Development of Guidelines and Specifications for Use of WMA Technology in Delivering HMA Products Inclusive of Non-Conventional Mixtures Such as SMA's, and Mixtures with High RAP and RAS Content

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16. Abstract

This report documents the work completed in WHRP Project 0092-12-02, *Development of Guidelines and Specifications for Use of WMA Technology in Delivering HMA Products Inclusive of Non-Conventional Mixtures Such as SMA's, and Mixtures with High RAP and RAS Content*. The objective of this research project was to develop specifications for asphalt concrete that cover all types of mixtures included in Section 460 of the State of Wisconsin Standard Specifications for Highway and Structure Construction, 2011 Edition (WisDOT Specifications). The specifications that were developed are equally applicable to hot mix asphalt (HMA) and warm mix asphalt (WMA). The report describes the development of the specifications and a limited validation of the specifications using data from two field projects.

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Executive Summary

Summary

This report documents the work completed in Wisconsin Highway Research Program (WHRP) Project 0092-12-02, *Development of Guidelines and Specifications for Use of WMA Technology in Delivering HMA Products Inclusive of Non-Conventional Mixtures Such as SMA's, and Mixtures with High RAP and RAS Content*. The objective of this research project was to develop recommended specifications for asphalt concrete that cover all types of mixtures included in Section 460 of the State of Wisconsin Standard Specifications for Highway and Structure Construction, 2011 Edition (WisDOT Specifications). The specifications that were developed are equally applicable to hot mix asphalt (HMA) and warm mix asphalt (WMA). The work completed during the project included:

1. A review of Section 460 of the WisDOT specifications in light of the findings from recent national research on WMA and the use of reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS). This review recommended several potential changes needed to properly consider WMA and mixtures with high recycle contents.

2. The design and execution of four laboratory experiments needed to implement the recommended changes.

3. A meeting with the Technical Oversight Committee (TOC) to discuss the recommended changes and the preliminary findings from the laboratory experiments.

4. The development of two draft specifications based on the findings of the laboratory experiments and comments from the TOC. One draft specification includes performance tests related to rutting resistance and thermal cracking resistance for mixture design and acceptance. The other uses a performance test for rutting resistance during design and the binder replacement criteria developed in WHRP Project 0092-10-06 to control thermal cracking.

5. The development of a sampling and testing plan for field validation of the draft specifications.

6. The collection and analysis of data from two field projects in accordance with the sampling and testing plan. Data required by the draft specifications developed during WHRP Project 0092-12-02 were collected and analyzed to make recommendations for further improvement of the specifications.

Process

The basic approach that was selected by the research team was to compliment volumetric design with performance testing to ensure adequate resistance to rutting and thermal cracking. To address both HMA and WMA, the volumetric design is done at the planned field production and compaction temperatures as specified in the Appendix to AASHTO R35 for WMA design. The effect of using recycled binders and mixture production temperature on rutting resistance and resistance to low temperature cracking is evaluated using the flow number and the Asphalt Thermal Cracking Analyzer tests. In this approach durability and fatigue resistance are governed by the minimum effective binder content provided by volumetric design and acceptance. The major changes to current WisDOT specifications needed to implement this approach included:

1. Allow the producer to select the virgin binder grade, modification, recycled binder content, WMA process, production temperature and compaction temperature yielding a mixture that meets volumetric design criteria and the rutting resistance and low temperature cracking requirements of the flow number and Asphalt Thermal Cracking Analyzer tests. Materials and processes used must be from Department approved lists.

2. Modify Table 460-2 of Section 460 to add requirements for (1) compactability, (2) flow number (3) maximum fracture temperature, and (4) reheat correction factor reporting.

3. Add quality control flow number and Asphalt Thermal Cracking Analyzer tests at the rate of one test per 10,000 tons of mixture produced. If required criteria are not met, notify

the engineer, stop production and make adjustments. Also modify field tensile strength ratio testing to make it a requirement for all mixtures.

Four laboratory experiments were designed and executed to finalize testing procedures required to implement the specification changes outlined above and to provide initial criteria limits. The four experiments addressed: (1) the potential for minimum temperature limits for mixtures incorporating RAS, (2) short-term conditioning for flow number and Asphalt Thermal Cracking Analyzer testing, (3) the development of a repeatable coating test for mix design and quality control, and (4) initial criteria limits for the Asphalt Thermal Cracking Analyzer test.

Based on the findings from the four experiments and the comments from the TOC, two draft specifications were prepared: one that includes performance testing and one that does not. The primary difference in the two specifications is the one with performance tests uses the flow number and the Asphalt Thermal Cracking Analyzer tests to evaluate the rutting and thermal cracking resistance of the mixture. This specification gives the producer the flexibility to select the virgin binder grade, recycled binder content, and production process to meet the required rutting and thermal cracking resistance. The specification without performance test relies on limits on binder replacement to provide acceptable resistance to thermal cracking.

Finally, a sampling and testing plan was prepared for initial field validation of the two specifications. The sampling and testing plan was used on two field validation projects: (1) Capitol Drive near Milwaukee and State Trunk Highway 70 near Woodruff. Data from these projects were analyzed considering the two specifications.

Conclusions

Several important conclusions were drawn from the laboratory experiments that were completed in WHRP Project 0092-12-02. The conclusions listed below shaped the draft specifications that were developed.

1. **RAS Mixing.** It does appear that RAS binders properly mix with new binders even at the highest WMA process temperatures. A minimum production temperature of 300 °F for

mixtures containing RAS was included in the draft specifications based on testing from other projects that showed adequate mixing of RAS binders occurs at this temperature.

2. **Short-Term Conditioning for Performance Testing.** The criteria for many performance tests are based in the properties of mixture conditioned in a force draft oven for 4 hours at 135 °C in accordance with the performance test section of AASHTO R30. Recently it has become apparent that this level of conditioning approximates the aging that occurs during construction and a short time in-service. WMA mixtures that are produced and compacted below the AASHTO R30 performance test conditioning temperature of 135 °C should not be conditioned at temperatures exceeding the field compaction temperature. The short-term conditioning experiment concluded that a two step process can be used with WMA mixtures to simulate construction and early in-service aging. Construction aging is simulated by conditioning the mixture for 2 hours at the compaction temperature. Early in-service aging is simulated by conditioning the mixture for 14 hours at 100 °C. When this conditioning is applied to HMA, the rutting resistance is equivalent to that obtained from the standard AASHTO R30 conditioning for performance tests. When applied to WMA, the rutting resistance of the WMA mixtures range from 60 to 90 percent of that for the HMA mixtures, which is reasonable considering the reported field performance of WMA mixtures.

3. **Coating.** A simple, repeatable procedure to evaluate coating could not be developed with the resources available in the project. Image analysis appears to be sensitive to ambient light source and reflectivity of light off the coated aggregate during the image capturing step confounding measurement of the percent uncoated area. Water absorption measurements are overwhelmed by the amount of water that is entrapped in asperities in the coating of the coarse aggregates. Absorption can be used to evaluate the coating of coarse aggregates when coated with binder only, but this approach cannot be used in mixture acceptance.

   Evaluating the quality of coating using the boiling test appears promising. Experiments completed during this project found that although equal coating extent was achieved during mixing, the quality of coating was influenced by viscosity for most conventional and modified binders tested. A moderate relationship between coating quality as measured by the coating index from the boiling test and the tensile strength ratio from AASHTO T283 was also observed. However, additional testing including more binder and aggregate sources is needed to confirm this relationship.

Since a reliable coating test could not be developed and the TOC was concerned with the reproducibility of AASHTO T195, minimum production temperatures for various processes were included in the draft specifications. These production temperatures were based on experience with various WMA processes.

4. **Resistance to Thermal Cracking.** Repeatable measurements of the glass transition temperature and the coefficients of thermal contraction in asphalt mixtures can be made with unrestrained tests in the Asphalt Thermal Cracking Analyzer. However, the thermo-volumetric properties of mixtures alone do not appear to be related to the thermal cracking resistance of mixtures. Based on additional work performed with the Asphalt Thermal Cracking Analyzer, it appears that both the development of thermal strain in an unrestrained sample and thermal stress build up in a restrained sample are needed to obtain a complete evaluation of thermal cracking performance. The draft specification with performance tests was modified to include parameters from both unrestrained and restrained tests using the Asphalt Thermal Cracking Analyzer.

Limited validation of the WHRP Project 0092-12-02 draft specifications was performed using materials from two field projects: (1) WisDOT Project 2025-14-70, Capitol Drive, State Highway 190 from Brookfield Road to State Highway 100, and (2) WisDOT Project 9070-03-60, STH 70 Fifield – Woodruff: North County Line – Morgan Rd. Data from three lots of paving for both projects were collected and analyzed. The mixtures used on these projects included a combination of RAP and RAS. Both mixtures were produced and placed at normal HMA temperatures, but included a WMA process as a compaction aid. The Capitol Drive project used a chemical WMA additive, the STH 70 project used water injection foaming. Conclusions drawn from the field validation testing and analysis are presented below.

1. **Performance Testing.** The WHRP Project 0092-12-02 Draft Specification With Performance Tests included flow number and Asphalt Thermal Cracking Analyzer tests during design and acceptance for specifying mixtures with adequate resistance to rutting and low temperature cracking. The field validation confirmed that these tests can be used to assess mixture performance. The flow number testing confirmed the reasonableness of the criteria that were developed in WHRP Project 0092-09-01 and included in the draft specifications. The Asphalt Thermal Cracking Analyzer testing showed good correlation between the fracture temperature and the low temperature continuous grade of binder recovered from the validation project mixtures. Tentative fracture temperature criteria consistent with current low temperature binder grading were developed using data from the validation project mixtures.

   Specimen fabrication and testing time will limit the frequency of acceptance testing using the flow number and Asphalt Thermal Cracking Analyzer tests. The conditioning procedure developed during WHRP Project 0092-12-02 to reasonably address both WMA and HMA mixtures requires overnight conditioning of loose mix prior to specimen fabrication. Specimen fabrication for both tests require sawing and coring test specimens from larger gyratory specimens. The testing time with the Asphalt Thermal Cracking Analyzer test is approximately 3 hours; the flow number test is much shorter requiring about 20 minutes for the highest traffic level mixtures. Overall, fabrication and testing of performance specimens requires approximately 3 days.

2. **Unified WMA and HMA Volumetric Design.** Both of the WHRP Project 0092-12-02 draft specifications include the WMA Appendix for AASHTO R35 to provide a unified mixture volumetric design procedure for WMA and HMA mixtures. For design, the draft specifications also include the establishment of reheat correction factors for reconciling quality control data which is collected on plant samples without reheating and verification data which is collected on retained samples after reheating. Validation of the complete design procedure was not possible using data from the two projects because both mixtures were produced at hot mix temperatures. Portions of the design

procedure were validated. First, volumetric properties of laboratory samples prepared from component materials using the specified design procedure compared well with those for field produced mixtures. Of particular interest was the comparison for the water injection foaming process used on the STH 70 project which was successfully reproduced in the laboratory using a Wirtgen WLB-10 laboratory foaming device. Second, the reheat correction factor was significant for the STH 70 water injection foaming mixture, but not for the chemical WMA additive used in the Capitol Drive mixture. The correction factor for the water injection foaming process was 0.7 percent, which is approximately one half of the allowable tolerance for verification results in current WisDOT specifications and the WHRP Project 0092-12-02 draft specifications.

3. **Recycled Material Properties.** The WHRP Project 0092-12-02 Draft Specification Without Performance Tests relies on the careful control of the virgin and recycled asphalt binder in the mixture to provide acceptable rutting and low temperature cracking performance. This control includes limiting the amount of recycled binder used depending on the source (RAP or RAS) when no adjustment is made to the virgin binder grade, and measuring the binder content of the recycled materials daily during production. The recycled binder content limits included in the draft specification were those developed in WHRP Project 0092-10-06.

   Both projects used recycled binder contents that were greater than permitted by the WHRP draft specification for surface mixtures. The maximum recycled binder ratio for RAS in the WHRP 0092-12-03 draft specification is 5 percent when no RAP is used. The maximum recycled binder ratio for RAP is 20 percent when no RAS is used. When RAP is used with RAS, the allowable RAP recycled binder ratio decreases 4 percent for each 1 percent RAS binder replacement. These criteria are somewhat more conservative for RAP than those developed in NCHRP Project 9-46, which recommends no change in the grade of the virgin binder as long as the RAP binder ratio is less than 25 percent. NCHRP Project 9-46 did not address RAS.

The change in the low temperature grade for binder recovered from the production mixtures averaged 5.7 °C for the Capitol Drive project and 1.4 °C for the STH 70 project. The RAS binder from the STH 70 was significantly softer than the RAS tested in WHRP Project 0092-10-06. The RAP from both projects and the RAS from the Capitol Drive project were within the range of the materials tested in WHRP Project 0092-10-06. Although the change in low temperature grade for the two projects cannot be used to validate the recycled binder ratio limits in the draft specification, they indicate that it is possible to have nearly a one grade change in low temperature properties using current WisDOT binder replacement criteria.

The WHRP 0092-12-02 draft specification also requires measuring the binder content of the recycled materials during production and controlling the binder replacement within tolerance limits that were to be determined using data from the validation projects. The characterization of the recycled materials showed that it is important to measure the binder content of the recycled materials during production. In some cases, there were significant differences between the binder contents reported in the mix designs and those measured during production. The variability of the binder content of the RAS during production was higher than that for the RAP. Production tolerance limits for the average of 4 samples of 1.3 percent for RAS binder replacement and 0.5 percent for RAP binder replacement were developed using the data from the two validation projects.

4. **Recovered Binder Properties.** The average continuous performance grade of binder recovered from the mixtures was PG 73.4 (21.7) -25.2 for the Capitol Drive project and PG 69.6 (19.8) -28.6 for the STH 70 project. Based on the nearest LTPPBind weather station, the reliability against thermal cracking was 97.3 percent for the Capitol Drive project, but only 77.9 percent for the STH 70 project. The primary reason for the lower reliability against thermal cracking for the STH 70 project was the selection of PG 58-28 virgin binder. Had no recycled binder been used on this project, the reliability against thermal cracking would have been 88.1 percent. This emphasizes the need to consider the environmental conditions at the project location when selecting

virgin binder grades. The recycled binder used in the Capitol Drive project had greater effect on the mixture low temperature properties compared to the recycled binder used in the STH 70 project, but because both projects used PG XX-28 binders and the environment for the Capitol Drive project was less severe, the Capitol Drive project had greater reliability against thermal cracking.

