the Texas overlay test. While the Texas overlay test is required for asphalt mixtures placed on existing deteriorated pavements in Texas, the flexural beam fatigue requirement of Georgia DOT is a recommended test which may be conducted as part of the mix design process.

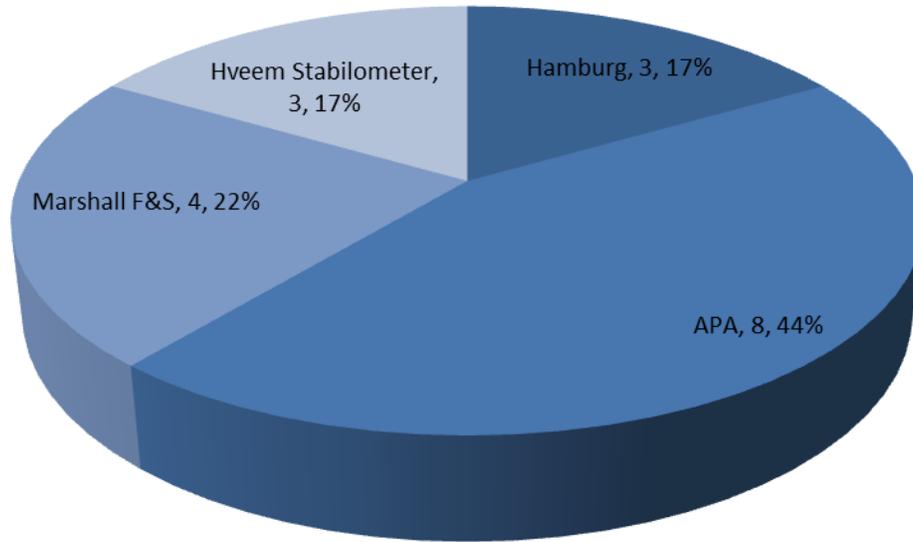


Figure 2.4 Rutting Performance Tests Used by DOTs

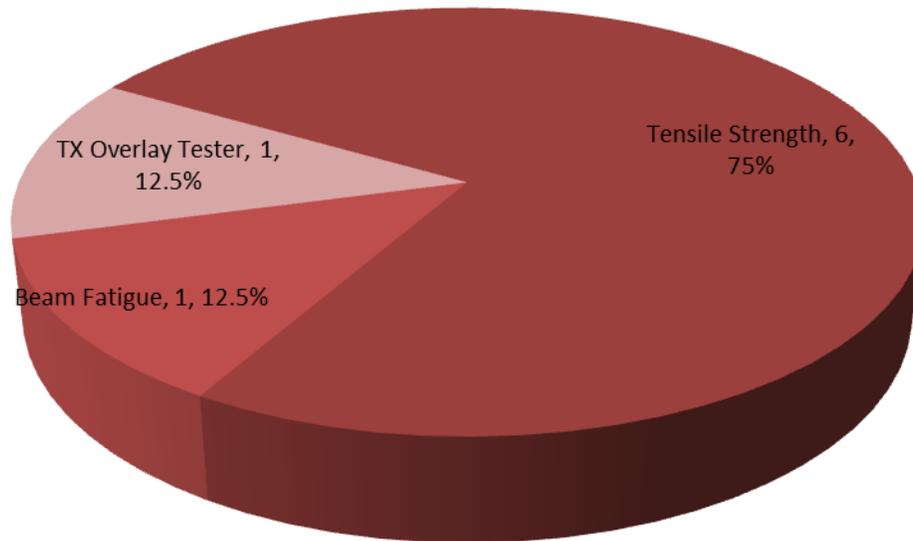


Figure 2.5 Cracking Performance Tests Used by DOTs

2.4.3 Summary of Findings

Based on the results from the review of State DOT standard material specifications, following key points can be summarized:

- Method and QC/QA specification procedures are most widely utilized;
- Asphalt concrete mix design procedures used by DOTs follow Superpave Level I methodology with some variations;

- Most States require mechanical testing to ensure good performance against moisture induced damage, with tensile strength ratio (TSR) test as most widely accepted practice;
- From typical pavement distress perspective, performance tests for rutting are most common, with asphalt pavement analyzer (APA) being the test of choice;
- Very few DOTs utilize commonly used performance tests for cracking distresses; and,
- Several agencies are requiring a minimum dry tensile strength as a requirement in addition to the tensile strength ratio.

Through literature search a few provisional and demonstrative specifications were found that include a cracking related performance testing requirements. Three such cases are presented in the subsequent section.

2.5 Use of Performance-Based Specifications for Cracking Distresses

2.5.1 New Jersey DOT Performance-Based Specification Study

The New Jersey DOT (NJDOT) conducted a research and implementation project in 2010 to use performance based specifications for a variety of asphalt pavement projects (Bennert et al., 2011). In total approximately 10% of the asphalt mixes used by NJDOT in 2010 were specified through performance based specifications. The performance testing for these projects were conducted at two levels, during the mix design stage as well as during the production. The performance based specification requirements were provided as part of the bid document along with the draft specifications. All performance testing was conducted at one approved lab for the whole State. The draft specifications from the NJDOT study were obtained from researchers at Rutgers University, which led the research side of the project. These specifications are attached in the appendix of this report. The required performance testing varied by the application of the mix, for example different type of performance tests were required for a thin wearing course versus a binder rich bottom course. Thus, the performance based specifications were developed truly in an application targeted manner rather than a blanket manner. Four set of performance based specifications were developed and implemented, these include:

- High Performance Thin Overlay: Major distress of concern is rutting and thus APA test is used as rutting performance test.
- Bridge-deck Asphalt Overlay: Both rutting and cracking are of concern. Especially due to high strain levels fatigue cracking is the expected failure mechanism. The required performance tests are APA for rutting and flexural beam fatigue test for cracking.
- Bottom Rich Base Course: The primary distress is fatigue cracking, however due to high asphalt content there is some potential for rutting. The fatigue endurance limit is used as a cracking performance measure and thus beam fatigue testing as multiple strain amplitudes is required. For rutting, APA test is required.
- Bottom Rich Intermediate Course: This type of asphalt lift is commonly used to alleviate the reflective cracking distress by acting as reflective crack relief interlayer. The primary cracking distress is reflective cracking, the Texas overlay tester is used to ensure good performance. Once again, due to high binder content of such mixes the APA test is used specified to safeguard against rutting.

2.5.2 Performance Based Specifications for Reflective Cracking

From perspective of pavement cracking, the literature review showed that performance based specifications has been most widely tried for reflective cracking distress. For example, the Texas DOT requires that all mixes placed on existing deteriorated and cracking pavements meet a minimum reflective cracking resistance as measured through Texas overlay tester. In this case the testing is conducted as part of the mix acceptance process. Work by Blankenship et al. (2004) showed that provisional performance based specifications have been used by Kansas, Louisiana, Missouri, New York, Oklahoma, Utah, and Wisconsin DOTs for reflective crack relief interlayer mixes. These provisional specifications have required Hveem stability tests to ensure rutting performance and flexural beam fatigue testing at high strain amplitudes to confirm good cracking resistance.

2.5.3 European Asphalt Concrete Specifications

The current specifications for the asphalt concrete from the European committee for standardization (CEN, 2006) have significant performance based component. In order for mix to meet the requirements three mechanical performance parameters are to be evaluated:

- Minimum stiffness modulus
- Resistance to fatigue cracking
- Resistance to permanent deformation.

Various agencies within Europe utilize different sets of tests to evaluate the above shown performance measures. In case of France, the requirements are application targeted, similar to the approach utilized in the NJDOT study from 2010. The French material specifications require that the performance tests be conducted for all asphalt mixes, the requirements are:

- All asphalt mixes: Minimum stiffness as measured by uniaxial compressive test;
- Base course mixes: Fatigue performance requirement measured using trapezoidal beam fatigue device; and,
- Wearing course mixes: Rutting performance requirement measured by the French rutting tester.

2.6 Synthesis of the Current State of Practice for Asphalt Performance Tests

Through the review of DOT specifications as well as review of technical literature the current state of the practice on the asphalt performance tests can be synthesized into following points:

- Moisture damage and rutting performance tests are most prevalent
- Dry tensile strength requirement is the most commonly used cracking related performance measure
- Few pilot studies have shown that cracking performance test requirements are feasible
- Review suggests that an extensive performance test requirement such as flexural beam fatigue test or APA should be application targeted to limit the testing burden in routine practice.

3 State of the Art for Asphalt Performance Tests

3.1 Introduction

This chapter presents summary of the state of the art in context of asphalt concrete performance tests. A comprehensive review of the literature was conducted to identify potential asphalt performance tests that may be candidate tests for MnDOT to adopt. Through published data the effectiveness of various tests in predicting field performance is qualitatively determined along with the equipment and specimen preparation needs associated them. The focus is kept at the level of capability of test in predicting performance, other details such as testing procedure, specimen preparation, data analysis etc. can be found in the cited references.

3.2 Review Methodology

The list of performance tests proposed for asphalt concrete is exhaustive. In order to keep this study focused on the needs of MnDOT and to ensure timely completion, the review of asphalt performance tests was focused on following:

- Tests used by other DOTs
- Tests suitable for cracking distresses, as this is primary distress of concern in Minnesota
- Tests with published data on field performance. Tests with only laboratory results and no available correlation with field performance were not included.
- Tests used for plant produced hot mix asphalt concrete.

3.3 Review of Asphalt Performance Tests

The review is broken down into two broad categories: bulk behavior tests (response characterization) and, damage and fracture tests. The bulk behavior tests are typically conducted in the linear range of material behavior to measure responses such as material stiffness or dynamic modulus etc., whereas fracture and damage tests focus on testing material's endurance towards resistance to failure. Within each of these categories a number of sub-categories were developed, primarily on basis of the mode of testing and the distresses of interest.

3.3.1 Bulk Behavior Tests

The bulk behavior tests for asphalt concrete can be divided into two main categories based on the loading sequence used for these tests that is cyclic tests and monotonic tests.

3.3.1.1 Cyclic Tests

Cyclic tests are further divided into two categories, tests for measurement of complex modulus and resilient modulus. The complex modulus testing typically involves continuous sinusoidal loading, versus resilient modulus test introduces a rest period between consecutive load pulses (Brown et al., 2009). The complex modulus testing has gotten tremendous attention in recent years with series of National Cooperative High Research Program (NCHRP) projects (Witczak, 2005, Bonaquist, 2008) undertaken to develop an asphalt mixture performance test (AMPT).

Alternative tests have also been proposed and developed to conduct cyclic testing of asphalt concrete, these include dynamic mechanical analyzer (DMA) and cyclic indirect tension test.