5. **Blending Chart Analysis.** The procedures recommend in WHRP Project 0092-10-06 were used to develop blending charts for the recycled materials for both projects. There was good agreement between the blending charts and the binder recovered from the production mixtures. On the Capitol Drive project, the blending chart estimated a continuous binder grade of PG 79.0 (21.9) -24.1 compared to an average recovered continuous binder grade of PG 73.4 (21.7) -25.1. The agreement for the STH 70 project was better with the blending chart estimating a continuous binder grade of PG 69.3 (19.7) -28.0 compared to an average recovered continuous binder grade of PG 69.6 (19.8) -28.6. These comparisons, while limited, confirm the usefulness of blending chart analysis in mixture design.

   The blended binder reliability analysis developed in WHRP Project 0092-10-06 appears to provide a reasonable and flexible approach for determining allowable binder replacement. This analysis uses low temperature data from LTPPBind for the nearest weather station and blending charts to determine the required low temperature grade for a given level of reliability. Using this approach, the blended binder in the mixture for the Capitol Drive project, had a reasonable reliability against thermal cracking of 97.3 percent. The STH 70, on the other had a lower reliability of against thermal cracking of 77.9 percent, primarily due to the selection of a PG 58-28 as the virgin binder grade.

6. **Moisture Sensitivity.** Both WHRP Project 0092-12-02 draft specifications include moisture sensitivity testing on production mixtures. The limited field validation confirmed that this testing should be included. The STH 70 mixture had a design tensile strength ratio of 71 percent. During production values as low as 62 percent were measured.

Recommendations

The primary recommendation concerning the draft specifications developed in WHRP Project 0092-12-02 is that additional validation work is needed before either specification can be considered for implementation. With the available budget, only two field projects could be included in the validation effort, and both project used WMA processes at HMA temperatures as compaction aids. If additional validation work is undertaken, a wider range of projects should be considered. Of particular interest are high recycle content mixtures produced at reduced temperatures using various WMA processes. WisDOT should consider performing the testing that was conducted during the field validation on additional projects from throughout the state and monitoring the performance of the projects. This will provide additional data to further refine the WHRP Project 0092-12-02 draft specifications. It will also provide important data on mixture composition that can lead to improvement in the performance of asphalt mixtures in Wisconsin.

The work completed in WHRP Project 0092-12-02 has shown promise in using performance related tests for the design and acceptance of a asphalt concrete mixtures. For the flow number and Asphalt Thermal Cracking Analyzer tests included in the WHRP Project 0092-12-02 specifications, specimen fabrication and testing time severely limit the frequency at which this testing can be conducted. WisDOT should consider investigating other performance related tests which require less time. The specific tests that should be investigated are: (1) the high temperature IDT test for rutting resistance, and (2) an acoustic emission test to characterize the embrittlement temperature of asphalt concrete mixtures. Both of these tests can be conducted on the gyratory specimens that are fabricated for normal volumetric quality control.

In addition to the recommendations specific to WHRP Project 0092-12-02 draft specifications, the following recommendations are provided for consideration in future research projects.

1. The coating study introduced the concept that mixture durability is dependent on both the extent and quality of coating. AASHTO T195 included in the WMA mix design

procedure measures only the extent of coating; coating quality is not considered. Recent research at UW-MARC conducted in parallel to this project assessed the quality of coating using the boiling test specified in ASTM D3625. The study served as a proof of concept that achieving a sufficient extent of coating does not necessarily guarantee quality. In the study, aggregates were coated to the same extent using different mixing temperatures. The results from the boiling test indicated that the quality of the bond was substantially less when the asphalt binder was mixed with the aggregate at lower temperatures. Limited indirect tensile test data was collected and a strong relationship between coating loss after boiling and TSR values was observed. It is recommended that WisDOT consider further development of the boiling test as a means to verify acceptable coating. This test could be used for mixture design and acceptance.

2. It may be possible to improve the current WMA coating evaluation, AASHTO T195, by incorporating the scale for determination of degree of asphalt binder coverage from UNI EN 12697-11 in the procedure. This will allow the consideration of the extent of coating on each particle.

3. Further evaluation of the tentative fracture stress criteria for the Asphalt Thermal Cracking Analyzer test developed from the field validation mixtures is needed. WisDOT should consider testing additional mixtures and monitoring field performance to establish appropriate specification limits for this test.

4. Both mixture thermo-volumetric properties and stress build up during cooling are strongly influenced by mixture components, specifically the glass transition temperatures of the bituminous materials and the aggregate structure developed during compaction. Additional validation efforts for the Asphalt Thermal Cracking Analyzer test should included the measurement of the aggregate structure of the test specimens through use of planar imaging processing and analysis techniques ($IPas^2$) to establish the effects of experimental factors on aggregate structure parameters and investigate correlations with thermal cracking resistance.

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Chapter 1 Introduction

This report documents the work completed in Wisconsin Highway Research Program (WHRP) Project 0092-12-02, *Development of Guidelines and Specifications for Use of WMA Technology in Delivering HMA Products Inclusive of Non-Conventional Mixtures Such as SMA's, and Mixtures with High RAP and RAS Content*. The objective of this research project was to develop recommended specifications for asphalt concrete that cover all types of mixtures included in Section 460 of the State of Wisconsin Standard Specifications for Highway and Structure Construction, 2011 Edition (WisDOT Specifications). The specifications that were developed are equally applicable to hot mix asphalt (HMA) and warm mix asphalt (WMA) and are based on, Sections 450 and 460 of the WisDOT Specifications Chapter 8, Section 65 of the Wisconsin Department of Transportation Construction and Materials Manual. The recommended specifications incorporate findings from applicable national research and implementation efforts, and the findings from laboratory studies conducted in this project to extend completed research and development work to non-conventional mixtures. The recommended specifications were validated through an evaluation of HMA and WMA materials used on construction projects in Wisconsin. WHRP Project 0092-12-02 included eight tasks that are briefly described below.

Task 1: Review Applicability of Current National WMA Recommendations to Wisconsin Specifications. In this task, modifications to Section 460 of the WISDOT Specifications were developed based on completed and on-going WMA research and development projects. These modifications formed an initial straw-man specification with a commentary that the research team used to focus the remaining work in the project and that the Technical Oversight Committee (TOC) used to guide the research.

Task 2: Design Laboratory Experiments. In Task 2, appropriate laboratory experiments needed to begin implementation of the straw-man specification developed in Task 1 were designed. Detailed experimental designs were prepared considering statistical and budgetary constraints.

Task 3: Finalize Laboratory Experiments. A concise report documenting the work completed in Tasks 1 and 2 was prepared in this task and submitted to the TOC. The coprincipal investigators met with the TOC to review the straw-man specifications and laboratory experiments.

Task 4: Conduct Laboratory Experiments. Task 4 included the execution and analysis of the experiments designed in Task 2 and approved by the TOC in Task 3. Experiments were conducted by experienced technicians in the laboratory at Advanced Asphalt Technologies, LLC (AAT) and by graduate students in the UW-Madison laboratory. Data analysis was performed on an ongoing basis once significant test data became available. Once all of the test data had been collected, various statistical and engineering analyses were conducted as identified in the experimental designs.

Task 5: Develop Draft Specification and Field Validation Plan. In Task 5, the straw-man specification and commentary developed in Task 1 was revised based on the findings from the laboratory experiments conducted in Task 4 and input from the TOC to produce draft specifications. The draft specifications were in the form of Section 460 of the WisDOT Specifications and addressed both HMA and WMA. The draft specifications were used to design a field validation plan.

Task 6: Prepare Interim Report. Task 6 consisted of the development of an interim report documenting the work completed through Task 5 of the project. It included: (1) the a summary of the development of the initial straw-man specification, (2) a summary of the design and analysis of the laboratory experiments, (3) revisions to the straw-man specification to produce the draft specifications, and (4) the recommended field validation plan.

Task 7: Perform Field Validation. Initial validation of the draft specifications was completed in using data from two Wisconsin field projects. The projects included in the validation were constructed and accepted based on current WisDOT specifications, but the data for the draft specifications were collected and analyzed. Each validation section included three days of production so that sufficient quality control data could be collected for analysis.

Task 8: Prepare Research Report. The final task, Task 8, included the preparation and submission of the Final Report for the project, documenting all significant work completed during the project. The report was prepared in accordance with the WHRP requirements. The report included, as a stand-alone appendices (1) the draft asphalt concrete specifications that cover HMA and WMA and in a format similar to Section 460 of the WisDOT Specifications, and (2) the procedures for non-standard tests that are included in the draft specifications.

Chapter 2 of this report summarizes the changes to Section 460 of the WisDOT Specifications initially recommended by the research team and discussed with the TOC. Details of these recommendations were provided in the Task 3 Interim Report (*1*). Chapter 3 discusses the four supporting laboratory studies: (1) temperature limits for recycled asphalt shingle (RAS) binders, (2) equivalent short-term conditioning for WMA and HMA, (3) development of a test to evaluate coating, and (4) the feasibility of using mixture thermo-volumetric and fracture properties measured by the Asphalt Thermal Cracking Analyzer in mixture design and acceptance. Chapter 4 describes the development of the draft specifications and field validation plan. The draft specifications address comments from the TOC on the recommended changes summarized in Chapter 2 and the results of the laboratory experiments discussed in Chapter 3. The field validation plan was developed to evaluate the draft specifications. Chapter 5 presents results of the initial validation of the draft specifications on two Wisconsin projects. Finally Chapter 6 presents conclusions and recommendations based on the completed work.

Chapter 2 Initial Recommended Specification Changes

This chapter summarizes the work completed in Task 1 of WHRP Project 0092-12-02 to develop a single specification covering all types of asphalt concrete mixtures. The basic approach that was selected by the research team was to compliment volumetric design with performance testing to ensure adequate resistance to rutting and thermal cracking. To address both HMA and WMA, the research team proposed that the volumetric design be done at the planned field production and compaction temperatures as specified in the Appendix to AASHTO R35 for WMA design. The research team proposed that the effect of using reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS) as well as the effects of mixture production temperature on rutting resistance and resistance to low temperature cracking be evaluated using the flow number and Asphalt Thermal Cracking Analyzer tests. In this approach durability and fatigue resistance will be governed by the minimum effective binder content provided by volumetric design and acceptance.

In Task 1, Section 450 and 460 of the State of WisDOT Specifications and Chapter 8, Section 65 of the Wisconsin Department of Transportation Construction and Materials Manual were reviewed considering the approach outlined above. Recommended changes to implement this approach were developed and documented in the Task 3 Interim Report (*1*). The major changes that were recommended are summarized below. Appendix A presents details of the initial recommended specification changes.

1. Allow the producer to select the virgin binder grade, modification, recycled binder content, WMA process, production temperature and compaction temperature yielding a mixture that meets: (1) volumetric design criteria, (2) the rutting resistance requirements of the flow number test and (3) low temperature cracking requirements of the Asphalt Thermal Cracking Analyzer test. Materials and processes used must be from Department approved lists.

2. Modify Table 460-2 to add requirements for (1) coating, (2) compactability, (3) flow number (4) properties from the Asphalt Thermal Cracking Analyzer, and (5) reheat correction factor reporting. Also modify test method number 1559 in CMM 8.65.5 to address these in mixture design.

3. Modify daily quality control testing to add: (1) binder content and gradation of each recycled source used, and (2) coating evaluation.

4. Add quality control flow number and Asphalt Thermal Cracking Analyzer testing at the rate of one test per 10,000 tons of mixture produced. If required criteria are not met, notify the engineer, stop production and make adjustments. Also modify field tensile strength ratio testing to make it a requirement for all mixtures.

5. Modify control charts and control limits to add: (1) binder replacement from each recycled source, and (2) coating.

6. Modify pay adjustment to add pay adjustments based on coating and binder replacement. The binder replacement pay adjustment will be waived if flow number and Asphalt Thermal Cracking Analyzer testing produces acceptable results.

7. Modify contractor assurance to include reheat factors in air void calculations and to add asphalt content, binder replacement, coating, flow number testing, and Asphalt Thermal Cracking Analyzer testing. Also add allowable differences between quality control and contractor assurance results for asphalt content, binder replacement, coating, flow number results, and Asphalt Thermal Cracking Analyzer results.

8. Modify department verification to include reheat factors in air void calculations, coating, flow number testing, and Asphalt Thermal Cracking Analyzer testing. Also verification limits for coating, flow number results and Asphalt Thermal Cracking Analyzer results.

In Task 2 four experiments were designed to finalize testing procedures required to implement the specification changes outlined above and to provide initial criteria limits. The four experiments addressed: (1) the potential for minimum temperature limits for mixtures incorporating RAS, (2) short-term conditioning for flow number and Asphalt Thermal Cracking Analyzer testing, (3) the development of a repeatable coating test for mix design and quality control, and (4) initial criteria limits for the Asphalt Thermal Cracking Analyzer test. The results of the four experiments are discussed in Chapter 3.

The recommended changes, the planned laboratory experiments, and preliminary results from the laboratory experiments were discussed with the TOC during a meeting on May 12, 2012. The TOC expressed concern about two elements of the proposed changes. The first was the use of a coating test in quality control and acceptance. Preliminary results from the coating experiment indicated that it was not likely that a repeatable coating test could be developed with the limited funding available in the project. The second concern was the additional burden that the flow number and Asphalt Thermal Cracking Analyzer testing would place on producer and WisDOT laboratories and personnel. Additional equipment and training will be needed to implement these tests, and the tests have not been completely standardized. These concerns were addressed by replacing the coating test with minimum production temperatures based on the coating experiment, and developing two draft specifications: (1) with performance testing, and (2) without performance testing. Development of the draft specifications is discussed in greater detail in Chapter 4.