3.3.1.1.1 Asphalt Mixture Performance Test (AMPT)

The AMPT has gained popularity in recent years as the asphalt performance test of choice. The Federal Highway Administration (FHWA) has extensively studied this test along with the previously mentioned NCHRP studies. One of the major reasons for this is the recently introduced AASHTO Mechanistic Empirical Pavement Design Guide (MEPDG), the complex modulus measurement obtained from AMPT is one of the primary inputs to MEPDG. The NCHRP 9-19 project has shown very good correlation between the measurements from AMPT and the rutting performance of the asphalt concrete. At present FHWA has undertaken a study to implement AMPT for Superpave validation as a Pooled Fund Study TPF-5(178). This pooled fund study is also tasked with development of the performance based specifications that utilize AMPT. There has been some research conducted to use the test results from AMPT for prediction of field performance. Underwood et al. (2006, 2008) and Kutay et al. (2008a) has shown that through use of computational models the results from AMPT can be utilized for prediction of fatigue cracking performance, the results have shown good correlation with cracking observed in accelerated pavement tests. One of the manufacturers of the AMPT device was contacted by the researchers of the current project, the estimated cost for the device is \$74,000. The requirements include a close-loop controlled servo-hydraulic loading frame and a minimum of three extensometers for measurement of specimen deformations.

3.3.1.1.2 Dynamic Mechanical Analyzer (DMA)

The DMA device has been widely used for cyclic testing of asphalt binder, for example work by Daly et al. (2010) to study aging of binders. The researchers at Texas A&M University and Texas Transportation Institute have used this device to conduct cyclic tests on asphalt mastics and fine graded mixes (Lytton et al., 2005, Estakhri et al., 2010). The initial results have shown that measurements from DMA can be related to field cracking performance through use of computational models.

3.3.1.1.3 Cyclic Indirect Tensile Test

Obtaining typical AMPT specimen from field sites is challenging due to requirement for 200 mm high cylindrical specimens. The cyclic indirect tension test can alleviate that by using a 50 mm thick cylindrical specimen. The testing and data analysis procedure for this geometry has been discussed by Zhang et al. (1997). In recent years, Kim et al. (2004) have used this test to obtain material parameters similar to AMPT. Thus, this test can serve as good alternative to AMPT and should have similar capabilities in effectiveness of field performance prediction.

3.3.1.2 Monotonic (Creep) Tests

Monotonic tests for asphalt concrete are commonly conducted at low and intermediate temperatures. Similar to cyclic bulk tests, the main objective is to measure the response of material under a loading condition without inducing significant damage to the material. Various types of test geometries have been proposed for creep testing.

3.3.1.2.1 Indirect Tension Creep Test (IDT Creep)

The IDT creep tests are the most popular for evaluation of viscoelastic modulus of asphalt concrete at low temperatures. The test procedure and analysis method was refined and standardized by Buttlar and Roque (1992) for its use in the Superpave mix design procedure. The properties obtained from this test along with its counterpart in the strength test regime (IDT Strength Test) have been extensively utilized for evaluating of thermal cracking performance of asphalt pavements (Roque et al., 1995a, 1995b). A good correlation has been observed between field cracking and the performance predictions from this test through use of computational model, commonly referred to as TCMModel (Hiltunen and Roque et al., 1994). The equipment requirements for this test are comparable to AMPT with a need for close-loop controlled loading frame and four sets of extensometers.

3.3.1.2.2 Bending Beam Rheometer Asphalt Mix Test (Mix BBR Creep Test)

The extensive equipment and specimen requirements have been noted by several researchers. As an alternative to IDT creep test with reduced equipment and specimen needs, Zofka et al. (2005) have proposed use of the bending beam rheometer (BBR) device to determine the creep properties of asphalt concrete. Romero et al. (2011) also reported similar findings as the work by Zofka et al. (2005) for test conducted on production mixes from Utah. Very good match between results from this test is observed with the IDT creep test. Thus, while direct comparisons between field performance and test results are not available, good performance prediction capabilities are expected.

3.3.1.2.3 Torsion Bar Dynamic Shear Rheometer (DSR) Test

The torsion bar DSR test proposed by Reinke and Glidden (2004) also utilizes a smaller sized asphalt mix samples like the Mix BBR test. The test procedure involves conducting a creep test on asphalt concrete sample in shear mode. The work by Reinke and Glidden (2004) has shown very good correlation between field rutting performance and results from this test. Furthermore, the test has been proposed as an alternative to the Superpave shear tester (SST).

3.3.1.2.4 Uniaxial Creep Test

As compared to other creep test geometries the simplest one is the uniaxial testing configuration. While not many researchers have used this type of geometry for study of cracking, some work has been conducted in Europe to use the uniaxial creep test for measurement of rutting performance of asphalt concrete (Khanzada, 2000). The uniaxial test with monotonic loading is also commonly used to measure the stiffness of asphalt concrete for purposes of specifying material using the European standards (CEN, 2006).

3.3.1.3 Comparison of Bulk Behavior Asphalt Performance Tests

In order to make comparisons between various bulk behavior tests, the findings from this literature review are presented in form of a table (c.f. Table 3.1). Please note that the test standardization is also added to this table, whereby if the test procedure has been standardized by with AASHTO to ASTM it is noted. The availability of test standardization is beneficial since the standardization process usually includes test ruggedness as well as test variability measures.

The findings in Table 3.1 indicate that of various bulk tests reviewed herein none show capability to have direct correlation with field cracking performance. Several tests have shown to be able to provide good correlation with field cracking through use of computational models. Both AMPT and Superpave IDT creep tests have high amounts of equipment and specimen needs, but are most widely accepted with well documented correlation between test results and field performance.

Table 3.1 Comparison of Bulk Behavior Asphalt Performance Tests

Test	Link to Performance		Test Standardization	Equipment and Specimen Needs
	Rutting	Cracking		
AMPT (SPT)	Yes	Indirect (using model)	AASHTO and ASTM	Moderate
DMA	No	Indirect (using model)	Not Standardized	Moderate
Cyclic IDT	Yes	Indirect (using model)	Not Standardized	Mod.- High
Superpave IDT (Creep)	No	Indirect (using model)	AASHTO and ASTM	Mod.- High
Torsion Bar DSR	Yes	No	ASTM	Moderate
Mix BBR Test	No	Indirect (related to Superpave IDT)	Not Standardized	Moderate
Uniaxial Creep	Yes	No	Not Standardized	Low - Mod.

3.3.2 Damage and Fracture Tests

As previously described, the damage and fracture tests can be distinguished from the bulk behavior or response test such that these tests usually involve loading mechanisms and measurements in regions of material damage and failure. Depending on the type of damage induced by the test these can be broadly divided as: strength tests, fatigue tests, fracture tests, simulative tests and bulk damage tests. Brief description of each category along with various candidate tests in each are presented in subsequent subsections.

3.3.2.1 Strength Tests

As the name suggests the strength tests are typically conducted to measure the strength of the material. Strength typically corresponds to a maximum stress level that material can undergo before onset of damage or failure. Various tests have been proposed to measure strength in different loading modes (tension versus compression) as well as different test conditions (test temperature, specimen conditioning etc.). The tensile strength of asphalt concrete has been

commonly associated with cracking performance of the pavement. Various tensile strength tests are discussed here.

3.3.2.1.1 Indirect Tensile Strength Test (IDT Strength)

The indirect tensile strength test for asphalt concrete has been used very extensively, as discussed in Chapter 2 of this report, the indirect tensile strength is also required by several DOTs as part of mix acceptance criteria. There has been quite large variation amongst the agencies, researchers and practitioners as far as the testing procedure and data analysis is concern for the IDT strength test. These variations include test temperatures, loading rate, displacement measurements, and selection of load corresponding to the failure, and specimen preparation and conditioning procedures. The two variants that are most popular are the Superpave IDT test procedure specified as AASHTO T-322 and the indirect tensile strength determined for calculation of tensile strength ratio (TSR) as specified by AASHTO T-283 test procedure.

The Superpave IDT strength test was developed in conjunction with the Superpave asphalt mix design process. The result from this test is one of the key inputs to the SHRP thermal cracking prediction model or TCMModel. Through use of TCMModel very good correlation has been shown between pavement cracking and the IDT strength (Roque et al., 1995a, 1995b). The testing complexity and equipment needs for the Superpave IDT strength is relatively high. Typically, a close loop loading system with 100 kN capacity is needed along with four extensometers and data acquisition system. Typically the testing is conducted to obtain results for IDT creep and strength simultaneously.

On the other end of complexity spectrum is the tensile strength measurement from the AASHTO T-283 procedure. The equipment and measurement requirements are quite low in this case. A single peak load measurement is typically needed as test measure and there is minimal need for data post-processing. One of the biggest benefits of this test is that it is already being utilized by most agencies including MnDOT. At present, most agencies use only one parameter from this test and that is, the ratio of tensile strengths for samples before and after moisture conditioning. If the requirement for tensile strength is added, no further testing efforts will be needed. The potential drawback is that the effectiveness of this tensile strength measure to predict field performance is not established from previous studies.

3.3.2.1.2 Bending Beam Rheometer Mix Tensile Strength (Mix BBR Strength)

The bending beam rheometer device commonly used for testing of asphalt binders has been modified by researchers at the University of Minnesota Twin Cities to measure tensile strength of the mixture by conducting a flexural strength test. The preliminary results show good correlation between the mix BBR strength and the Superpave IDT strength. Thus, the mix BBR strength test can be used as a simpler alternative to the Superpave IDT with expectation that similar efficiency in field cracking performance prediction will be obtained.

3.3.2.2 Fatigue Tests

The fatigue tests are typically designed to simulate failure in material due to accumulation of damage due to high number of load repetitions. In some sense these tests are geared towards emulating accumulation of damage in pavements due to repetition of traffic loading.

3.3.2.2.1 *Four Point Bending (4PB) Beam Fatigue Test*

The 4PB beam fatigue test is most commonly utilized asphalt pavement fatigue evaluation test. Several researchers have shown the efficiency of the 4PB beam fatigue test in predicting the pavement life, for example work by Tangella et al. (1990) and Willis and Timm (2009). Over the period of years a wide range of test variations have been proposed. Commonly varying parameters include: test control method (stress control versus strain control), test amplitude, and test temperature. The evaluation criteria has also varied quite significantly, early research work focused on number of cycles to failure (Epps and Monismith, 1969), whereas in recent years the focus has moved to use of fatigue endurance limits (Prowell et al., 2010). The 4PB fatigue test is also a recommended proof test for Superpave Level III mix design procedure; the test is standardized as AASHTO T-321 specification. Additionally, it is also one of the most commonly used test in the performance based provisional specifications to ensure good pavement cracking resistance.

3.3.2.2.2 *Uniaxial Cyclic Fatigue Test (Uniaxial Push-Pull Test)*

In order to simplify the test geometry of the 4PB beam fatigue and to reduce the test equipment requirements Soltani and Anderson (2005) proposed a uniaxial fatigue test. The 4PB beam fatigue test requires a square beam sample that is difficult to manufacture in lab or obtains from actual pavement. The uniaxial cyclic fatigue test utilizes specimen similar to the one used in AMPT. The results from Soltani et al. (2006) show that this test is a viable alternative to the 4PB beam fatigue test. Kutey et al. (2008) showed a good correlation between the results obtained from uniaxial cyclic fatigue test and accelerated field tests through use of computational models. At present this test procedure is not standardized.

3.3.2.2.3 *Trapezoidal Beam Fatigue Test (Two Point Bend Fatigue Test)*

The trapezoidal or cantilever beam fatigue test is another alternative to the 4PB beam fatigue test. This test has been widely utilized in the Europe for study of fatigue cracking in asphalt pavements and is currently the only standardized asphalt material fatigue test as per the European test specifications (CEN, 2006). One of the major limitations of this test is the requirement of a specimen that is trapezoidal in shape making it difficult to use on routine basis.