Chapter 3 Laboratory Experiments

Four laboratory experiments were conducted to finalize the testing procedures required to implement the specification changes recommended in Chapter 2 and to provide initial criteria limits. The four experiments addressed: (1) the potential for minimum temperature limits for mixtures incorporating RAS, (2) short-term conditioning for flow number and Asphalt Thermal Cracking Analyzer testing, (3) the development of a repeatable coating test for mix design and acceptance, and (4) initial criteria limits for the Asphalt Thermal Cracking Analyzer test. This chapter documents these four experiments.

3.1 RAS Mixing Experiment

The objective of this experiment was to determine if there are production temperature limits below which RAS binders no longer properly mix with virgin binders in mixtures incorporating RAS. National Cooperative Highway Research Program (NCHRP) Project 9-43 included a laboratory experiment that concluded that RAP and virgin binders mix at WMA mixing and compaction temperatures as low as 230 and 212 ºF, respectively (*2*). Based on the stiffness of the RAP binder at these temperatures a criteria that the compaction temperature should be greater than the high temperature continuous grade temperature of the binder was established (*2*). For typical Wisconsin RAP, the high temperature continuous grade temperature is approximately 83 ºC or 181 ºF (*3*), and the criteria will not affect the addition of RAP to WMA mixtures. For typical Wisconsin RAS, the high temperature continuous grade is approximately 118 ºC or 244 ºF (*3*), which would limit RAS usage to higher temperature WMA processes. Limited verification of the recycled binder criteria was completed in NCHRP Project 9-43 for plant mixtures (*2*). For a producer in Delaware, AAT also evaluated mixtures produced with RAS using a foaming processes at 265 ºF and found adequate mixing of the RAS and virgin binders (*4*).

The mixing of RAS was evaluated using the dynamic modulus procedure developed by AAT for the Maryland State Highway Administration to evaluate the acceptability of plant mixing of recycled materials (*2,4*). It involves comparing the dynamic modulus measured on samples of mixtures with RAS with the dynamic modulus estimated using the properties of the binder recovered from the samples. The measured modulus values represent the “as mixed” condition. The modulus values estimated from recovered binder properties represent the “fully blended” condition. The dynamic modulus is very sensitive to the stiffness of the binder in the mixture. The ratio of the "as mixed" to "fully blended" modulus values is a measure of the degree of mixing of the RAS and virgin binders. A value of 1.0 indicates full blending.

The key to this analysis is a good estimate of the modulus of the mixture for the fully blended condition. This is obtained from the Hirsch model using recovered binder properties and volumetric properties of the specimens tested (*5*). The accuracy of the Hirsch model was demonstrated in WHRP Project 0098-08-06 (*6*).

The RAS mixing experiment is summarized in Table 1. In this experiment, laboratory mixtures incorporating 25 percent RAS binder were prepared at the optimum binder content using three different temperatures and three different processes. The dynamic modulus mixing analysis was performed on each of the mixtures to determine if the temperature or process affects the degree of mixing. RAS previously tested in WHRP Project 0092-10-06 was used in the mixtures (*3*). Table 2 summarizes the properties of the RAS. The RAS was heated in an oven to the mixing temperature prior to mixing. The mixtures at different temperatures were produced using the same aggregate and gradation. The aggregate was a crushed gravel from Elmyra, NY. Design properties for the mixture are presented in Table 3. The RAS mixtures were mixed at the mixing temperature specified in Table 1, then short-term oven conditioned for 2 hours at the compaction temperature. This is the same mixing and short-term conditioning as was used in the NCHRP Project 9-43 RAP mixing study (*2*). Evotherm 3G and Advera WMA processes were selected to represent two different WMA processes.

Table 1. Experimental Design for the RAS Mixing Study.

Mixture	Mixing/Compacting Temperatures, ºF		
	280/255	248/230	230/212
PG 58-28	X	X	X
PG 58-28 3G	X	X	X
PG 58-28 Advera	X	X	X

Table 2. Properties of RAS Used in RAS Mixing Experiment (*3*).

Parameter	Extrapolated Continuous Grade Temperature, °C
Recovered High	123.0
RTFOT High	125.7
High	**123.0**
Intermediate	**34.3**
Stiffness Low	-25.3
m-value Low	-4.8
Low	**-4.8**

Table 3. Properties of Mixture Used in RAS Mixing Experiment.

Property		RAS Mix
	Sieve size, mm	
Gradation, % passing	25	100
	19	95
	12.5	79
	9.5	72
	4.75	49
	2.36	33
	1.18	20
	0.6	13
	0.3	8
	0.15	5
	0.075	3.1
Total Binder content, wt %		6.2
Design Air Voids, vol %		4.0
Design VMA, vol %		16.8
Design VFA, vol %		76.2
Maximum Specific Gravity		2.405
Aggregate Bulk Specific Gravity		2.603
Effective binder content, vol %		12.8
Design Gyrations		75

Figures 1 through 9 compare the measured and Hirsch model estimated modulus values. Figures 1 through 3 show the high temperature result: mixing temperature of 280 °F and compaction temperature of 255 °F. Figures 4 through 6 are show the intermediate temperature result: mixing temperature of 248 °F and compaction temperature of 230 °F. Finally Figures 7 through 9 show the low temperature results: mixing temperature of 230 °F, compaction temperature of 212 °F. In all cases, the master curve of estimated dynamic moduli is significantly greater than the measured dynamic modulus master curve. The error bars for the estimated values are 95 percent prediction intervals for the Hirsch model. Since the measured data are not captured by the Hirsch model prediction intervals, it is concluded that poor mixing of the RAS binders occurs at all temperatures and for all processes. This is summarized in Figure 10, which shows the average ratio of the measured to fully blended moduli. Ratios below about 70 percent indicate poor mixing. Figure 10 shows a trend of increasing ratio with increasing temperature, but even at the highest temperature, 280 °F for mixing and 255 °F for compaction, the average ratios are well below 70 percent. The error bars in Figure 10 are one standard deviation of the ratios calculated at the various testing conditions.

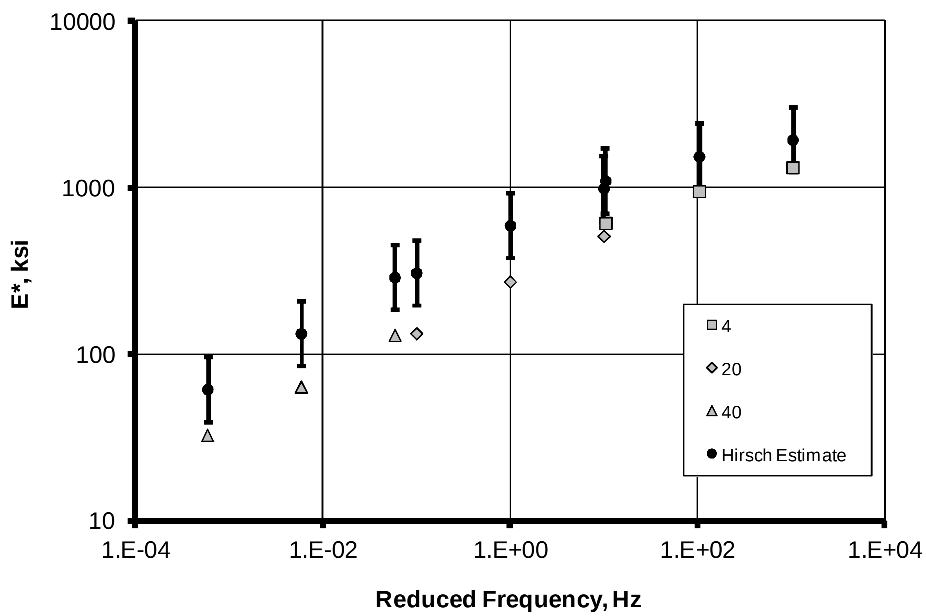


Figure 1. Comparison of Measured and Estimated Fully Blended Master Curves for PG 58-28 RAS Mixture at 280/255 °F.

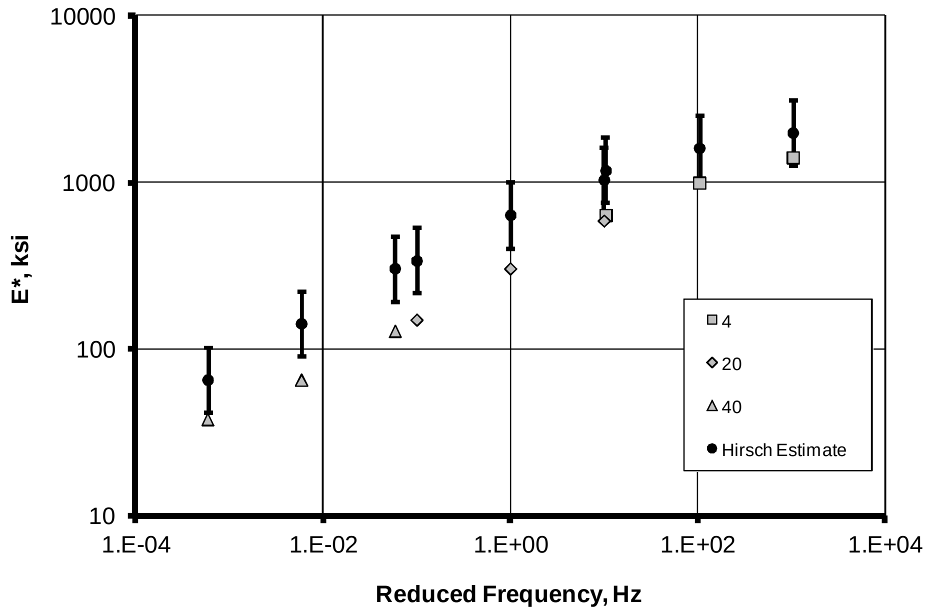


Figure 2. Comparison of Measured and Estimated Fully Blended Master Curves for Advera PG 58-28 RAS Mixture at 280/255 °F.

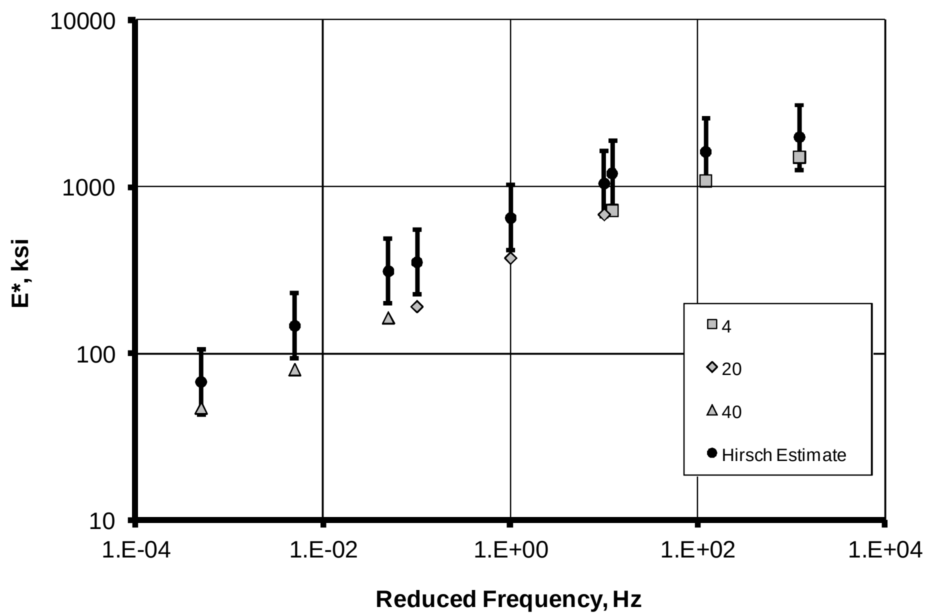


Figure 3. Comparison of Measured and Estimated Fully Blended Master Curves for Evotherm 3G PG 58-28 RAS Mixture at 280/255 °F.

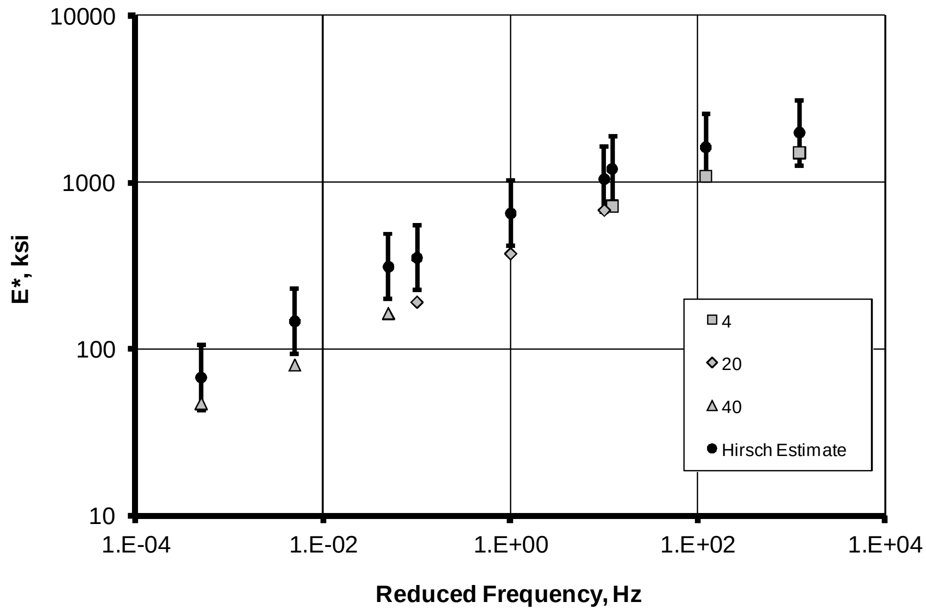


Figure 4. Comparison of Measured and Estimated Fully Blended Master Curves for PG 58-28 RAS Mixture at 248/230 °F.

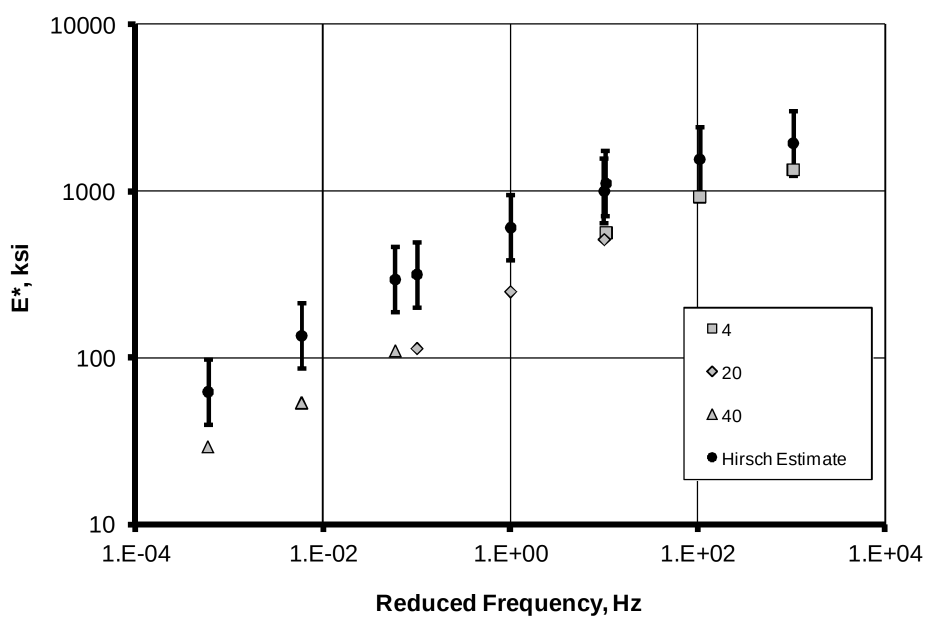


Figure 5. Comparison of Measured and Estimated Fully Blended Master Curves for Advera PG 58-28 RAS Mixture at 248/230 °F.

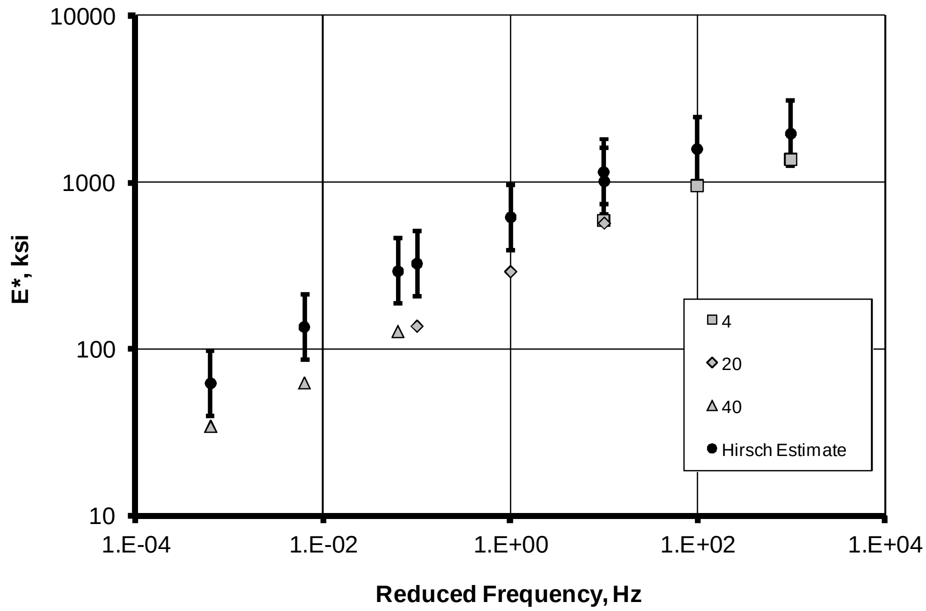


Figure 6. Comparison of Measured and Estimated Fully Blended Master Curves for Evotherm 3G PG 58-28 RAS Mixture at 248/230 °F.

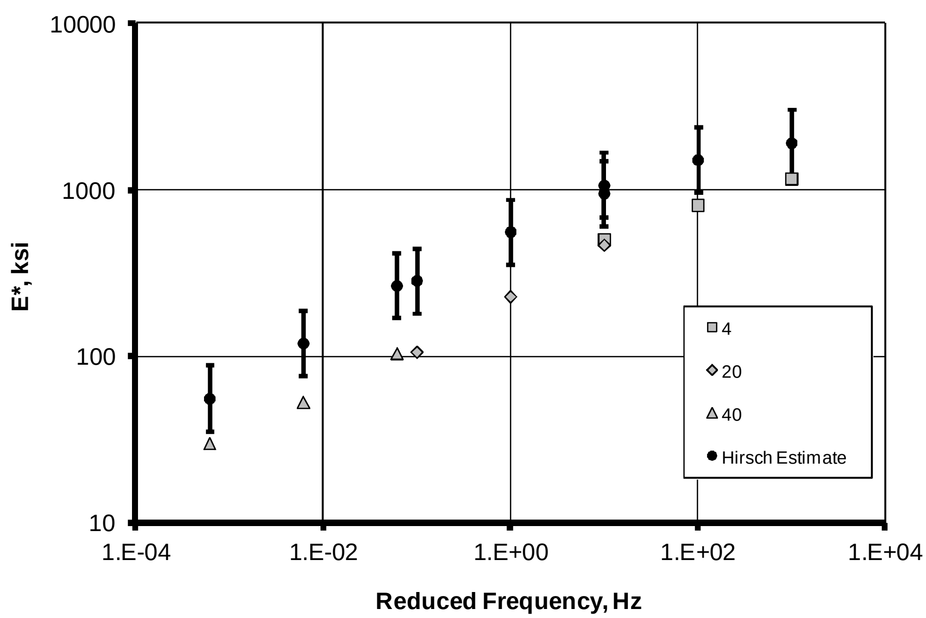


Figure 7. Comparison of Measured and Estimated Fully Blended Master Curves for PG 58-28 RAS Mixture at 230/212 °F.

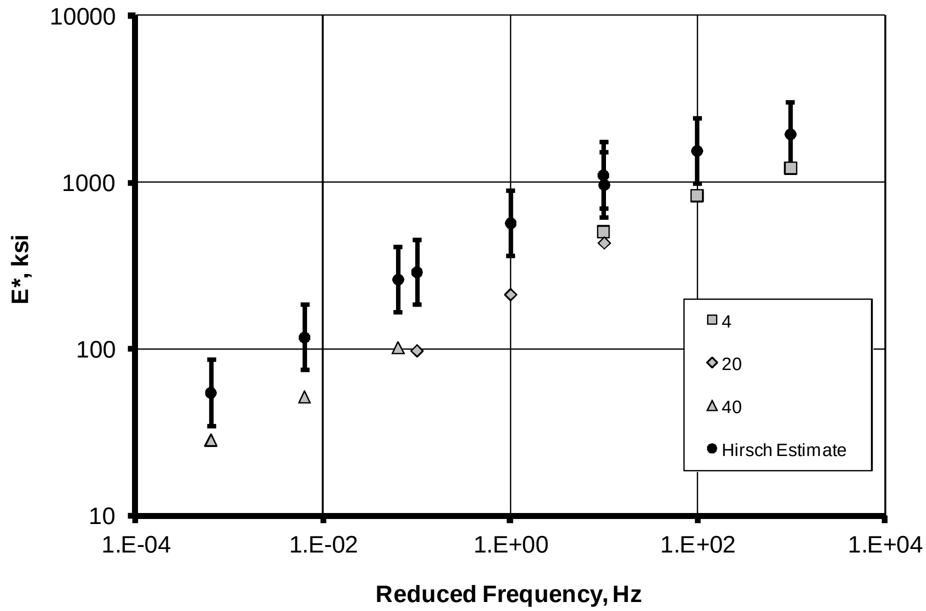


Figure 8. Comparison of Measured and Estimated Fully Blended Master Curves for Advera PG 58-28 RAS Mixture at 230/212 °F.

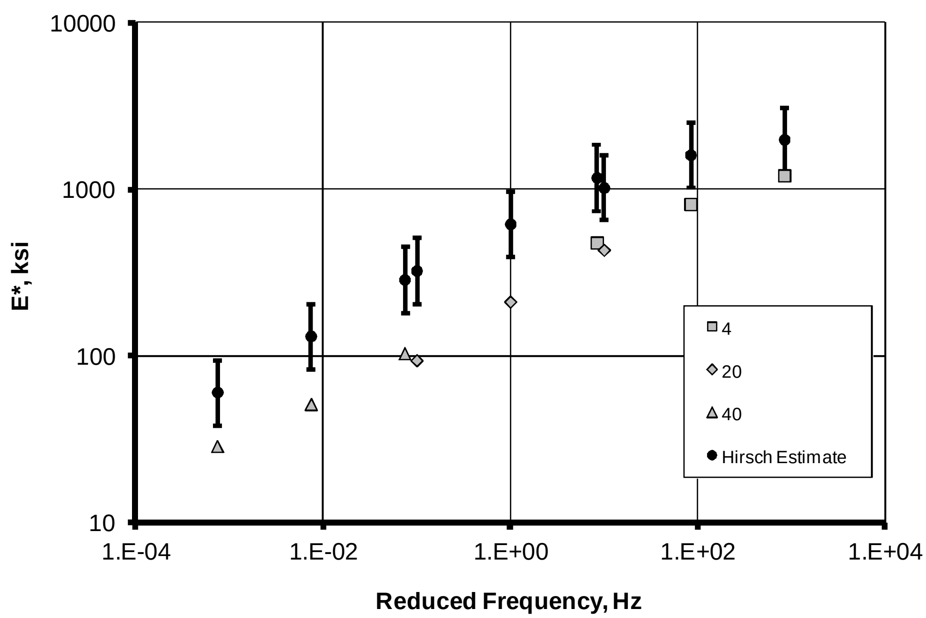


Figure 9. Comparison of Measured and Estimated Fully Blended Master Curves for Evotherm 3G PG 58-28 RAS Mixture at 248/230 °F.

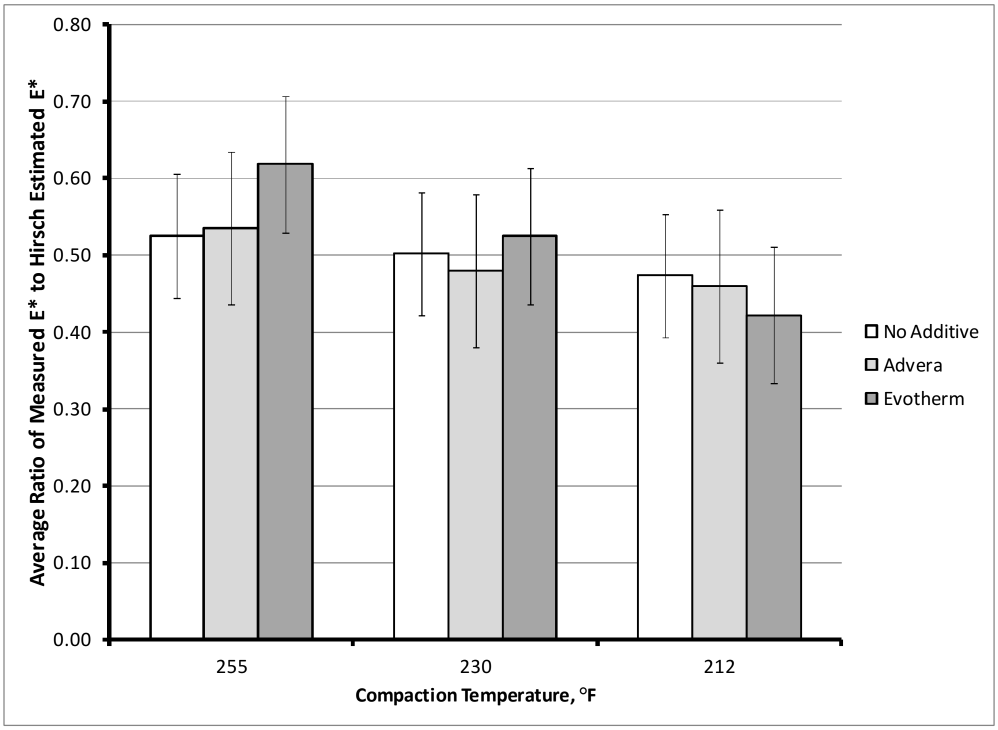


Figure 10. Comparison of Average Ratio of Measured to Fully Blended Dynamic Modulus.

The findings of the RAS mixing study indicate that field compaction temperatures greater than the high temperature grade of the RAS binder are needed to ensure adequate mixing of the new and recycled binders. Based on work that AAT has done evaluating plant produced RAS mixtures, a minimum mixing temperature of 300 °F was included in the draft specifications for mixtures containing RAS.

3.2 Short-Term Oven Conditioning Experiment

The objective of this experiment was to recommend a short-term conditioning procedure that can be applied to both HMA and WMA mixtures. Recent research on short-term conditioning of HMA and WMA completed during NCHRP Project 9-43 indicated that the short-term conditioning of 4 hours at 135 ºC specified in AASHTO R30 for performance testing of HMA represents aging that occurs during construction and a short period of time in-service (*2*). To address both WMA and HMA, the short-term conditioning procedure should include higher temperature conditioning to represent simulate production aging, followed by lower temperature conditioning at a representative service temperature to simulate early service life aging. Based on data collected in NCHRP Project

9-13 for different short-term conditioning procedures, it appeared that 16 hours of loose mix conditioning at 60 ºC resulted in slightly greater mixture stiffening than the standard 4 hours at 135 ºC (*2*). Thus it appeared that overnight conditioning, similar to that used in AASHTO T283, can be used for both HMA and WMA mixtures.

The short-term oven conditioning experiment was designed to determine a reasonable temperature for service temperature conditioning that will result in similar stiffening as AASHTO R30 for performance testing, 4 hours at 135 ºC. The steps for the conditioning process are summarized in Table 4 for mix design and quality control testing. The times in these steps are based on an analysis of two technicians working split 8.5 hour shifts with a 0.5 hour unpaid lunch and 15 minute paid breaks. If mixtures are compacted at 0.5 hour intervals, these technicians can prepare up to 44 samples per week. In addition to the specimen fabrication, each technician will have one full work day available for other tasks. Figure 11 presents a time line for specimen fabrication. The major issue is the number of ovens required. For mix design specimens, ovens for 4 different temperatures are needed: (1) heat aggregate and asphalt to mixing temperature, (2) short-term conditioning for 2 hours at the compaction temperature, (3) short-term conditioning for 14 hours at service temperature, and (4) 105 ºC for specimen compaction. For quality control specimens, ovens for 2 different temperatures are needed: (1) short-term conditioning for 16 hours at service temperature, and (2) 105 ºC for specimen compaction.