3.3.2.3 Fracture Tests (DCT, SCB, SENB)

The fracture tests for asphalt concrete are relatively new. Contrary to strength tests the fracture tests focus on measurement of the necessary amount of energy that is required to propagate a crack through the material rather than focus on the amount of stress necessary to initiate a crack. In the case of materials that exhibit quasi-brittle and ductile failure behavior this property is of particular interest. This is primarily due to the fact that material has significant capacity to carry load once the peak capacity, as commonly indicated by tensile strength, is reached. The material

behavior past the peak load is commonly referred to as “softening” behavior. Like other test categories, different test procedures have also been proposed for fracture tests. The primary differences are the rate of loading and the specimen geometry. The three most popular tests are: the disk shaped compact tension (DCT) (Wagoner et al., 2005a), semi-circular bend (SCB) (Li et al., 2006a) and single edge notch beam (SENB) (Wagoner et al., 2005b). All three of these tests have been used to study cracking in asphalt concrete with major thrust on thermal and reflective cracking. With these three DCT and SCB allow for use of 6 inch diameter cylindrical asphalt concrete sample, this type of specimens are often readily available from lab and field. Brief descriptions of DCT and SCB test are presented in subsequent subsections.

3.3.2.3.1 Disk-Shaped Compact Tension (DCT) Test

The disk-shaped compact tension (DCT) test standardized as the ASTM D7313-07 test procedure. The test is controlled to obtain a constant rate of crack mouth opening displacement or CMOD. As per ASTM D7313-07 specifications a constant CMOD rate of 0.0167 mm/s (or 1 mm/minute) is used. Study on low temperature cracking by Marasteanu et al. (2007) showed very good capability of fracture tests (DCT, SCB and SENB) in predicting thermal cracking as compared to the IDT strength test. Paulino et al. (2006) showed good correlation between results from DCT test and field reflective cracking performance. A current FHWA pooled fund study (TPF-5(132)) will validate use of fracture tests for prediction of field cracking and also develop draft performance-based specifications for limiting low temperature cracking.

3.3.2.3.2 Semi-Circular Bend (SCB) Test

The semi-circular bend (SCB) has been widely utilized for evaluation of cracking potential in asphalt concrete. Li et al. (2006a, 2006b) and Marasteanu et al. (2007) have determined fracture energy and critical stress intensity factor of asphalt concrete from the SCB test. Both of these parameters have shown good correlation with low temperature cracking in asphalt pavements. As described above, both SCB and DCT have been used extensively on two Pooled Fund Studies (TPF 776 and TPF-5(132)) on low temperature cracking in asphalt pavements. Several asphalt mixtures from Minnesota have been used in both of these studies. Especially SCB tests have been conducted on mixtures from most recently constructed MnROAD test sections.

3.3.2.4 Simulative Tests

The majority of tests described so far in this chapter fall under category of fundamental or engineering tests. Whereby, the testing conditions are optimized to measure either a fundamental or an engineering material property. The simulative tests differ in that sense as to they are usually designed to simulate the loading and failure conditions that occur in field rather than focus on measurement of a certain material property. Typically the output of simulative test is needed to be calibrated and validated for a given set of field conditions. While a number of simulative tests have been proposed the three most commonly used tests for prediction of cracking in pavements is discussed in following sub-sections.

3.3.2.4.1 *Texas Overlay Tester (TxOT)*

The TxOT was developed by Zhou et al. (2004) at the Texas Transportation Institute (TTI) as a simulative test for reflective cracking in overlays. Since its development the test has been used in conjunction with computational models to predict fatigue cracking performance of the pavements (Zhou et al., 2007). A preliminary validation of this test was presented by Zhou et al. (2004) where the test results showed good qualitative comparisons with the field cracking of three pavement test cells at MnROAD facility. The comparisons were made with total transverse cracking, details are not known whether the thermally induced cracking or fatigue cracking were predominant.

3.3.2.4.2 *Thermal Stress Restrain Specimen Test (TSRST)*

TSRST is another simulative test that was developed through the SHRP program as part of the Superpave performance based mix design process (Jung and Vinson, 1994). This test was developed as a proof test for low temperature cracking performance in the Level III mix design procedure. Good correlation has been observed between TSRST and low temperature cracking (Zubeck et al., 1996). The requirement for beam samples for this test makes it difficult to use on routine basis along with need for dedicated equipment that cannot be shared with other tests.

3.3.2.4.3 *Asphalt Concrete Cracking Device (ACCD)*

The ACCD was developed as an extension to a conceptually similar device for evaluation of low temperature performance of asphalt binders (Kim et al, 2009). This test procedure significantly reduces equipment requirements of TSRST while providing similar information about the low temperature cracking performance of asphalt concrete. The test procedure is relatively recent and initial results have shown very good correlation between this test and TSRST (Kim et al., 2009). Direct comparison of test results from this ACCD and field cracking performance is not available.

3.3.2.5 *Bulk Damage Tests*

The tests in this category are usually designed to measure the resistance of material to permanent and excessive deformations under the given loading conditions. Usually these tests measure the stability of the asphalt concrete by measuring the resistance to plastic flow under loaded conditions. Three set of bulk damage tests are presented here which encompass fundamental, simulative and empirical tests.

3.3.2.5.1 *Superpave Shear Tester (SST)*

Like many other asphalt performance tests, the SST device was developed through SHRP as part of Superpave test suite. As described in Chapter 2 for Level II and Level II mix design a number of tests are recommended to be conducted using SST. The SST focuses on determining fundamental material properties associated with shearing of asphalt mixture. The main distresses tackled by these tests are rutting and fatigue cracking. This test has not been widely accepted due to excessive equipment requirements. The NCHRP 9-19 project indicated that the AMPT is capable of predicting pavement performance with similar rigor as the SST (Witczak, 2005). The test procedure for SST is standardized as AASHTO T-320 specification.

3.3.2.5.2 *Simulative Rutting Tests*

The simulative rutting tests are similar in nature as the simulative cracking tests presented earlier, with the main difference that these focus on rutting performance of the pavement. The two test procedures that are most widely used include: Hamburg wheel tracking device and the asphalt pavement analyzer (APA). Both of these test procedures are standardized by AASHTO and ASTM. Several DOTs have adopted them to ensure good rutting performance (c.f. Chapter 2). Hall and Williams (1999) and Cooley et al. (2000) have shown viability of the Hamburg wheel tracking device in its capability to evaluate rutting and moisture stripping performance of asphalt concrete. Similarly for APA researchers have shown that it could be successfully used as a proof test for rutting performance (Kandhal and Cooley, 2002).

3.3.2.5.3 *Empirical Mix Stability Tests*

Prior to implementation of the Superpave mix design process on wide-spread basis the Marshall and Hveem mix design approaches were most commonly used. Both of these mix design methodologies require stability testing of the designed mix to ensure good rutting performance. While many agencies have transitioned to simulative rutting tests, there are still significant number of DOTs that require Marshall stability test in the mix acceptance criteria. Both Marshall and Hveem stability tests have also been used for evaluating the moisture damage potential of asphalt concrete, for example by Arkansas and California DOTs.

3.3.2.6 *Comparison of Fracture and Damage Tests*

The various tests presented in this section are compared in manner similar to the comparison of bulk behavior tests. Table 3.2 presents qualitative comparisons of various fracture and damage tests with information based on the published literature regarding link of test to performance, availability of test standardization and typical equipment, specimen and specimen conditioning needs.

Based on the information provided in the table as well as the review of the literature few key points about fracture and damage tests for asphalt performance evaluation can be made:

- The tensile strength measures show good links to field cracking performance, especially low temperature cracking. The complexity of test varies from low to high depending on the particular type of test configuration. Once again the simple indirect tensile strength is most readily available parameter that is usually determined as part of mix design process. While it is not clear from literature if this tensile strength value has same rigor in predicting pavement cracking as most complicated Superpave IDT strength, it is definitely one of the easiest performance test requirement to add to existing material specifications. The mix BBR test can be a good alternative to Superpave IDT, however the test is still in development stage and needs further validation.
- Various fatigue tests have shown good correlation to field cracking with four point beam bending test being most widely accepted and used. This test has also been used for several provisional performance based specifications. A major drawback in use of fatigue tests in performance based specification is the amount of time associated with each test. Typically a

fatigue test spans across a number of days to complete and thus its use on wide-spread basis is not efficient.

- Fracture tests are relatively new to the field of asphalt performance evaluation. Initial studies have shown great potential in them. Fracture tests (DCT and SCB) are the only tests that have shown good validation against thermal and reflective cracking in pavements. Furthermore, significant numbers of previous studies have used these tests to characterize asphalt mixtures from Minnesota. The testing requirements for DCT and SCB are generally on high to moderate side due to associated equipment needs as well as complexity in preparation of the test specimens. If test simplification is possible, then these tests will be optimal candidates for development of performance based specifications in Minnesota.
- The TxOT shows good potential for evaluation of cracking performance in pavements. It should be noted that there has been limited amount of results to demonstrate suitability of this test in colder climatic conditions. Also being a simulative test, a calibration and validation effort will need to be undertaken if this test is to be used in performance based specification in Minnesota. The ACCD is the next best suited simulative test due to lower equipment requirement; however it has been used even scarcely than TxOT to have enough confidence in its ability for predicting field cracking performance.
- The simulative rutting tests have shown very good potential in predicting rutting performance of the pavement and are widely accepted.

Table 3.2 Comparison of Fracture and Damage Tests

Test	Link to Performance		Test Standardization	Equipment and Specimen Needs
	Rutting	Cracking		
IDT Strength	No	Yes	AASHTO and ASTM	Low – High
Mix BBR Strength	No	Yes (correlated to IDT Strength)	Not Standardized	Moderate
4PB Beam Fatigue	No	Yes	AASHTO and ASTM	High
Uniaxial Cyclic Fatigue	No	Yes	Not Standardized	Mod. – High
Fracture Tests	No	Yes	ASTM (AASHTO in process)	Mod. - High
Texas Overlay Tester	No	Yes	ASTM in process	Mod. – High
TSRST	No	Yes	AASHTO	High
ACCD	No	Yes (correlated to TSRST)	Not Standardized	Low – Mod.
SST	Yes	Yes	AASHTO	High
Simulative Rutting Tests	Yes	No	AASHTO and ASTM	Mod. - High
Empirical Stability Tests	Yes	No	AASHTO and ASTM	Low – Mod.

3.4 Synthesis of the Current State of the Art for Asphalt Performance Tests

The current state of the art for the asphalt performance tests can be synthesized into following points:

- Significant number of mechanical tests have been proposed as asphalt performance tests, relatively low number have actually shown good correlation between the test results and field performance. This is especially true for pavement cracking distresses.
- Of those tests that have shown good correlation to field cracking distress very few are used on routine basis. At present, beam fatigue and Texas overlay tester are the only ones that are part of standard material specifications for a DOT.
- Large number of tests with good correlation to field performance relies on use of computational and analytical models to achieve these correlations.
- Very few tests fall in category where they can be used on routine basis, require minimal data post-processing and show good correlation to field performance.

- The AMPT has been researched very extensively in recent years and is continuing to gain acceptance from researchers and agencies. The test has great potential in predicting pavement rutting performance and also has good potential in predicting fatigue cracking by means of computational models. The suitability of test in terms of low temperature cracking has not been evaluated and thus limits its suitability for use in Minnesota.
- Bulk property tests are usually complicated to use in performance based specifications, they are better suited for pavement design purposes.
- Some strength tests have good potential for use in performance based specifications; however, they may be limited due to testing complexities.
- Fracture tests, particularly DCT and SCB, have shown very good correlation with cracking performance of pavements. Significant data is already available for several mixtures and pavements in Minnesota for both of these tests. These tests have also been recommended for routine use to screen mixtures for thermal cracking performance. The only limitations for these tests are their complexity, which may hinder their widespread and routine use.
- Simulative tests may be viable options for use in developing performance based specifications and to serve as proof tests. A mature and simple simulative test for low temperature cracking is not available. Furthermore, use of simulative tests will require a local calibration and validation process. Typically testing requirements are also quite elaborate and lengthy.

4 Review of Previous MnDOT Projects on Asphalt Performance Testing

4.1 Introduction and Motivation

In 2010 alone, the MnDOT Research Services program spent nearly 10 million dollars on transportation research. Topics researched have been extremely diverse including traffic and safety, materials and construction, and environmental research. Research Services supports Minnesota's transportation industry by meeting the innovation and information needs of transportation practitioners and the transportation community.

Using decade's worth of compiled knowledge on asphalt performance testing from MnDOT research only helps the efforts of this project. It gives this project additional information that can be expanded upon in future tasks to fully exploit the efforts of this project and leverage upon the related efforts that were undertaken in the previous projects.

4.2 Methodology

A literature review was performed to collect findings from past research on performance-based asphalt tests. The benefit of reviewing previous projects from Minnesota ensures that every report available already relates to Minnesota pavements and failure characteristics. Three hundred and ninety-three research publications about MnROAD, pavement, and materials research were reviewed with varying levels of scrutiny. The focus was kept on reports that include asphalt pavement field performance as well as test results.

Several projects were selected for review. The review projects covered variety of asphalt lab tests including: Asphalt Pavement Analyzer, Indirect Tensile Test, and the Thermal Stress Restrained Specimen Test (TSRST). Data from lab tests were also correlated in some of the reports such as: coefficient of thermal contraction, Poisson's ratio, complex modulus, resilient modulus, and relaxation modulus.

4.3 Review of Previous Projects

4.3.1 Diametral Compression Test

The research by Drescher, et al. (1996), gives an overview of the diametral compression test (aka IDT) for asphalt concrete. It discusses the test, and its possible correlations with pavement performance. The work also discusses the procedures to obtain complex modulus, resilient modulus and Poisson's ratio of asphalt concrete using the diametral compression test. The key findings from this project are as follows,

- The resilient modulus and Poisson's ratio are insufficient in correlating viscoelastic properties of an asphalt mix.
- These parameters can be useful indications of mix quality and deformation ability, but are not useful for predicting specific material response to in-field use.
- In the case of traffic-induced loading, the viscoelastic properties of an asphalt mix can be quantified by the complex modulus.

- The pulse/rest test from resilient modulus test is unsuitable for determining the viscoelastic properties of an asphalt mix.
- The viscoelastic properties of an asphalt mix can be quantified by the relaxation modulus for non-periodic loading.
- Fair correlation is observed between field performance and complex modulus as well as field performance and relaxation modulus.

4.3.2 Evaluation of Asphalt Pavement Analyzer

This research on rutting performance evaluation by Skok, et al. (2002), describes MnDOT's research of the Asphalt Pavement Analyzer (APA). The research was centered on whether or not the APA is a useful tool for analyzing hot-mix asphalt concrete used in Minnesota. The project yielded following recommendations:

- Specific criteria for APA test specimens should be developed.
- A specific relationship can be developed between APA rut depth and dynamic modulus.
- A comprehensive database for APA measurements of Minnesota asphalt mixtures should be developed.
- APA is a viable tool for evaluation of rutting performance of typical mixes used in Minnesota. A database of APA measurements for mixtures from Minnesota has been developed by MnDOT. This database is in process of being populated through testing of mixtures.

4.3.3 Study of Low Temperature Cracking

A number of studies have been sponsored by MnDOT on topic of low temperature cracking in asphalt pavements. The primary findings on asphalt performance testing were obtained from work by Marasteanu et al. (2004, 2007) and Li et al. (2006b). The cumulative findings from these studies are as follows,

- Fracture energy and fracture toughness of asphalt concrete is related to the pavement low temperature cracking and has potential to predict cracking.
- Fracture energy measurements are preferred screening measure for evaluation of low temperature cracking potential of mixtures.
- Aggregate type, binder grade and aging amongst other factor have significant effect on fracture energy of asphalt concrete.
- The indirect tensile test (IDT) provides useful data for complete evaluation of low temperature cracking, but it is not a preferred as simple screening test.
- With some refinement, the thermal stress restrained specimen test (TSRST) can be a useful tool in analyzing stress development in low temperature mixtures.
- The coefficient of thermal contraction of asphalt mixture is a critical parameter in estimation of field performance. The test to find this coefficient is difficult; the project suggests the creation of a database to reduce routine testing.

4.3.4 Complex (Dynamic) and Resilient Modulus Testing

Two recent projects have been conducted by MnDOT that utilize complex and resilient modulus testing for evaluation of various asphalt mixes (Clyne et al., 2003, Johnson and Olson, 2009). While, field performance is not discussed in these project they give good overview of complex and resilient modulus testing as performance indicator.

4.4 Findings from Previous MnDOT Research

The findings from various research projects related to asphalt performance testing conducted by MnDOT is presented in this section. Table 4.1 presents the summary of findings. For each test type and the corresponding test parameter, the observations in terms of their suitability in linking field performance are shown. The strength of the correlation is also provided. Within the scope of this project it was not possible to quantify the strength of correlations between test measurements and field performance. Qualitative comparisons were made using the information provided in the reports. While there is some variability between qualitative comparisons, typically good correlation had coefficient of determination of 0.6 or greater. It can be seen that a number of tests show correlation with field performance with the fracture tests showing the best association. Also, it should be noted that the findings from previous MnDOT projects are in agreement with the review of asphalt performance tests provided in Chapter 2 and 3.

Apart from these observations about the suitability of test in predicting performance this preliminary review also showed that significant amount of test results and field performance data is available. The laboratory test results and field performance data for all pavement sections tested at MnROAD facility are readily available. If this data is compiled in to a single database, great deal of observations can be made. Things such as effects of material selection (binder type, aggregate gradation etc.), pavement structure, and effect of recycled components or additives can be quantified through this type of compiled database. It could also significant reduce the future testing needs and allow practitioners and researchers to estimate of a variety of material properties using known parameters.

Table 4.1 Asphalt Performance Test Findings from Previous MnDOT Research

Test Type	Test Parameter	Link to Performance		Strength of Correlation
		Rutting	Cracking	
Diametral Compression	Resilient Modulus	---	No	
	Poisson's Ratio	---	No	
	Complex Modulus	---	Yes	Fair
	Relaxation Modulus	---	Yes	Fair
Fracture Tests	Fracture Energy	---	Yes	Good
	Fracture Toughness	---	Yes	Good
TSRST	Critical Cracking Temperature	---	Yes	Fair
Coefficient of Thermal Contraction	---	---	Yes	Fair
APA	Number of Cycles to Failure	Yes	---	Good

5 Summary, Conclusions and Recommendations

5.1 Project Summary

This research project undertook the task of synthesizing the topic of performance testing for asphalt concrete. In order to conduct such evaluation the project was divided into three tasks. The three tasks focused on evaluating the state of the practice and state of the art for asphalt performance tests and conducting preliminary review of previous MnDOT sponsored projects on asphalt performance testing. The current state of the practice on asphalt performance tests was quantified by review of various State Highway Agency (SHA) standard specifications. The performance test requirements from those were analyzed along with some provisional performance-based specifications. The state of the art review was focused on technical literature that presents comparisons between performance tests and their effectiveness in predicting actual field performance. Qualitative comparisons were made between various candidate performance tests. Based on such comparison a few tests are short listed for future evaluation. Finally, a preliminary review of previous MnDOT research projects was conducted. The findings from the review are in agreement with the findings from the other two tasks. Specific summaries and findings of each task are presented in the corresponding chapters. The key conclusions and recommendations from this research present in subsequent sections.

5.2 Conclusions

Based on the findings from this research project following conclusions can be drawn:

- Performance tests are being required by several State Departments of Transportation (DOTs) on routine basis through standard material specifications. At present, the performance test requirements are primarily limited to rutting distress.
- Few pilot studies have shown that use of performance test based specifications to reduce risk of pavement cracking is feasible.
- Implementation of application targeted performance-based specifications for asphalt concrete may be suitable. This allows for focus on specific performance test requirement that is most related to the distress that a mix will encounter during pavement service. The application target could be selected on basis of location of lift in pavement, type of pavement, traffic level or other variables.
- Significant amount of effort has been put nationally to develop the asphalt material performance test (AMPT). However, its applicability for direct use to determine pavement cracking performance is not given due priority, this is especially true for thermally induced pavement cracking.
- Number of cracking performance tests are available, based on this review the tests that show greatest potential for use in performance based material specifications are: indirect tensile strength, especially from moisture damage evaluation tests; fracture tests such as semi-circular bend tests or disk-shaped compact tension test; Texas overlay tester; and four point bending beam fatigue test.
- Significant amount of test and field performance data is available from previous MnDOT projects. The preliminary review agrees with general findings on asphalt performance testing.

5.3 Recommendations

The objective of this research project was to conduct a review of current state of asphalt performance testing. Apart from identification of few candidate performance tests, several recommendations were identified. Several of these recommendations point towards future research efforts that will enable extension of the present effort into a fruitful and implementable outcome. The recommendations from the present research study are following:

- The use of indirect tensile strength measure from the moisture susceptibility testing should be evaluated to determine if it can be used as a performance measure. Already significant amount of lab data is available for this measurement and minimal research effort will be necessary to determine if this parameter can be used. Furthermore, it is most widely used requirement in DOT specifications.
- Fracture tests (disk-shaped compact tension and semi-circular bend tests) show great potential as suitable performance tests, they should be evaluated for asphalt mixtures and field sections from Minnesota and to evaluate possibility of their widespread and routine usage.
- The testing requirements in terms of equipment, specimens and data post-processing should be quantified to inform the selection of asphalt performance test.
- Trial projects should be undertaken to evaluate feasibility of using performance based specifications.
- A compilation of all available laboratory tests data and field performance data should be generated. Significant amount of field performance data is available through pavement management system. This database can really inform the decision regarding the selection of asphalt performance test.