Table 4. Steps in Short-Term Conditioning for Mix Design and Quality Control.

Step	Mix Design	Quality Control
Construction	2 hours at compaction temperature	NA
Early Service	14 hours at high service temperature	16 hours at high service temperature
Heat for Compaction	2 hours at 105 C	2 hours at 105 C

Afternoon Shift Monday-Thursday		Mix	2 hr at compaction temp [1]	14 hours at service temp [1]		Day Shift Tuesday - Friday		Increase to 105 C	Compact Specimen
3:00	Start Shift					7:00	Start Shift		
3:15		1	1			7:15		1	
3:30						7:30			
3:45		2	2			7:45		2	
4:00						8:00			
4:15		3	3			8:15		3	
4:30						8:30			
4:45		4	4			8:45		4	
5:00	Break					9:00	Break		
5:15				1		9:15			1
5:30						9:30			
5:45		5	5	2		9:45		5	2
6:00						10:00			
6:15		6	6	3		10:15		6	3
6:30						10:30			
6:45		7	7	4		10:45		7	4
7:00						11:00			
7:15	Lunch					11:15	Lunch		
7:30						11:30			
7:45		8	8	5		11:45		8	5
8:00						12:00			
8:15		9	9	6		12:15		9	6
8:30						12:30			
8:45		10	10	7		12:45		10	7
9:00	Break					1:00	Break		
9:15		11	11			1:15		11	
9:30						1:30			
9:45				8		1:45			8
10:00						2:00			
10:15				9		2:15			9
10:30						2:30			
10:45				10		2:45			10
11:00						3:00			
11:15				11		3:15			11
11:30	End Shift					3:30	End Shift		

[1] If preparing quality control specimens condition mix 16 hours at service temperature.

Figure 11. Example Specimen Fabrication Schedule.

There were two parts to the short-term oven conditioning experiment. The experimental design for the first part is shown in Table 5. This part of the experiment was designed to determine an appropriate service conditioning temperature that, for HMA mixture design specimens, yields similar mixture stiffening as would be obtained using 4 hours of oven conditioning at 135 ºC as specified in AASHTO R30 for performance testing. AASHTO R30 stiffening was chosen as the target because current criteria for many performance tests are based on this level of stiffening. The experiment included testing four mixtures using aggregates of various geologies and different grades of binder. Mixing and compaction temperatures were selected at the mid-point of the viscosity criteria for laboratory mixing and compaction. Table 6 summarizes properties of the mixtures that were used. Service temperatures of 40, 50, and 60 ºC were initially selected, based on research conducted in NCHRP 9-13 (*7*), but these were increased after initial results at 50 ºC indicated little additional stiffening. For each cell in Table 5, replicate flow number specimens were prepared and tested at 49.5 °C using the testing conditions recommended in NCHRP Project 9-33 (*8*).

The second part of the short-term oven conditioning experiment was designed to investigate the effect of warm mix production on the flow number. Specimens were prepared for each mixture from Table 6 using mixing and construction conditioning temperatures that were 28 ºC (50 ºF) lower than used when producing the HMA mixtures. The service life conditioning temperature was that determined from the first part of the experiment.

Table 5. Experimental Design for Selecting Short-Term Service Conditioning Temperature.

Aggregate	Binder	4 hours at 135 ºC	2 hours at compaction temperature plus 14 hours at			
			50 ºC	60 ºC	70 ºC	100 ºC
A	PG 58-28	2	2	2	2	2
B	PG 58-34	2	2	2	2	2
C	PG 64-28	2	2	2	2	2
D	PG 70-28	2	2	2	2	2

Notes:
1. Specimens prepared at the mid-point of the binder viscosity criteria for mixing and compacting
2. Flow number tests conducted on each specimen after conditioning at 49.5 ºC using 0 confining stress and deviatoric stress of 600 kPa as recommended in NCHRP Project 9-33

Table 6. Properties of Mixture Used in Short-Term Oven Conditioning Experiment.

Property	Sieve size, mm	Gravel PG 64-28	Granite PG 58-28	Limestone PG 70-28	Diabase PG 58-34
Gradation, % passing	25	100	100	100	100
	19	100	100	100	100
	12.5	95	96	100	100
	9.5	90	85	93	95
	4.75	65	63	49	52
	2.36	44	47	32	38
	1.18	31	36	21	28
	0.6	24	26	14	20
	0.3	11	13	9	12
	0.15	6	6	7	7
	0.075	5.3	4.1	5.2	4.9
Binder content, wt %		5.4	4.9	6.8	5.0
Effective Binder Content, vol. %		8.3	9.9	13.0	10.6
Mixing Temperature, °C		150	145	155	145
Construction Conditioning Temperature, °C		140	135	145	135

Table 7 summarizes the results for different service conditioning temperatures. Figure 12 presents a graph of the ratio of the flow number at different service conditioning temperatures to the flow number for the standard AASHTO R30 conditioning. From this analysis, a service conditioning temperature of 100 °C was selected. Using construction conditioning of 2 hours at the compaction temperature followed by 14 hours at a service conditioning temperature of 100 °C yielded an average flow number ratio of 0.98 for the four mixtures tested.

Table 7. Flow Number of Different Conditioning Temperatures.

Mixture	Flow Number				
	Standard AASHTO R30, 4 hours at 135 °C	2 hours at construction temperature followed by 14 hours at:			
		50 °C	60 °C	70 °C	100 °C
Gravel PG 64-28	316	116	162	228	322
Granite PG 58-28	16	8	8	8	14
Limestone PG 70-28	100	40	62	78	90
Diabase PG 58-34	74	47	47	56	82

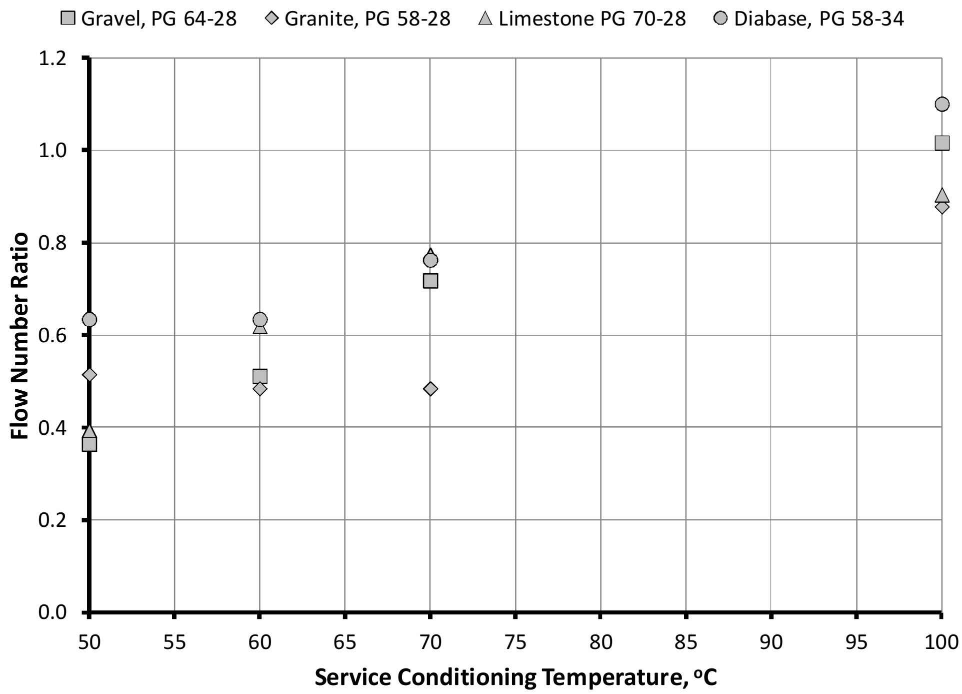


Figure 12. Flow Number Ratio (Flow Number for Service Conditioning Temperature Divided by Flow Number for AASHTO R30 Conditioning).

Table 8 compares the flow numbers for the four mixtures using construction conditioning temperatures for hot mix and warm mix and a service conditioning temperature of 100 °C. Table 8 also includes differences in allowable traffic based on the criteria developed in WHRP Project 0092-09-01 (*9*). The same mixture designed as WMA rather than HMA has somewhat lower rutting resistance. The WMA rutting resistance is 60 to 90 percent of that for the HMA mixture, which appears reasonable considering rutting in WMA demonstration sections has been reported to be similar to that in HMA control sections.

Table 8. Comparison of Rutting Resistance for HMA and WMA.

Mixture	HMA		WMA	
	Flow Number	Allowable Traffic, MESAL	Flow Number	Allowable Traffic, MESAL
Gravel PG 64-28	322	31.2	224	22.8
Granite PG 58-28	14	2.0	8	1.2
Limestone PG 70-28	90	10.3	79	9.2
Diabase PG 58-34	82	9.4	62	7.4

Based on the findings of the short-term conditioning experiment, the flow number criteria from WHRP Project 0092-09-01 for 4 hours of short-term conditioning were included in the draft specifications. The conditioning for the test procedure is as outlined in Table 4 to address construction and early service aging.

3.3 Coating Test Experiment

Initial mix design guidance to accommodate the use of WMA recommended numerous revisions to AASHTO R35 including a minimum specification limit of 95 percent coating as measured by AASHTO T195 (*2*). The coating evaluation was proposed as a replacement for the viscosity based mixing and compaction temperatures that are normally used in the design of HMA. Viscosity based temperatures were not considered appropriate for some WMA processes. AASHTO T195 involves mixing at the prescribed temperature and immediately separating the coarse aggregates retained on the 9.5 or 4.75 mm sieve from the rest of the mix. The coarse aggregate is visually inspected, any particle with aggregate surface exposed is deemed uncoated. The evaluation parameter for the procedure is percent aggregate coated, defined as the ratio of coated to total particles. The published standard is intended for field sampled mixtures; however, the procedure has also been adapted to mixes produced in the laboratory. Literature review and previous work identified the following deficiencies with the procedure (*10*):

- **Subjective:** Determination of coated and uncoated particles is based on the judgment of the operator. Also it will be easier to identify uncoated areas when lighter colored aggregates are used in the mix.
- **Time consuming:** AASHTO T195 requires individual inspection of 200 – 500 coarse particles for calculation of percent aggregate coated.
- **Lack of precision:** AASHTO T195 instructs practitioners to consider a particle uncoated if "even a tiny speck of uncoated aggregate is visible," thus an aggregate that is not coated is treated the same as one that is almost fully coated. An example of aggregates deemed uncoated is provided in Figure 13.

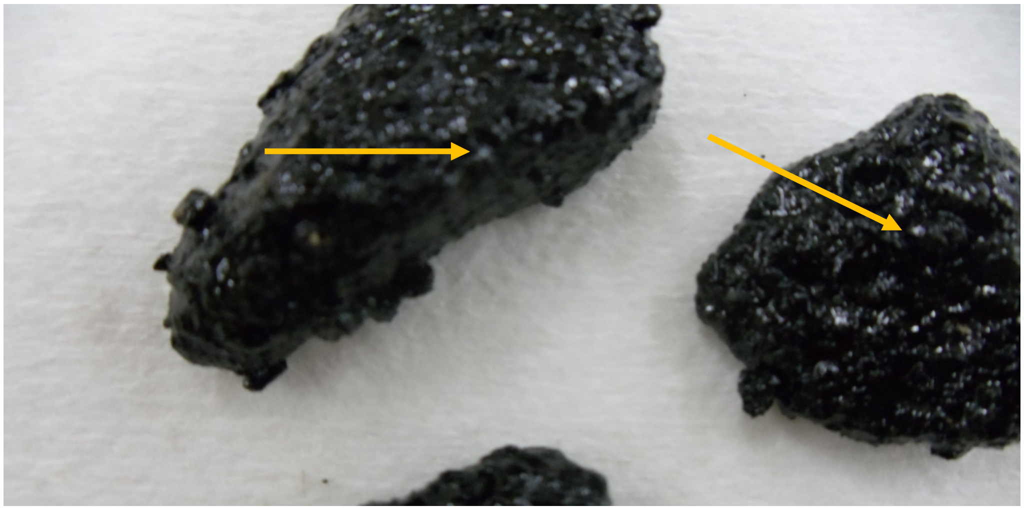


Figure 13. Example of "Uncoated" Particles as Defined by AASHTO T195.

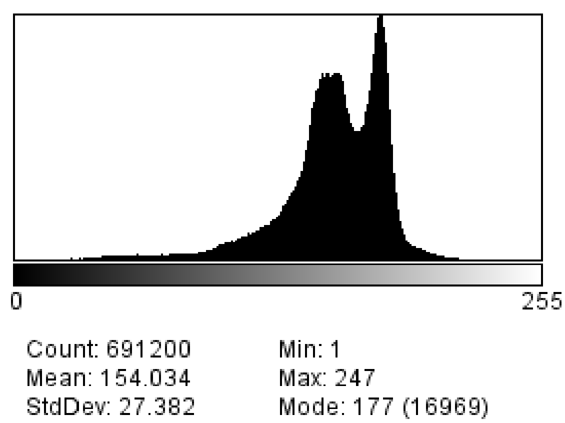
Although the AASHTO T195 coating procedure has procedural issues the concept of including a coating test as a means to select mixing temperatures for WMA is valid. Current practice selects mixing temperatures based on an acceptable asphalt binder viscosity range either defined by AASHTO T316 for conventional binders or supplier recommendations for modified binders. Given the potential for WMA mixing temperatures to be below the recommended range there is a need to verify that sufficient coating is achieved to ensure mixture durability, as conceptually the exposed aggregate surfaces associated with poor coating increase the potential for moisture damage and raveling. To maintain a coating evaluation in WMA specifications image analysis and an indirect measurement of coating based on aggregate absorption were considered. These methods were considered with the objective to provide a quantitative coating measurement that was less time consuming than the current AASHTO T195 procedure. Originally the coating evaluation was intended for potential implementation as both a mix design and acceptance tool. Based on discussion of the Interim Report with the TOC, efforts were refocused to consider the coating test for use solely in the mix design phase as it was deemed impractical and not established enough to be used as an acceptance tool that may impact payment.