References

- [1] S.D. Anderson, and J.S. Russell, *Guidelines for Warranty, Multi-Parameter, and Best Value Contracting*, Washington, D.C.: National Cooperative Highway Research Program, Report No. 451, 2001.
- [2] T. Bennert, "Implementation of Performance-Based HMA Mixtures in NJ." Presentation, Presented at Annual Meeting of the Association of Asphalt Paving Technologists, Tampa, FL, March, 2011.
- [3] P. Blankenship, N. Iker, and J. Drbohlav, "Interlayer and Design Considerations to Retard Reflective Cracking," *Transportation Research Record*, no. 1896 (2004), 177-186.
- [4] R. Bonaquist, *Refining the Simple Performance Tester for Use in Routine Practice*, Washington, D.C.: National Cooperative Highway Research Program, Report No. 614, 2008.
- [5] E.R. Brown, P.S. Kandhal, F.L. Roberts, Y.R. Kim, D.-Y. Lee, and T.W. Kennedy, *Hot Mix Asphalt Materials, Mixture Design and Construction* Lanham, MD: National Asphalt Pavement Association, 2009.
- [6] W.G. Buttlar and R. Roque, "The Development of a Measurement and Analysis System to Accurately Determine Asphalt Concrete Properties Using the Indirect Tensile Mode," *Journal of Association of Asphalt Paving Technologists*, vol. 61 (1992), 304-332.
- [7] W.G. Buttlar and A. Manik, *Evaluation of Risk in End-Result Specifications for Asphalt Pavement Construction* Urbana, IL: Illinois Center for Transportation, Report No. FHWA-ICT-07-013, October 2007.
- [8] *Material Specifications - Asphalt Concrete* Brussels, Belgium: European Committee for Standardization, Standard No. 13108-1, 2006.
- [9] R.J. Cominsky, G.A. Huber, T.W. Kennedy, and M. Anderson, *The Superpave Mix Design Manual for New Construction and Overlays*, Washington, D.C.: Strategic Highway Research Council, National Research Council, Report No. SHRP-A-407, 1994.
- [10] L.A. Cooley, Jr., P.S. Kandhal, M.S. Buchanan, F. Fee, and A. Epps, *Loaded Wheel Testers in the United States: State of the Practice*, Auburn, AL: Auburn University, National Center for Asphalt Technology, 2000.
- [11] W.H. Daly, I.I. Negulescu, L.N. Mohammad, and I. Chiparus, *The Use of DMA to Characterize the Aging of Asphalt Binder*, Baton Rouge, LA: Louisiana Department of Transportation and Development, Louisiana Transportation Research Center, Report No. FHWA/LA.07/46, 2010.
- [12] J.A. Deacon, C.L. Monismith, and J.T. Harvey, *Pay Factors for Asphalt-Concrete Construction: Effect of Construction Quality on Agency Costs*, Berkeley, CA: University

- of California, Pavement Research Center, Report No. TM-UCB-CAL/APT-97-1, April 1997.
- [13] A. Drescher, D. Newcomb, and W. Zhang, *Reassessment of Diametral Compression Test on Asphalt Concrete*, Minneapolis, MN: University of Minnesota, Minnesota Department of Transportation, 1996.
- [14] J.A. Epps, and C.L. Monismith, "Influence of Mixture Variables on the Flexural Fatigue Properties of Asphalt Concrete," *Journal of Association of Asphalt Paving Technologists*, vol. 38 (1969).
- [15] C. Estakhri, J. Button, and A.E. Alvarez, *Field and Laboratory Investigation of Warm Mix Asphalt in Texas* College Station, TX: Texas A&M University, Texas Transportation Institute, Report No. 0-5597-2, July 2010.
- [16] V. Gallivan, *Development of Warranty Programs for Hot-Mix Asphalt Pavements*, Washington, D.C.: Transportation Research Board, Transportation Research Circular E-C154, June 2011.
- [17] K.D. Hall and S.G. Williams, *Acquisition and Evaluation of Hamburg Wheel-Tracking Device*, Fayetteville, AR: University of Arkansas, Mack-Blackwell Transportation Center, 1999.
- [18] D.R. Hiltunen, and R. Roque, "A Mechanics-Based Prediction Model for Thermal Cracking of Asphaltic Concrete Pavement." *Journal of the Association of Asphalt Paving Technologists*, vol. 63 (1994), 81-108.
- [19] D.H. Jung, and T.S. Vinson, *Low Temperature Cracking: Test Selection* Washington, D.C.: Strategic Highway Research Council, National Research Council, Report No. SHRP-A-400, 1994.
- [20] P.S. Kandhal, and L.A. Cooley Jr., *Evaluation of Permanent Deformation of Asphalt Mixtures Using Loaded Wheel Tester* Auburn, AL: Auburn University, National Center for Asphalt Technology, 2002.
- [21] S. Khanzada, *Permanent Deformation in Bituminous Mixtures*, Nottingham, UK: University of Nottingham, 2000.
- [22] S.-S. Kim, S. Sargand, and A. Wargo, *A Simple Test Procedure for Evaluating Low Temperature Crack Resistance of Asphalt Concrete*, Athens, OH: Ohio University, Ohio Research Institute for Transportation and the Environment, Report No. FHWA/OH-2009/5, November 2009.
- [23] Y.R. Kim, Y. Seo, M. King, and M. Momen, "Dynamic Modulus Testing of Asphalt Concrete in Indirect Tension Mode," *Transportation Research Record*, no. 1891 (2004), 163-173.
- [24] M.E. Kutay, N.H. Gibson, and J. Youtcheff, "Conventional and Viscoelastic Continuum Damage (VECD) Based Fatigue Analysis of Polymer Modified Asphalt Pavements," *Journal of Association of Asphalt Paving Technologists*, vol. 77 (2008a), 395-434.

- [25] M.E. Kutay, N.H. Gibson, and J. Youtcheff, "Use of Pseudostress and Pseudostrain Concepts for Characterization of Asphalt Fatigue Tests," *Pavement Cracking: Mechanisms, Modeling, Detection, Testing and Case Histories*, vol. 1 (2008b), 305-314.
- [26] X. Li, M.O. Marasteanu, N. Iverson, and J.F. Labuz, "Observation of Crack Propagation in Asphalt Mixtures with Acoustic Emission," *Transportation Research Record*, no. 1970 (2006a), 171-177.
- [27] X. Li, A. Zofka, X. Li, M.O. Marasteanu, and T.R. Clyne, *Investigation of the Low-Temperature Fracture Properties of Three MnROAD Asphalt Mixtures*, Minneapolis, MN: University of Minnesota, Minnesota Department of Transportation, 2006b.
- [28] R.L. Lytton, E. Masad, C. Zollinger, R. Bulut, and D. Little, *Measurements of Surface Energy and its Relationship to Moisture Damage*, College Station, TX: Texas A&M University, Texas Transportation Institute, Report No. FHWA/TX-05/0-4524-2, 2005.
- [29] M.O. Marasteanu, X. Li, T.R. Clyne, V.R. Voller, D.H. Timm, and D.E. Newcomb, *Low Temperature Cracking of Asphalt Concrete Pavements* Minneapolis, MN: University of Minnesota, Minnesota Department of Transportation, 2004.
- [30] M. Marasteanu, A. Zofka, M. Turos, X. Li, R. Velasquez, and X. Li, *Investigation of Low Temperature Cracking in Asphalt Pavements* St. Paul, MN: Minnesota Department of Transportation, Final report, Pooled Fund Study 776, March 2007.
- [31] G.H. Paulino, W.G. Buttlar, P.B. Blankenship, M.P. Wagoner, S.H. Song, and E.V. Dave, *Reflective Crack Control Treatment and Design Procedures: A New Integrated Approach*, Washington, D.C.: National Science Foundation, Final Report NSF-GOALI Project - CMS:0219566, 2006.
- [32] B.D. Prowell, E.R. Brown, R.M. Anderson, J.S. Daniel, A.K. Swamy, H.V. Quintus, S. Shen, S.H. Carpenter, S. Bhattacharjee, and S. Maghsoodloo, *Validating the Fatigue Endurance Limit for Hot Mix Asphalt*, Washington, DC: National Cooperative Highway Research Program, Report No. 646, 2010.
- [33] P. Romero, C.-H. Ho, and K. VanFrank, *Development of Methods to Control Cold Temperature and Fatigue Cracking for Asphalt Mixtures*, Salt Lake City, UT: University of Utah, UDOT Research Division, Report No. UT-10.08, May 2011.
- [34] G. Reinke, and S. Glidden, *Development of Mixture Creep Performance Tests using a Dynamic Shear Rheometer*, Washington, D.C.: Transportation Research Board, Transportation Research E-Circular, No. E-C068, 1-43, 2004.
- [35] R. Roque, D.H. Hiltunen, W.G. Buttlar, and T. Farwana, "Development of the SHRP Superpave Mixture Specification Test Method to Control Thermal Cracking Performance of Pavements," *ASTM Special Technical Publication*, no. 1265 (1995a), 55-73.
- [36] R. Roque, D.H. Hiltunen, and W.G. Buttlar, "Thermal Cracking Performance and Design of Mixtures Using Superpave™," *Journal of Association of Asphalt Paving Technologists*, vol. 64 (1995b), 718-735.

- [37] E.L. Skok, E. Johnson, and A. Turk, *Asphalt Pavement Analyzer (APA) Evaluation*, Minneapolis, MN: University of Minnesota, Minnesota Department of Transportation, 2002.
- [38] A. Soltani, and D.A. Anderson, *Uniaxial Fatigue of Asphalt Mixes: A New Approach*, State College, PA: The Pennsylvania State University, Pennsylvania Transportation Institute, Report No. PTI 2003-13, January 2005.
- [39] A. Soltani, M. Solaimanian, and D.A. Anderson, *An Investigation of the Endurance Limit of Hot-Mix Asphalt Concrete Using a New Uniaxial Fatigue Test Protocol*, University Park, PA: The Pennsylvania State University, Pennsylvania Transportation Institute, Report No. FHWA-HIF-07-002, May 2006.
- [40] S.C.S.R. Tangella, J. Craus, J.A. Deacon, and C.L. Monismith, *Summary Report on Fatigue Response of Asphalt Mixtures*, Berkley, CA: University of California, SHRP A-003-A, Report No. TM-UCB-A-003A-89-3, 1990.
- [41] B.S. Underwood, Y.R. Kim, and M.N. Guddati, "Characterization and Performance Prediction of ALF Mixtures Using a Viscoelastoplastic Continuum Damage Model," *Journal of Association of Asphalt Paving Technologists*, vol. 75 (2006), 577-636.
- [42] B.S. Underwood, Y.R. Kim, M.N. Guddati, S. Thirunavukkarasu, and S. Savadatti, "Responses and Fatigue Performance Modeling of ALF Pavements Using 3-D Finite Element Analysis and a Simplified Viscoelastic Continuum Damage Model," *Journal of Association of Asphalt Paving Technologists*, vol. 78 (2009), 829-868.
- [43] M.P. Wagoner, W.G. Buttlar, and G.H. Paulino, "Disk-Shaped Compact Tension Test for Asphalt Concrete Fracture," *Experimental Mechanics*, vol. 45 (2005a), 270-277.
- [44] M.P. Wagoner, W.G. Buttlar, and G.H. Paulino, "Development of a Single-Edge Notched Beam Test for Asphalt Concrete Mixtures," *Journal of Testing and Evaluation*, vol. 33, no. 6 (2005b), 452-460.
- [45] R.C. Williams, D. Hill, K. Hofmann, M. Zelenock, and J. Bausano, *Development of Laboratory Performance Test Procedures and Trial Specifications for Hot Mix Asphalt*, Houghton, MI: Michigan Technological University, Report No. RC-1410, October 2004.
- [46] J.R. Willis, and D.H. Timm, *Field-Based Strain Thresholds for Flexible Perpetual Pavement Design*, Auburn, AL: Auburn University, National Center for Asphalt Technology, Report No. 09-09, September 2009.
- [47] M. Witczak, *Simple Performance Tests: Summary of Recommended Methods and Database*, Washington, D.C.: National Cooperative Highway Research Program, Report No. 547, 2005.
- [48] W. Zhang, A. Drescher, and D. Newcomb, "Viscoelastic Analysis of Diametral Compression of Asphalt Concrete," *Journal of Engineering Mechanics*, vol. 123, no. 6 (1997), 596-603.

- [49] F. Zhou, and T. Scullion, *Overlay Tester: A Rapid Performance Related Crack Resistance Test*, College Station, TX: The Texas A&M University, Texas Transportation Institute, Report No. 0-4467-2, March 2005.
- [50] F. Zhou, S. Hu, and T. Scullion, *Development and Verification of the Overlay Tester Based Fatigue Cracking Prediction Approach*, College Station, TX: The Texas A&M University, Texas Transportation Institute, Report No. 9-1502-01-8, January 2007.
- [51] A. Zofka, M.O. Marasteanu, X. Li, T.R. Clyne, and J. McGraw, "Simple Method to Obtain Asphalt Binders Low Temperature Properties from Asphalt Mixtures Properties," *Journal of the Association of Asphalt Paving Technologists*, vol. 74 (2005), 255-282.
- [52] H.K. Zubeck, H. Zeng, T.S. Vinson, and V.C. Janoo, "Field Validation of Thermal Stress Restrained Specimen Test: Six Case Histories," *Transportation Research Record*, no. 1545 (1996), 67-74.

Appendix A: Review of State Department of Transportation Specifications

The mechanical testing requirements as required by the material specifications for each State DOT are listed:

- (1) Alabama: AASHTO T 283: TSR
- (2) Alaska: AASHTO T-245: Marshall Flow and Stability
- (3) Arizona:
Method Based Material: AASHTO T-245: Marshall Stability and Flow.
End Result Materials with Marshall Method: Marshall Stability and Flow **plus** TSR and Wet or Conditioned Tensile Strength (AASHTO T-283). 60% retained strength in TSR (70% if mix is placed above elevation of 3500 ft).
End Result Material with Superpave Method: TSR and Wet or Conditioned Tensile Strength (AASHTO T-283). 60% retained strength in TSR (70% if mix is placed above elevation of 3500 ft).
- (4) Arkansas: ATHD 480: Loaded Wheel Tester (a.k.a. Asphalt Pavement Analyzer).
Link: http://www.arkansashighways.com/materials_division/A--FIELDMAN.pdf
ATHD 455 (Water Sensitivity): Marshall Stability determined using modified Lottman moisture conditioning procedure.
Link: http://www.arkansashighways.com/materials_division/A--FIELDMAN.pdf
Optional QC test: AASHTO T 245: Marshall Stability
- (5) California: 2006 Specifications: Moisture Swell Test CTM 305 Link:
http://www.dot.ca.gov/hq/esc/ctms/pdf/CT_305.pdf
Moisture Vapor Susceptibility in Stabilometer CTM 307 Link:
http://www.dot.ca.gov/hq/esc/ctms/pdf/CT_307.pdf
Hveem Stabilometer CTM 366 Link: http://www.dot.ca.gov/hq/esc/ctms/pdf/CT_366.pdf
2010 Specifications: Stabilometer Value CTM 366 Link:
http://www.dot.ca.gov/hq/esc/ctms/pdf/CT_366.pdf
AASHTO T-283: TSR
- (6) Colorado: AASHTO T-283: TSR
- (7) Connecticut: AASHTO T 245: Marshall Stability and Flow
- (8) Delaware: AASHTO T 245: Marshall Stability and Flow (For Marshall Mixes)
For Superpave Mixes no mechanical test is required.
- (9) Florida: AASHTO T-283: TSR.
Minimum Indirect Tensile Strength (unconditioned sample): 100 psi
FM 1-T 283 (TSR) Link:
<http://www.dot.state.fl.us/statematerialsoffice/administration/resources/library/publications/fstm/methods/fm1-t283.pdf>

- (10) Georgia: Beam Fatigue Testing: AASHTO TP 8-94 (fatigue testing, not mandatory but may be imposed)
Asphalt Pavement Analyzer: GDT 115: Determining Rutting Susceptibility Using the TSR: AASHTO T-283. Link:
<http://www.dot.state.ga.us/doingbusiness/TheSource/gdt/gdt066.pdf>
- (11) Hawaii: Marshall (Stability and flow) or Hveem Stabilometer Test (contractor's choice)
- (12) Idaho: AASHTO T-165: Effect of Water on Cohesion of Compacted Bituminous Paving Mixtures as determined using Hveem Deformation and Cohesion Device
Note: Asphalt Film Thickness is used for mix design
- (13) Illinois: TSR: Modified AASHTO T-283 (no freezing)
Minimum unconditioned indirect tensile strength
- (14) Indiana: TSR: AASHTO T-283 (Loose mixes will be oven aged using AASHTO R 30 method).
- (15) Iowa: TSR: AASHTO T-283
- (16) Kansas: TSR: AASHTO T-283
- (17) Kentucky: TSR: ASTM D 4867 (Mix saturated to approximately 65% prior to Freezing)
- (18) Louisiana: TSR: LADOTD Procedure (similar to AASHTO T-283), 55 – 80% saturation prior to freezing.
- (19) Maine: No mechanical testing requirement
- (20) Maryland: TSR: AASHTO T 283
- (21) Massachusetts: No mechanical testing requirement (Volumetrics only)
Note: Specifications have not been updated since 1995; there are supplemental specs from 2006 and 2010.
- (22) Michigan: TSR: AASHTO T 283
- (23) Minnesota: TSR: AASHTO T-283
- (24) Mississippi: TSR: AASHTO T-283
Boiling Water Stripping Test:
Link:
<http://www.gomdot.com/Divisions/Highways/Resources/Research/pdf/Reports/InterimFinal/SS167.pdf>
- (25) Missouri: TSR: AASHTO T-283

- (26) Montana: Hamburg Wheel Tracking Test (Used for determination of moisture damage/stripping)
- (27) Nebraska: TSR: AASHTO T-283
- (28) Nevada: TSR: AASHTO T-283 (Nev. T341)
Minimum Unconditioned Indirect Tensile Strength (T-283), 50-65 psi
Hveem Stabilometer Value (Nev. T303)
- (29) New Hampshire: TSR: AASHTO T-283
- (30) New Jersey: TSR: AASHTO T-283 (only if required by ME)
- (31) New Mexico: No mechanical testing requirement.
- (32) New York: TSR: AASHTO T-283
- (33) North Carolina: TSR: AASHTO T-283
- (34) North Dakota: Marshall Mixes: AASHTO T 245: Marshall Stability and Flow
Superpave Mixes: TSR: AASHTO T-283
- (35) Ohio: Marshall Mixes: AASHTO T 245: Marshall Stability and Flow
Superpave Mixes: TSR: AASHTO T-283
- (36) Oklahoma: TSR: AASHTO T-283
APA: AASHTO TP 63 (OHD L-43)
- (37) Oregon: TSR: AASHTO T-283
APA: AASHTO TP 63 (If required for the project)
- (38) Pennsylvania: TSR: AASHTO T-283
- (39) Rhode Island: AASHTO T 245: Marshall Stability and Flow
AASHTO T 182: Static Water Immersion (Boiling Water Stripping Test)
- (40) South Carolina: TSR: Modified AASHTO T-283 (SC T 70)
Indirect Tensile Strength of Wet Conditioned Samples (SC T 70)
Asphalt Pavement Analyzer: AASHTO TP 63
- (41) South Dakota: TSR: AASHTO T-283
Asphalt Pavement Analyzer: AASHTO TP 63
- (42) Tennessee: TSR: AASHTO T-283

Asphalt Pavement Analyzer: AASHTO TP 63 (Only for SMAs, not required but if material is available the DOT Central Lab will conduct test)

- (43) Texas: Method Specification: Indirect Tensile Strength (Low and High Limit)
Boil Test
QC/QA Specification: Indirect Tensile Strength
Hamburg Wheel Test
Boil Test
Special Provisions: Texas Overlay Tester for Overlay Mixes
- (44) Utah: Hamburg Wheel Test
- (45) Vermont: Marshall mixes: AASHTO T 245: Marshall Stability and Flow
Superpave Mixes: TSR: AASHTO T-283
- (46) Virginia: TSR: AASHTO T-283
Asphalt Pavement Analyzer: AASHTO TP 63
- (47) Washington: TSR: AASHTO T-283
- (48) Washington D.C.: TSR: AASHTO T-283
For Stone filled sheet asphalt: AASHTO T-245: Marshall Stability and Flow
- (49) West Virginia: TSR: AASHTO T-283
- (50) Wisconsin: TSR: AASHTO T-283
- (51) Wyoming: TSR: AASHTO T-283

Appendix B: Provisional Performance-Based Specifications from NJDOT Study

Section 555 - Bridge Deck asphalt overlays

555.01 DESCRIPTION

This Section describes the requirements for constructing bridge deck waterproof surface course (BDWSC), asphaltic plug joint system and retrofit strip seal joint system to be used for bridge deck rehabilitation projects.

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
1/2"	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 Requirements	99	90 - 100	≥ 18.0 %	0.3 – 0.9	≤ 0.1 %
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 $280 \pm 5^{\circ}\text{F}$. 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
<p>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.</p>		

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 °F). 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:

<i>Item</i>	<i>Pay Unit</i>
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.

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.....902.07

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 Distributor1003.07
HMA Plant.....1009.01
HMA Trucks1009.02

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 written permission is received 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.** Drill cores as specified in 401.03.05. The Department will evaluate air void requirements as specified in 401.03.03.H except that after consistent passing results are obtained the RE may increase the maximum lot size to cover one day's paving production. If multiple plants produce the BRBC, separate lots by individual plant.
- 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:

<i>Item</i>	<i>Pay Unit</i>
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:

902.07 BOTTOM RICH BASE COURSE (brbc)

902.07.01 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 902.07.03-1.

Use asphalt binder for BRBC with a minimum continuous grade of PG 76-26 as specified in AASHTO M 320,. Use 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 70 percent when tested for at 25 °C. The Contractor shall adjust the binder PG grade as necessary to meet the mixture performance requirements of 902.07.02. 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.

902.07.02 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 902.07.03-1, 902.07.03-2 and 902.07.03-3.

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 902.07.03-1.

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.

Submit six gyratory specimens and four 5-gallon buckets of loose mix to the ME. The ME will use these samples for verification of performance properties of the BRBC mix. To be acceptable all six gyratory specimens must comply with the gradation and asphalt content requirements in Table 902.07.03-1 and with the control requirements in Table 902.07.03-2. 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 predicted 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 occurs, the ME will require that a new JMF be established and approved before production can continue.

902.07.03 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 902.07.03-1, 902.07.03-2, and 902.07.03-3. 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 902.07.03-2, and to the gradation requirements in Table 902.07.03-1. 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 $280 \pm 5^\circ\text{F}$. 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 902.07.03-3.

Table 902.07.03-1 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 902.07.03-2 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 902.07.03-3 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

Section 407 High Performance Thin Overlay (HPTO)

407.01 Description.

This work shall consist of the construction of a high performance thin HMA overlay.