3.3.1 Digital Image Analysis

Digital image analysis was piloted as a method to remove the subjectivity from the coating evaluation by removing user dependency and classifying the extent of coating as a percent of area coated rather than solely using a binary (Yes/No) classification system. The method developed applies image processing software to images obtained from a photograph or digital scanner to quantify the percent of area that is not coated. The software used in this study was Image J 1.46m (http://imagej.nih.gov/ij), which is a public domain Java image processing program developed by the National Institutes of Health (NIH). The following procedure was used for determination of the uncoated area.

- Capture the original RGB image of the bare aggregate (Figure 14(a)).
- Convert to grayscale and compute the pixel intensity histogram using image processing analysis (Figure 14(b)).
- Use the pixel intensity histogram to select a range of pixel intensities that is representative of the bare aggregate. For the example provided in Figure 14 the majority of pixels have intensity values that vary between 140-180 in gray scale (i.e., 0-black and 255-white).
- The pixel intensity of the aggregate is used as a baseline value to identify uncoated spots in the image of the loose mix.

(a)



(b)

Figure 14. Image of Bare Aggregate (a) and Histogram of Pixel Intensity for Bare Aggregate (b) (*11*).

- Sieve retained 3/8" material from the HMA loose mix and capture the image using a camera or desktop scanner.
- Convert the original RGB (color) image to gray-scale using the image processing software.
- Compute the pixel intensity histogram of the gray scale image. Generally, the histogram will be distributed near 0 (black) due to the coating of the aggregate with asphalt.

- Determine the number of pixels in the range that correspond to the pixel intensity of the bare aggregate by using the HMA pixel intensity histogram. This step is demonstrated in Figure 15.

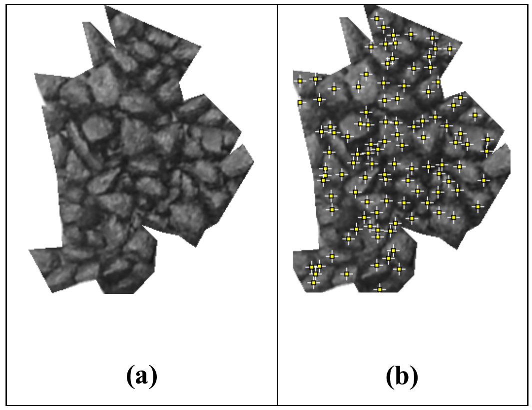


Figure 15. Gray-Scale Image of HMA R3/8" Material (a) and Identification of Pixels with Intensities within the Range of the Bare Aggregate (140 -180 for the Example).

- Calculate the percent of uncoated area as the ratio of number of pixels in the bare aggregate range to the total number of pixels, as shown in Equation 1.

$$\%Uncoated\ Area = \frac{\#\ of\ Pixels\ in\ Bare\ Aggregate\ Range}{Total\ \#\ of\ Pixels\ in\ R3/8"\ HMA\ Image} \quad (1)$$

The procedure was evaluated using one aggregate gradation and three different polymer modified binders mixed at a range of temperatures. The mixing temperatures used for each binder and the images used in the analysis are provided in Table 9, the polymer concentration used for each binder is provided in parenthesis. Images were processed using the Image J1.46m software and the percent coated area was determined using the procedure previously described; the results are presented in Figure 16. The results of the percent coating as measured by the AASHTO T195 test are provided above each bar in the figure. These results demonstrate sensitivity to mixing temperature when the asphalt binder is held constant as the percent uncoated area increases with decreasing mixing temperature for PMA #1 (Blue Bars). By definition an increase in uncoated area corresponds to a decrease in the extent of coating. For PMA#1 the differing resolutions observed for the percent uncoated Area (0.2% -0.6%) and AASHTO T195 (12%-96%) are expected as the AASHTO T195 procedure does not consider the area of the particle coated, classifying a particle with an any exposed aggregate as "uncoated." The image of the sample from PMA#1 mixed at 94°C is provided in Figure 17. The results indicate that the percent uncoated area parameter is more representative of the actual coating in the sample, as many of the particles have small areas that are uncoated, thus simply counting these particles as "uncoated" over-estimates extent of uncoated areas.

Table 9. Summary of Polymer Modified Binders, Mixing Temperatures, and Images used for Evaluation of Coating Evaluation Using the Uncoated Area Parameter.

Binder	Image and Mixing Temperature Used in Analysis		
PMA #1 (1.0%)			
	155°C	114°C	94°C
PMA #2 (0.5%)			
	125°C		
PMA #3 (2.0%)			
	125°C		

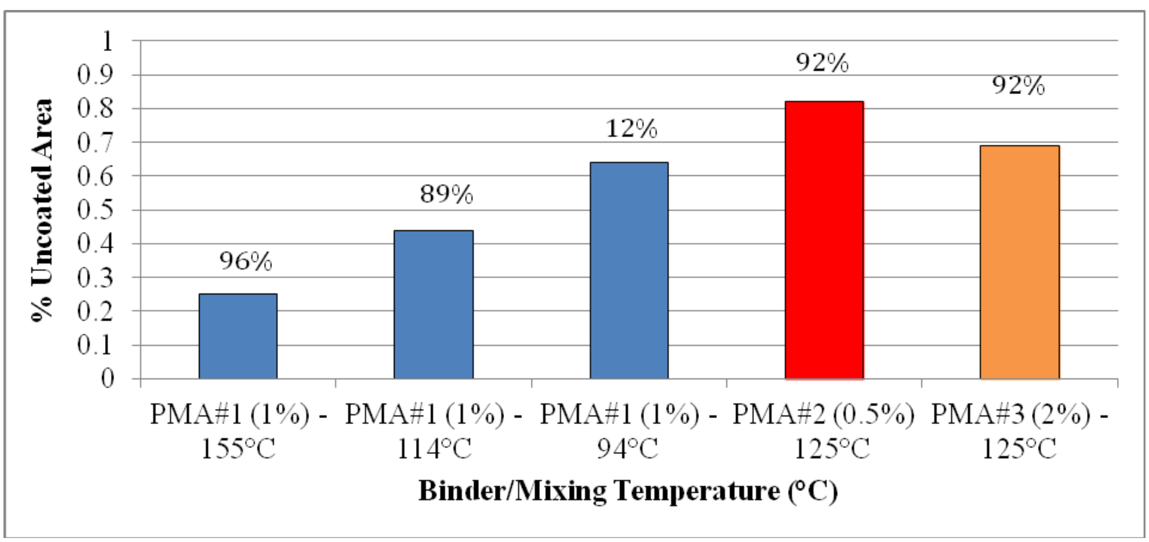


Figure 16. Effect of Mixing Temperature and Binder Modifier on Extent of Coating as Measured by the Uncoated Area Parameter.

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Figure 17. Image of PMA#1 - 94°C Mixing Temperature (*11*).

When comparing different binders inconsistent trends between the percent uncoated area parameter measured by image analysis and percent coated particles measured by AASHTO T195 are observed. Specifically, both PMA#2 and PMA #3 have >90 percent coating according to AASHTO T195, but have higher values of uncoated area (12%) than the sample deemed uncoated by AASHTO T195. While differences between the two procedures are expected due to the way coating is evaluated, this discrepancy was deemed extreme as all binders used in this study had similar values of viscosity. The relationship between mixing temperature and percent uncoated area for all five binders is provided in Figure 18.

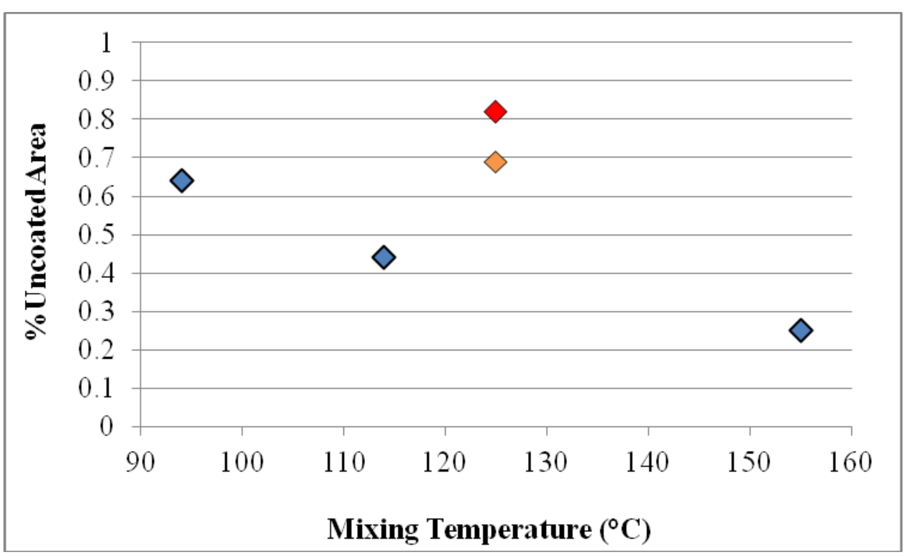


Figure 18. Percent Uncoated Area vs. Mixing Temperature (*11*).

In application of this test the overall goal is to select a mixing temperature that will result in an acceptable level of uncoated area. Based on results presented in Figure 18 the current procedure is not capable of achieving this objective as substantially different results are observed when the asphalt binder is varied and the results are inconsistent with other methods of measuring the extent of coating. These inconsistencies were attributed to differences in ambient light source and reflectivity of light off coated aggregate during the image capturing step confounding measurement of the percent uncoated area (*11*). Based on the need to further standardize both control of ambient lighting and how the image is captured further development of this procedure was not pursued. Given these complications, it is clear that significant effort in additional development was required and that the procedure was deviating from the project objective of providing a simple, reliable method to quantify extent of coating.

3.3.2 Absorption Test

An absorption method for determining the extent of coating in asphalt mixtures was derived from ASTM C127 using HMA particles retained on the 3/8" sieve and a soaking time of 60 minutes. The test was developed based on the assumption that a fully coated aggregate will have near zero absorption as water does not penetrate through the asphalt binder film; conversely an aggregate that is partially coated will absorb water. Comparison of the absorption test conducted at various mixing temperatures to AASHTO T195 is presented in Figure 19. The results presented in Figure 19 serve as proof of concept indicating that as the extent of coating qualitatively measured by AASHTO T195 increases the water absorption into the aggregate decreases. Based on these initial results, further evaluation of the absorption method was conducted using different combinations of binder and mixing temperature. For the test the HMA was sieved to obtain retained 3/8" material which was then soaked in water for 60 minutes. After soaking, samples were dried with a towel to the saturated surface dry (SSD) condition and the absorption was determined. Initial results of the experiment are presented in Figure 20. A detailed description of the approach is available in the conference proceedings of the Canadian Technical Asphalt Association (CTAA) 2012 Annual Meeting (*11*). The coating as measured by AASHTO T195 is provided above each bar.

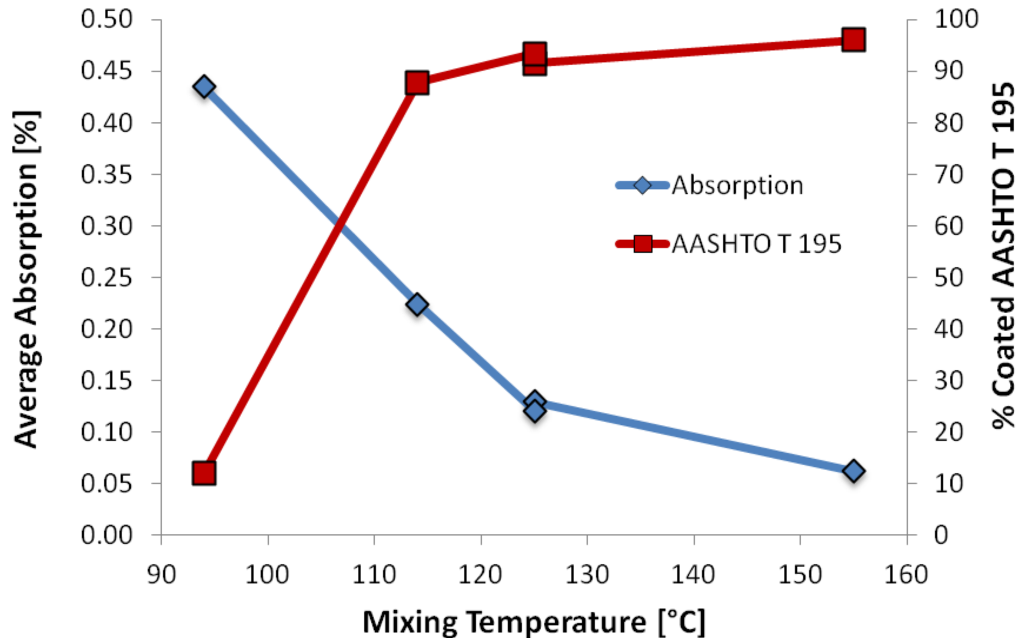


Figure 19. Comparison of Absorption Test Method to AASHTO T195 to Evaluate the Relationship between Aggregate Coating and Mixing Temperature (*11*).

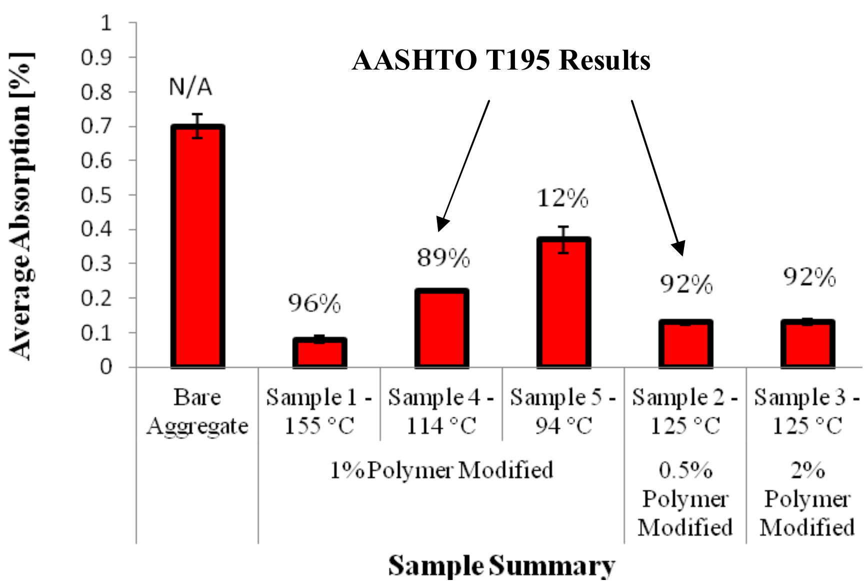


Figure 20. Initial Results of Absorption Method – Loose Mix (*11*).