MATERIALS

407.02 Materials.

The high performance thin overlay material shall conform to Section 921. All other materials shall conform to Subsection 404.02.

EQUIPMENT

407.03 Equipment.

The equipment shall be according to [Subsections 404.03](#), [404.04](#), [404.06](#), [404.07](#), [404.08](#), [404.09](#), [404.10](#), [404.11](#), and 406.04.

CONSTRUCTION

407.05 Preparation of Existing Surface.

The preparation of the existing surface shall be according to Subsection 404.12.

407.06 Weather Limitations.

The limitations shall be according to Subsection 404.13.

407.07 Conditioning of Existing Surface.

The conditioning of the existing surface shall be according to Subsection 404.15 except that only Tack Coat 64 may be used

407.08 Transportation and Delivery of Mixture.

The transportation and delivery of mixture shall be according to Subsection 404.16.

407.09 Spreading and Finishing.

The spreading and finishing shall be according to Subsection 404.17 except for the following:

1. The thickness of the overlay shall be $1 \pm 3/8$ inches.
2. Polymerized Joint Adhesive shall not be used.

407.10 Compaction.

The compaction of the mixture shall be according to Subsection 404.18.

407.11 Air Voids Acceptance Plan.

Traveled Way lots are defined as the area covered by a day's paving production of the same lift of placed material consisting of a minimum of 1,100 tons and a maximum of 3,300 tons. Except for test strip lots, daily production areas less than 1,100 tons, will be combined with previous or subsequent production areas to meet the minimum requirements. When the maximum requirement is exceeded in a day's production, the area of material placed will be divided into two lots with approximately equal areas.

Ramp Pavement Lots are defined as the area of highway access ramps consisting of approximately 4,800 square yards of full depth uniform thickness pavement or 9,600 square yards of full depth variable thickness pavement. Ramp pavement lots will be calculated from the pavement structures within the Traveled Way of access ramps only. Ramps with less than the minimum area may be combined into a single lot. Where two or more non-adjacent ramps are included in a single lot, additional cores may be required to insure that at least one core is taken from each ramp.

Other Pavement Lots are defined as approximately 4,800 square yards of Superpave HMA of full depth, uniform thickness or 9,600 square yards of full depth, variable thickness material in shoulders and other incidental pavement construction. Shoulders less than 5 feet in width are excluded from these requirements.

Each mixture in a given lot shall be compacted so that the combined percentage of material below 2.0 percent voids or above 7.0 percent voids shall be no more than ten percent. Air voids will be determined from five drilled cores taken from each lot in random locations as directed by the Engineer. The Engineer will witness all core drilling. The drilled cores will be tested according to Subsection 920.03(G) to determine the air voids content.

Conformance with these requirements will be determined on the basis of the amount of material estimated to fall outside of the specification according to the following steps:

- (1) Compute the sample mean (\bar{X}) and the standard deviation (S) of the N Test Results (X1, X2, ..., XN):

$$\bar{X} = \frac{X1 + X2 + \dots + XN}{N}$$

$$S = [(X1 - \bar{X})^2 + (X2 - \bar{X})^2 + \dots + (XN - \bar{X})^2 / (N-1)]^{1/2}$$

- (2) Compute Quality Index.

$$QL = (\bar{X} - 2.0)/S \text{ and } QU = (7.0 - \bar{X})/S, \text{ where "Q" is the quality index.}$$

- (3) Compute Percent Defective. (PD) Using Table 914-5 for the appropriate sample size, determine the percentage of material (PD) falling outside specification limits associated with QL (lower limit) and QU (upper limit). Add these two values to obtain the total PD.

If for any reason the number of available test results is different from $N = 5$ for initial testing or $N = 10$ for retesting, tables for the appropriate sample size are to be used for Step 3.

- (4) Compute the percent pay adjustment (PPA) for voids for Traveled Way paving (including ramps) and newly constructed shoulders 5 feet in width or more as follows:

- a. Surface:

<u>QUALITY</u>	<u>PPA</u>	
$PD < 10$	$PPA_v = 4 - (0.4 PD)$	(Eq. 1)

$10 \leq PD < 30$	$PPA_v = 1 - (0.1 PD)$	(Eq. 2)
-------------------	------------------------	---------

$PD \geq 30$	$PPA_v = 40 - (1.4 PD)$	(Eq. 3)
--------------	-------------------------	---------

- b. Intermediate and Base:

<u>QUALITY</u>	<u>PPA</u>	
$PD < 30$	$PPA_v = 1 - (0.1 PD)$	(Eq. 4)

$PD \geq 30$	$PPA_v = 40 - (1.4 PD)$	(Eq. 5)
--------------	-------------------------	---------

Compute the percent pay adjustment for voids for shoulders (other than newly constructed shoulders) 5 feet or more in width as follows:

- c. Surface:

<u>QUALITY</u>	<u>PPA</u>	
$PD < 10$	$PPA_v = 4 - (0.4 PD)$	(Eq. 6)

$$10 \leq PD < 50 \quad PPA_v = 1 - (0.1 PD) \quad (\text{Eq. 7})$$

$$PD \geq 50 \quad PPA_v = 92 - (1.92 PD) \quad (\text{Eq. 8})$$

d. Intermediate and Base:

<u>QUALITY</u>	<u>PPA</u>	
PD < 50	$PPA_v = 1 - (0.1 PD)$	(Eq. 9)

PD \geq 50	$PPA_v = 92 - (1.92 PD)$	(Eq. 10)
--------------	--------------------------	----------

Shoulders less than 5 feet in width are excluded from these requirements.

- (5) Retest. If the initial series of N = 5 tests produces a percent defective value of PD \geq 30 for mainline paving, or PD \geq 50 for shoulders, the Contractor may elect to take an additional set of N = 5 drilled cores at new random locations, as designated by the Engineer. The additional cores shall be taken within 10 Working Days of receipt of the initial core results. If the additional cores are not taken within the 10 Working Days, the initial core results (N = 5) will be used to determine the percent pay adjustment. When the additional cores are taken, Steps 1 through 3 will be repeated using the combined data set of N = 10 test values to obtain the total PD estimate using Table 914 - 5, and Step 4 will be repeated to obtain the final lot percent pay adjustment using Equations 1 through 10 in Step 4, as appropriate.
- (6) Removal and Replacement. If the final lot percent defective based on the combined set of N = 10 tests, or N = 5 if the Contractor fails to take additional cores, is equal to or greater than PD = 75, the Department will require removal and replacement of the lot at the Contractor's expense. When replacement is made, the replaced layers are subject to the same requirements as the initial construction.
- (7) Outlier Provision. All cores will be examined for obvious physical damage at the Department Laboratory. Any core found to be damaged shall be replaced by taking an additional core within a two foot radius of the original location.

All acceptance cores will be screened for outliers using a statistically valid procedure. If an outlier is detected, that core shall be replaced by taking an additional core within a 2-foot radius of the original location. The following procedure applies only for a sample size of 5.

Step 1: Arrange the 5 core results in ascending order as follows, in which X1 represents the smallest value and X5 represents the largest value:

X1, X2, X3, X4, X5

Step 2: If X5 is the value suspected of being an outlier, compute:

$$R = (X5 - X4) / (X5 - X1)$$

If X1 is suspected of being an outlier, compute:

$$R = (X2 - X1) / (X5 - X1)$$

Step 3: If $R \geq 0.642$, the value is judged to be statistically significant and the core is excluded.

407.12 Core Samples.

Core samples shall be according to Subsection 404.23.

407.13 Opening to Traffic.

The pavement shall be opened to traffic according to Subsection 404.24.

COMPENSATION

407.14 Method Of Measurement.

High Performance Thin Overlay will be measured by the ton excluding wasted material and according to Subsection 404.25.

407.15 Basis of Payment.

Payment will be made under:

<i>Pay Item</i>	<i>Pay Unit</i>
HIGH PERFORMANCE THIN OVERLAY	TON

Payment reductions due to non-conformance to air voids requirements will be made according to Subsection 407.11.

Separate payment will not be made for Test Strips and Quality Control for Compaction, including comparison cores and nuclear density testing. All costs thereof shall be included in the prices bid for the High Performance Thin Overlay.

Payment for Surface Preparation, Tack Coat and Core Samples, HMA will be made according to Subsection 404.26.

ADD THE FOLLOWING SECTION TO DIVISION 900:

Section 921 High Performance Thin Overlay (HPTO)

921.01 Composition of Mixtures.

Composition of the mixture for HPTO shall be coarse aggregate, fine aggregate, and asphalt binder, and may also include mineral filler. Reclaimed Asphalt Pavement (RAP), Ground Bituminous Shingle Material, Remediated Petroleum Contaminated Soil Aggregate, or Crushed Recycled Container Glass (CRCG) will not be permitted.

The asphalt binder shall be PG 76-22 conforming to AASHTO M 320, Table 1 except that the PAV aged asphalt will be tested for dynamic shear at 25°C. In addition, the asphalt binder shall have the following properties:

1. The RTFO aged asphalt shall have an elastic recovery of at least 65 percent when tested at 25°C according to AASHTO T 301.
2. In the separation test, the maximum allowable difference for the original asphalt binder shall be 4.5 degrees when tested according to ASTM D 5976.

The coarse aggregate shall conform to Subsection 901.10(A) and shall be argillite, gneiss, granite, quartzite, or trap rock.

The fine aggregate shall be stone sand conforming to Subsection 901.10(C) and shall have an uncompacted void content of at least 45 percent when tested according to AASHTO T 304, Method A. In addition, the minimum sand equivalent shall be 45 percent when tested according to AASHTO T 176.

The mineral filler, if used, shall conform to Subsection 901.14.

921.02 Formula for Job Mix.

At least 30 days before initial production, a job mix formula for the HPTO shall be submitted on forms supplied by the Department, which shall include a statement naming the source of each component and a report showing the results meet the criteria specified in Table 921-1 and 921-2.

The job mix formula for the HPTO mixture shall 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. The optimum percentage of asphalt binder shall be determined according to AASHTO R 35 and M 323 with an N_{des} of 50 gyrations. Before maximum specific gravity testing or compaction of specimens, the mix shall be conditioned 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, the mix shall be 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). The job mix formula shall be within the master range specified in, Table 921-1.

The job mix formula shall provide 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. If visual stripping is detected, modify or readjust the mix.

For each mix design, three gyratory specimens and one loose sample corresponding to the composition of the job mix formula, including the design asphalt content, shall be submitted with the mix design forms. These will be used for verification of the properties of the job mix formula. The specimens shall be compacted 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 921-1 and with the control requirements in Table 921-2. The Engineer reserves the right to be present at the time of molding the gyratory specimens.

In addition, 6 gyratory specimens and a 5 gallon bucket of loose mix shall be submitted to the Engineer. The additional gyratory specimens shall be compacted according to AASHTO T 312, shall be 77 mm high, and shall have an air void content of 5.0 ± 0.5 percent. These additional samples will be used for performance testing of the HPTO mix. The specimens will be tested using an Asphalt Pavement Analyzer according to AASHTO TP63 at 64°C, 100 psi hose pressure, and 100 lb. wheel load. The job mix formula will be approved if the average rut depth for the 6 specimens in the asphalt pavement analyzer testing is not more than 4 mm in 8,000 loading cycles. If the job mix formula does not meet the APA criteria, the HPTO mix shall be redesigned.