The results shown in Figure 20 demonstrate sensitivity to mixing temperature but not changes in binder type. Piloting of the test procedure identified a potential issue as significant absorption was observed at very high levels of coating (i.e. above 90 percent). Specifically, a value of absorption that is approximately 15 percent of the absorption of the bare aggregate was observed for HMA deemed 96 percent coated based on the AASHTO T195 procedure. Based on the sample size required by AASHTO T195 and the definition of uncoated by the procedure as a tiny speck of exposed aggregate, it was proposed that both absorption of water into the aggregate and entrapment of water on the surface of the coated aggregate contributed to the aggregate absorption values observed. This assumption was made based on the fact that when using the full mix the asphalt mastic, defined here as a combination of asphalt and fine aggregate, coats the surface of the coarse aggregates. As a result, the coated coarse aggregate particle contains surface asperities capable of entrapping water, this is qualitatively observed in Figure 13. The amount of water potentially absorbed was estimated by preparing asphalt mastics by holding the filler content constant and varying asphalt content from 19 to 34 percent by weight of the mineral filler, submerging the mastics, and drying them to SSD condition. The results found the surface asperities of the mastics retained moisture ranging from 0.32 - 0.48 percent by weight of the mastic (*11*). To assess the impacts of this absorption on the proposed test methods, drying curves were constructed for the bare aggregate and the HMA retained 3/8" coated aggregate. The results are presented in Figure 21. As a point of reference the absorption as determined by ASTM C127 (towel drying) is provided as well.

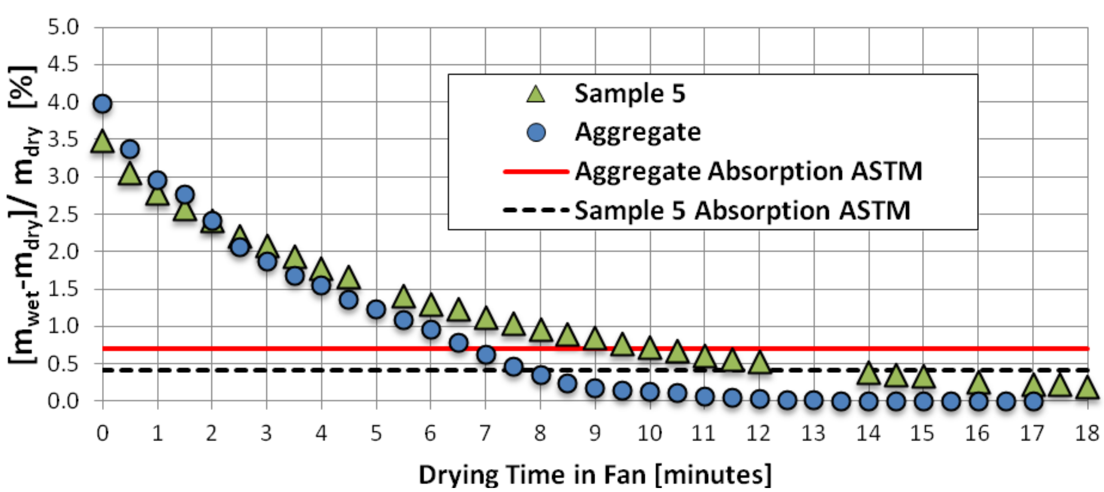


Figure 21. Drying Curves for Bare Aggregate and HMA Coarse Aggregate Coated by Mastic (*11*).

The similarities of the drying curves observed in Figure 21 indicate that the surface asperities introduced by the mastic are influencing the evaporation with time relationship of the coated aggregate. In the bare aggregate the evaporation versus time is dictated by the inherent roughness of the aggregate surface. Given that the coated and bare aggregate follow the same trend in Figure 21 indicates that similar to the bare aggregate water is filling the surface asperities of the coated aggregate. In application of the absorption procedure, this introduces the potential for wrongly assuming water has been absorbed into the aggregate when it is in fact entrapped in the mastic. To provide further confirmation of this behavior, coarse aggregate was coated only with asphalt binder and the absorption test was conducted. The results are presented in Figure 22. In this figure, the linear portion of both graphs corresponds to excess water leaving the surface of both materials. The transition from the linear to the non-linear portion of the curve corresponds to the SSD condition.

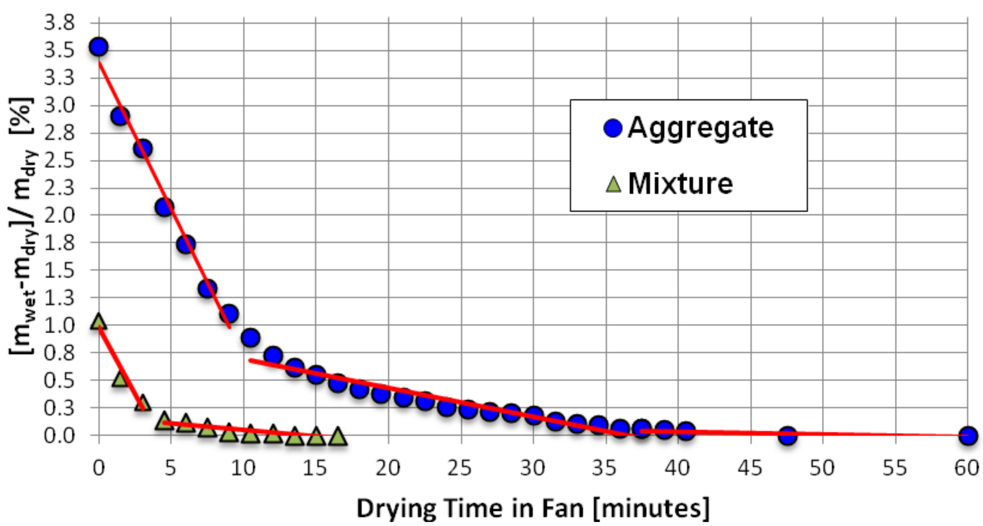


Figure 22. Evaporation Curves for Bare Aggregate and Aggregate Coated with Asphalt Only (*11*).

In contrast to the results presented in Figure 21, comparison of the evaporation curves for the bare aggregate and aggregate only coated with asphalt binder demonstrate differing behavior. Specifically, the coated aggregate reaches the SSD condition (transition from linear to non-linear loss with time) at a much faster rate relative to the bare aggregate. Furthermore, the moisture loss of the coated aggregate tends to zero with time. In combination these behaviors indicate that there is minimal moisture entrapped in the surface of the coated aggregate and that full coating was achieved as the absorption tends to zero. As a result, coating the coarse aggregate with only binder rectifies the moisture entrapment in the mastic issue and was thus recommended as a more appropriate means to assess coating.

Based on the results the final recommended test procedure is summarized as follows:

1. Wash coarse aggregates and dry over night at 100°C in a forced draft oven.
2. Sieve aggregates to obtain sufficient materials for at least 4 – 1000g samples of retained 3/8" aggregate. The samples will consist of two samples coated with asphalt and two for bare aggregate absorption testing as specified in ASTM C127.
3. Place aggregate and asphalt binder in a forced draft oven at the design mixing temperature for 2 hours.
4. Place aggregate in mixing bucket and add user-defined asphalt content. Determine minimum asphalt content based on a target effective film thickness of 8µm. For subsequent trials increase asphalt content by 0.5%.
5. Mix asphalt and aggregate in bucket mixer for 90 seconds.
6. Transfer coated aggregates to a pan and condition in oven at the compaction temperature (10°C below the mixing temperature) for 2 hours to simulate storage in the field.
7. Remove samples from oven and cool over night.
8. After cooling obtain the dry weight of each sample.
9. For each sample, follow the ASTM C127 procedure for evaluating absorption, using a soak time of 1 hr instead of the 24 hours specified in the standard.
10. Remove the aggregate sample from the water bath and pat dry with a towel, this represents the SSD condition of the material. Weigh and record the aggregate weight.
11. Calculate absorption using Equation 2.

$$\%Absorption = \frac{W_{Dry} - W_{SSD}}{W_{Dry}} \times 100 \quad (2)$$

Where:

W_{Dry} = Dry weight of bare aggregate or asphalt coated aggregate (g)

W_{SSD} = SSD weight of bare aggregate or asphalt coated aggregate (g)

3.3.2.1 Absorption Procedure Evaluation – Experimental Design

The overall goal of the absorption procedure was to provide an objective method to quantify the effects of mixing temperature and presence of WMA additives on aggregate coating. The experiment design to meet this objective is provided in Table 10.

Table 10. Experimental Table Coating Experiment.

Factor	Levels
Binder PG Grade (2)	PG 70-28 PG 58-34
Aggregate Mineralogy (1)	Limestone (Absorption retained 3/8" = 0.9%)
WMA Additive (2)	None CWM (Chemical Warm Modification)*
Mixing Temperature (2)	155°C 125°C

* The CWM Additive was only mixed at 125°C because it is a WMA additive.

Each combination of factors presented in Table 10 was prepared at four asphalt contents according to step four in the procedure listed above. The outcome of the test is a plot of absorption versus actual asphalt content for a given asphalt binder and mixing temperature. Actual asphalt binder content is defined as the design binder content less material lost during mixing or handling. In presentation of the data, absorption values for each asphalt content are plotted and fit with a linear trend line to better show trends. Most R^2 values were above 90 percent indicating a linear relationship between asphalt content and absorption.

3.3.2.2 Absorption Procedure Results and Analysis

<u>Asphalt Binder Viscosity</u>

The viscosity versus temperature relationship for all binders used in this study is presented in Figure 23, all values of viscosity were measured at a shear rate of 6.8 1/s (20 RPM), as required by AASHTO T316. Based on this standard, the viscosity range for mixing is 170 cPs ± 20 cPs for conventional binders. The mixing temperatures for the PG 58-34 and PG 58-34+2%CWM were 152°C and 144°C respectively. The AASHTO T316 mixing temperature limits were not applied to the PG 70-28 series binders as previous research has established that use of a single shear rate and the associated viscosity limits is not appropriate for modified binders (*12,13*).

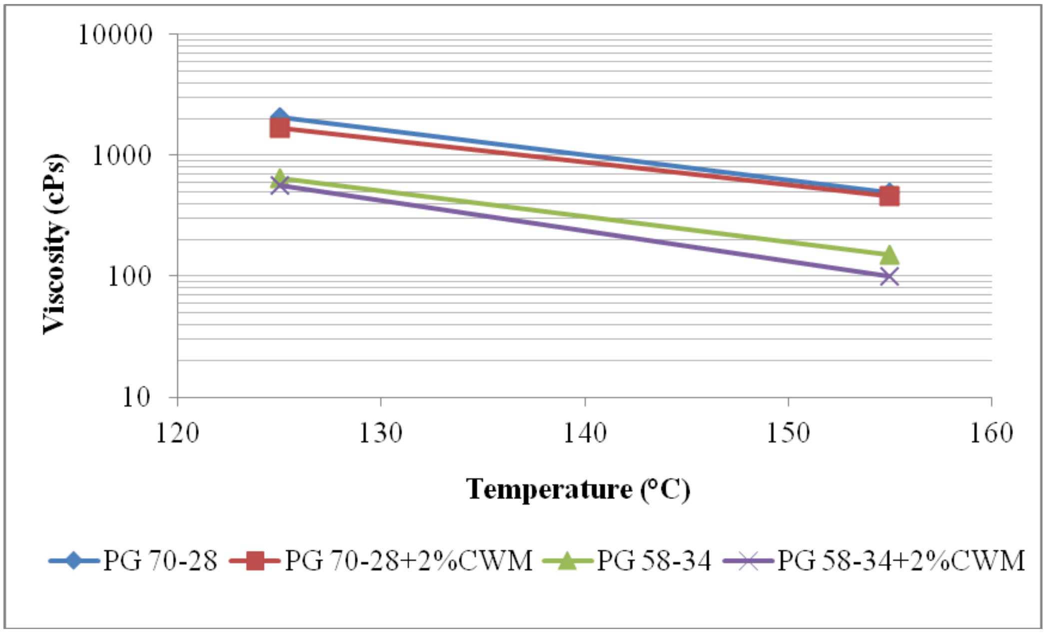


Figure 23. Viscosity at 6.8 1/s vs. Temperature.

As shown in Figure 23, the effect of the WMA additive (CWM) on viscosity is negligible relative to the other factors varied in this study (binder PG grade and temperature). This finding is consistent with published work that the presence of WMA additives does not significantly reduce asphalt binder mixing and compaction temperatures determined through viscosity based methods (*14*).

Absorption Test Results

Prior to starting the experiment, a short study was conducted to address the issue of curing time on the extent of coating evaluation. Two conditions were selected for measuring absorption, immediately after mixing (consistent with guidance in AASHTO T195) and after two hours curing at the compaction temperature to simulate storage. Results are presented in Figure 24. As indicated by the yellow arrow in Figure 24 significant improvements in the extent of coating, as demonstrated by a reduction in coarse aggregate absorption are observed across all asphalt contents. The trend is consistent with curing time decreasing absorption by approximately 40 percent. These results support the concept that coating is not an instantaneous process; instead adequate time at elevated temperatures is necessary to completely wet the aggregate surface and establish the bond between the asphalt and aggregate. Based on these findings and simulation of storage after mixing in the field, the curing time of two hours was selected for subsequent absorption tests.