The job mix formula for the HPTO mixture shall be in effect until modification is approved.

When unsatisfactory results for any specified characteristic of the work make it necessary, a new job mix formula may be established for approval. In such instances, if corrective action is not taken, the Engineer reserves the right to require an appropriate adjustment.

Should a change in sources be made or a change in the properties of materials occur, the Engineer may require that a new job mix formula be established and approved before production can continue.

921.03 Sampling and Testing

- A. General Sampling and Testing Requirements.** Acceptance testing of HPTO will be performed in a timely manner. Sampling will be performed according to AASHTO T 168, NJDOT B-2, and/or ASTM D 3665.

The temperature of the mix at discharge from the plant or storage silo shall be between 300 and 350°F.

The producer's quality control technician shall be present during periods of mix production for the sole purpose of quality control testing and to assist the Department's representative in order to ensure compliance. The Department will not perform the quality control testing or other routine test functions in the absence of or instead of the plant laboratory technician.

Acceptance testing does not preclude the Engineer from requiring disposal of any batch or shipment without further testing which is rendered unfit for its intended use due to contamination, segregation, improper temperature, or incomplete coating of the aggregate. For other than improper temperature, visual inspection of the material by the Engineer is considered sufficient grounds for such rejection.

When materials are rejected for any of the above reasons, except for improper temperature, samples will be taken for testing. Should such testing indicate that the material was erroneously rejected, payment will be made for the rejected material.

HPTO mixtures processed through a surge or storage system will be inspected visually to ensure that they are essentially free of lumps of cold material. Any batch or shipment of material found to be so contaminated will be rejected and shall be disposed of.

- B. Drum Mix Plants.** Five stratified random samples for acceptance will be taken from each lot of approximately 3,000 tons of each type of mix. When a lot of HPTO mix is necessarily less than 3,000 tons, samples will be taken at random for each type of mix at the rate of one sample for each 600 tons or fraction thereof and will be treated as a short lot.

To determine the quantity of binder and the gradation of the aggregate to determine volumetric properties for quality control testing purposes, extractions or ignition testing at the sampling rate specified shall be performed each day for each type mixture according to AASHTO T 164, Method A or AASHTO T 308.

- C. Fully Automated Batch Plants.** When using bin analysis, five stratified random samples shall be taken from each lot, under the supervision of the Engineer, otherwise sampling is done according to the requirements for drum mix plants. A lot is approximately 3,000 tons of each type of mix. When a lot of HPTO mix is necessarily less than 3,000 tons, samples shall be taken at random for each type of mix at the rate of one sample for each 600 tons or fraction thereof and will be treated as a short lot.

Quality control testing for gradation and volumetric properties shall be performed using bin samples and printed weigh tickets according to NJDOT B-5 or according to the requirements for drum mix plants.

- D. Quality Control and Acceptance Requirements.** The quality control technician at the asphalt plant shall perform sampling and testing according to the approved quality control plan for the plant, to keep the mix within the limits specified in Tables 920-1 and 920-2. Volumetric properties, dust to binder ratio, and compaction requirements at N_{des} for quality control samples shall be determined on the basis of extraction, ignition oven, or hot bin analysis, and air voids as determined by bulk specific gravity according to AASHTO T 166 and maximum specific gravity according to AASHTO T 209. The quality control technician shall use the results to control production.

Coarse aggregate, fine aggregate, mineral filler and RAP shall be sampled and tested according to the approved quality control plan for the plant.

Volumetric properties at N_{des} and dust to binder ratio will be determined for acceptance from samples taken, compacted and tested at the mixing plant. The material will be compacted to the number of design gyrations (N_{des}) of 50, using equipment according to AASHTO T 312. The bulk specific gravity of the compacted sample will be determined according to AASHTO T 166.

Maximum specific gravity shall be tested as needed to control production and at least once per day's production by the producer's quality control technician on loose material, according to AASHTO T 209.

The HPTO mixture shall conform to all of the control requirements listed in Table 921-2, and to the gradation requirements in Table 921-1. If two samples in a lot do not conform to these requirements, corrective action shall be initiated immediately.

The moisture content of the mixture at discharge from the plant shall not exceed 1.0 percent. Moisture determinations are based on the weight loss on heating for one hour in an oven at $280 \pm 5^\circ\text{F}$ of an approximately 1500 gram sample of mixture. A minimum of one sample per lot will be tested for moisture.

The total mineral aggregate and asphalt cement material shall be so combined and mixed that at least 95 percent of the coarse aggregate particles are entirely coated with asphalt binder as determined by AASHTO T 195. At the option of the Engineer, random samples will be obtained from each of five trucks, and the adequacy of the mixing will be determined on the average of particle counts made on these five test portions. If the above requirement is not fully met plant operations shall be modified as necessary to obtain the required degree of coating.

- E. Performance Testing.** Five 5 gallon buckets of loose mix shall be provided to the Engineer for testing in the Asphalt Pavement Analyzer. The first sample shall be taken in the first lot of production. Thereafter, every second lot shall be sampled. The Engineer may stop production of HPTO if a sample does not meet the design criteria for performance testing as detailed in Subsection 921.02.

921.04 Tables.

Tables referenced in the Specifications are as follows:

Table 921-1 Job Mix Formula Requirements for HPTO	
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 921-2 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 %

Section 408- Bottom Rich intermediate Course

408.01 DESCRIPTION

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

408.02 MATERIALS

408.02.01 Materials

Provide materials as specified:

BRIC.....902.08

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 Distributor1003.07
HMA Plant.....1009.01
HMA Trucks1009.02

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.** Do not place BRIC 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.** 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 330°F maximum discharge temperature. 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.
- 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 (\bar{X}) and Standard Deviation (S) of the N Test Results (X_1, X_2, \dots, X_N).**

$$\bar{X} = \frac{(X_1 + X_2 + \dots + X_N)}{N}$$

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

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

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

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

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 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 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. 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:

<i>Item</i>	<i>Pay Unit</i>
BOTTOM RICH INTERMEDIATE COURSE, 4.75MM	TON

The Department will measure BOTTOM 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:

902.08 BOTTOM RICH INTERMEDIATE COURSE (BRIC)

902.08.01 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 902.08.03-1.

Use asphalt binder for BRIC that is PG 70-28 as specified in AASHTO M 320, Table 1 except that PAV aged asphalt will be tested for dynamic shear at 25°C. 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 65 percent when tested at 25 °C. In the separation test (ASTM D 5976); ensure that the maximum allowable difference for the original asphalt binder is not more than 4.5 degrees.

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.

902.08.02 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 902.08.03-1 and 902.08.03-2.

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 902.08.03-1.

Ensure that the job mix formula provides a mixture that meets a minimum tensile strength ratio (TSR) of 85% when prepared according to AASHTO 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 902.08.03-1 and 902.08.03-2. 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 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.

902.08.03 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.

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 902.08.03-1, 902.08.03-2, and 902.08.03-3. 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 902.08.03-2, 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 $280 \pm 5^{\circ}\text{F}$. 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. The ME may stop production of BRIC if a sample does not meet the design criteria for performance testing as specified in Table 902.08.03-3.

Table 902.08.03-1 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 902.08.03-2 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 902.08.03-3 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

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.

Apparatus. Use the following apparatus:

1. Overlay Tester. An electro-hydraulic system that applies repeated direct tension loads to specimens. The machine features two blocks, one is fixed and the other slides horizontally. The device automatically measures and records loads, displacement, and temporary every 0.1 sec.

The sliding block applies tension in a cyclic triangular waveform to a constant maximum displacement of 0.06 cm (0.025 in.). This sliding block reaches the maximum displacement and then returns to its initial position in 10 sec. (one cycle).

2. Temperature Control System. The temperature chamber must be capable of controlling the test temperature with a range of 32 to 95°F (0 to 35°C).
3. Measurement System. Fully automate data acquisition and test control system. Load, displacement, and temperature are simultaneously recorded every 0.1 sec.
4. Linear Variable Differential Transducer. Use to measure the horizontal displacement of the specimen (+/- 0.25 in.). Refer to manufacturer for equipment accuracy for LVDT.
5. Electronic Load Cell. Use to measure the load resulting from the displacement (5000 lb capacity). Refer to manufacturer for equipment accuracy for load cell.
6. Specimen Mounting System. Use 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.

Procedure. Perform the following steps:

13. **Sample Preparation.**

- a. *Laboratory Molded Specimens* - Use cylindrical specimens that have been either compacted using the gyratory compactor (AASHTO T312). 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 T166.

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.

14. **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 marker 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 T166. Discard and prepare a new specimen if it does not meet the density requirement provided by the New Jersey Department of Transportation.

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.

15. **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.

16. 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 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.

17. Mounting Specimen Assembly to Testing Device. Ensure to 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.

18. 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.

Report. Include the following items in the report:

19. Date and time molded or cored.
20. NJDOT mixture identification.
21. Trimmed specimen density.
22. Starting Load.
23. Final Load.
24. Percent decline (or reduction) in Load.
25. Number of cycles until failure.
26. Test Temperature.

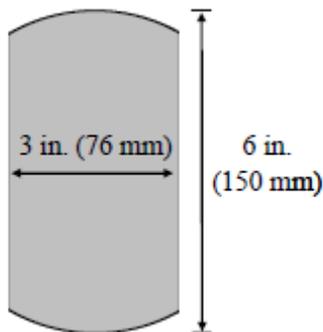
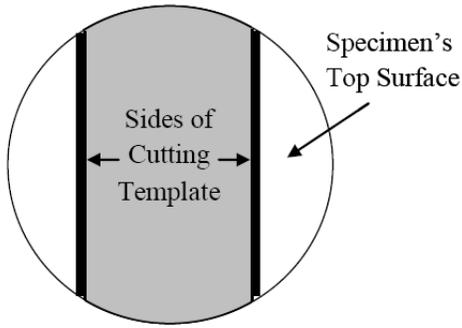
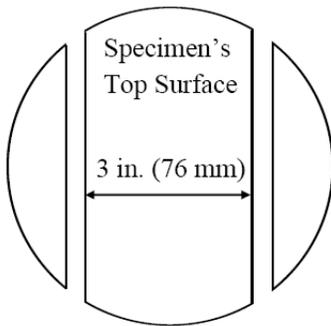


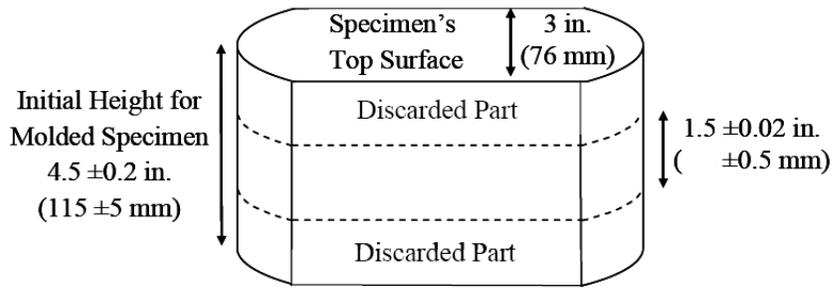
Figure 1 – Cutting Template



Tracing lines using cutting template



Trimming specimen's ends



Trimming specimen to required height

Figure 2 – Trimming of Cylindrical Specimen