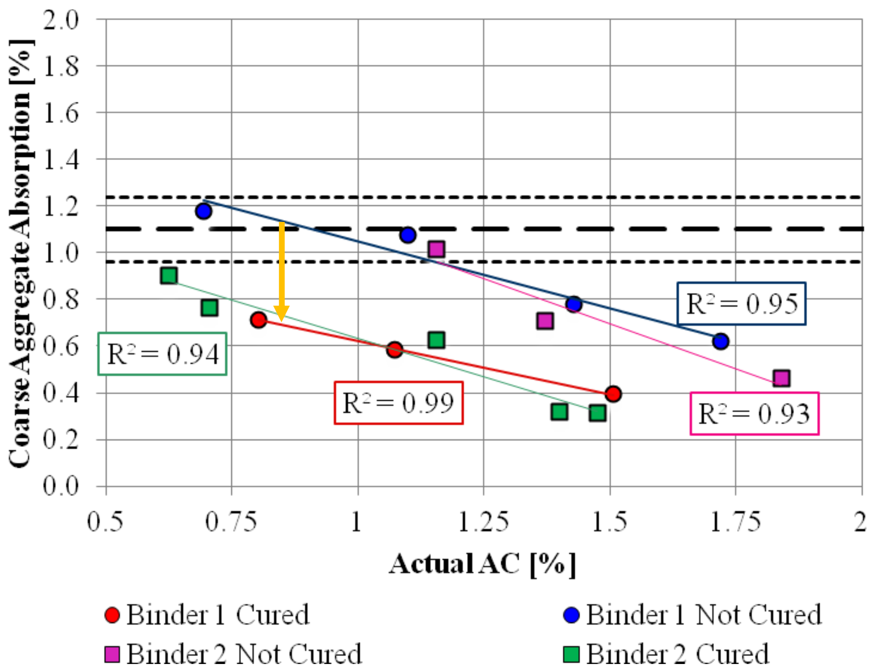
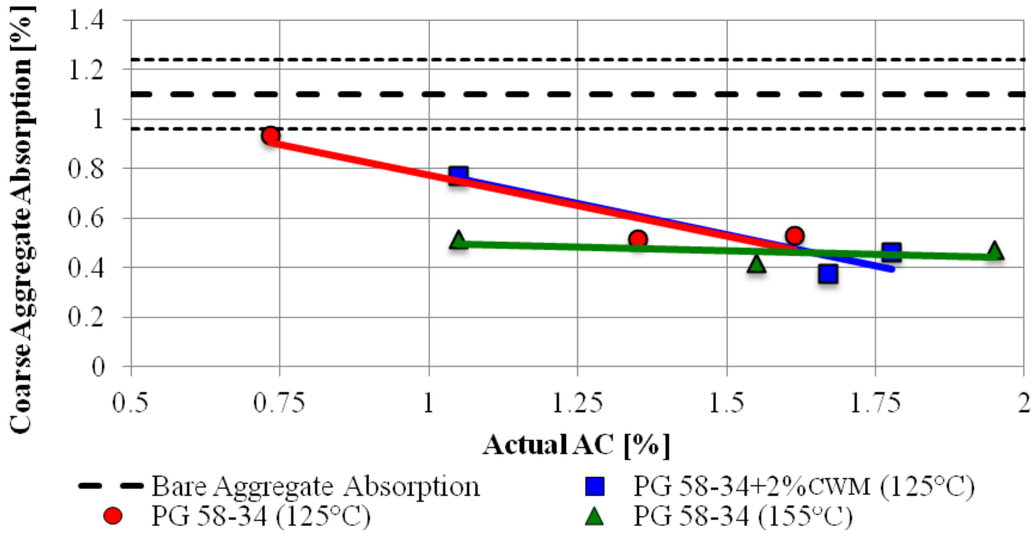
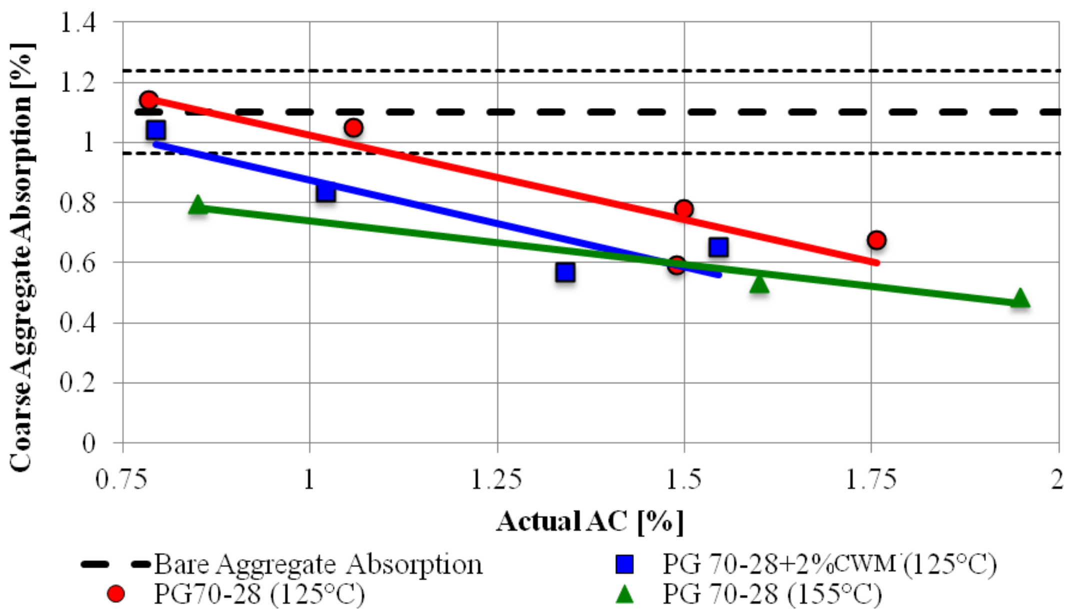


Figure 24. Effect of Curing Time on Water Absorption by Coated (Binder Only) Aggregate.

The absorption versus asphalt content relationships for the PG 58-34 series (a) and PG 70-28 series (b) binders are presented in Figure 25. Each figure includes results for three combinations of asphalt binder type and mixing temperature: Control at 155°C, Control at 125°C, and CWM at 125°C. For this testing the WMA additive was evaluated based on its ability to reduce coarse aggregate moisture absorption relative to the conventional binder mixed at the same temperature. The results presented in Figure 25 indicate that absorption follows a linear trend with asphalt binder content, with the slope of the trend dependent on asphalt binder viscosity. The absorption parameter is also insensitive to mixing temperature at asphalt contents greater than 1.5 percent. Similar values of absorption are observed for both binders. At lower binder contents sensitivity to mixing temperature is observed, with higher values of absorption and increased sensitivity to asphalt content for binders with higher viscosities. For this data set an increase in binder viscosity is realized due to a change in binder grade or lower mixing temperatures. Asphalt binder viscosity also influences the effectiveness of the WMA additive CWM. For the PG 58-34 series binders, there is negligible additive effect on absorption, whereas absorption is decreased by approximately 20 percent for the PG 70-28 series binders. This result indicates there is a potential relationship between the effectiveness of WMA additives to improve the extent of coating and the viscosity of the base asphalt. The viscosity dependence of the absorption method was further investigated through plotting the relationship between viscosity and absorption at three different asphalt contents. The results are presented in Figure 26.



(a)



(b)

Figure 25. Results of Coating Measurements based on Indirect Water Absorption Method for PG 58-34 (a) and PG 70-28 (b) Binders.

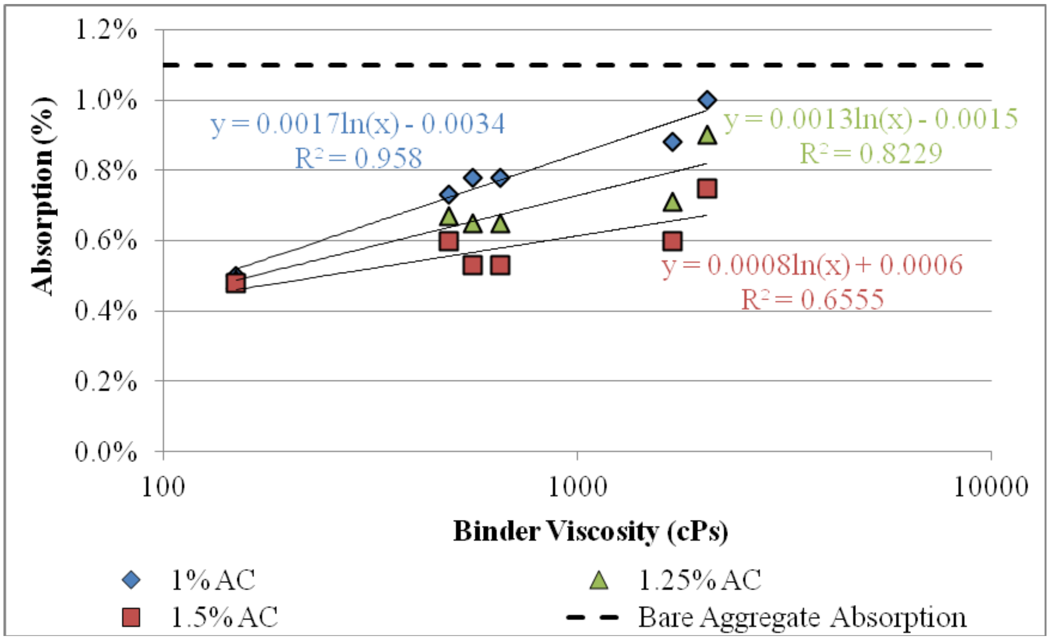


Figure 26. Effect of Asphalt Content on the Relationship between Absorption and Asphalt Binder Viscosity.

The effect of asphalt binder content on the relationship between absorption and viscosity discussed previously is confirmed in Figure 26 as both the sensitivity to changes in viscosity and the strength of the relationship with viscosity decrease with increasing asphalt binder content. In practical terms this implies that an adequate extent of coating can be achieved by selecting the appropriate value for viscosity or a higher binder content. However, the ability to adjust these factors is limited as according to current specifications the mix design must meet volumetric and moisture sensitivity requirements.

3.3.3 Evaluation of Coating Quality

Current guidance in AASHTO T195 and the new coating evaluation procedures described previously focused on evaluation of the extent of coating immediately after mixing through the use of qualitative and quantitative measures to identify uncoated areas in the aggregate. These procedures fail to relate the extent of coating to resistance to moisture damage or assess the integrity of the bond developed during mixing. Given the objective of warm mix asphalt to reduce production temperatures, a related study conducted by the Asphalt Research Consortium was developed to evaluate the hypothesis that reduced mixing and storage temperatures negatively affect the quality of the bond developed and thus have potential to increase moisture damage potential.

The concept of coating quality evaluation is not new as a standard boiling test has been available as standard ASTM D3625 since 1996. Currently the boiling test is not prevalent in agency specifications because it is a torture test that is not representative of moisture damage mechanism in the field and due to the qualitative nature of the test output. In the current test, coating after boiling is determined based on visual inspection with no detailed guidance on how to assess the level of coating that remains on each coarse aggregate particle. Given the potential expansion in the range of production temperatures used due to the increased popularity of WMA, application of the boiling test as an indicator of coating quality was revisited. Detailed results are currently available in a M.S. thesis and will be incorporated into Asphalt Research Consortium Report P *(15)*.

3.3.3.1 Development of Revised Boiling Test Procedure and Coating Evaluation Methods

Based on review of the ASTM D3625 standard procedure the following opportunities for modification were identified: 1) Define mixing time to remain consistent with guidance for mix design sample preparation; 2) Define short term conditioning temperature and time to simulate the absorption that occurs during mixture storage and transport; 3) Specify a sufficient boiling time for the test to produce results sensitive to aggregate type, binder modification, and binder viscosity; and 4) Improve guidance for coating evaluation by introducing a more refined classification system for visual coating inspection. The detailed test procedure is provided below and justification for items 1-3 are provided in the subsequent text.

<u>Boiling Test Procedure:</u>

1. Wash sufficient retained 3/8” material from the gradation intended for use in the mix design to obtain a 200 g sample. Dry washed material overnight.
2. Heat aggregates and asphalt binder to the prescribed mixing temperature for a minimum of 2 hours.
3. Add the aggregate and 3 percent asphalt binder by total mix weight (~6.2 g of asphalt). Transfer bucket to mixing station and mix for 90 s.
4. Place coated aggregate in a pan and place in oven set at the intended compaction temperature for 2 hours.

5. Remove the pan from the oven and reduce the oven temperature to 90°C. Once oven temperature has stabilized return pan to oven and condition coated aggregate for an additional hour.
6. Remove pan from oven and transfer coated aggregate to a wire basket with dimensions sufficient to fit inside a 5000 ml glass beaker. Orient the handle of the wire basket such that it is resting on the lip of the beaker. The depth of the wire basket is required to be less than that of the beaker such that when resting the bottom of the basket is approximately 1 inch above the bottom of the beaker.
7. Fill the beaker-wire basket assembly with tap water sufficient to fully submerge the aggregate and place on a hot plate. The final assembly is provided in Figure 27.

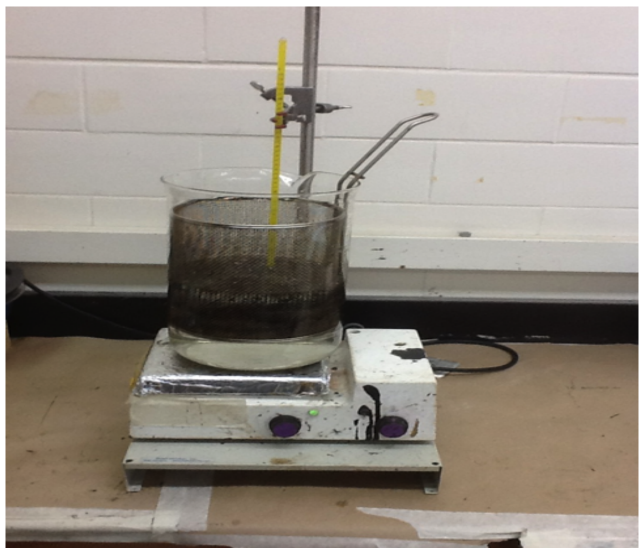


Figure 27. Photograph of Boiling Test Assembly *(15)*.

8. Adjust the settings of the hot plate to provide sufficient heat to bring the water to a boil. After the water is boiling condition the aggregate for 60 minutes.
9. Remove wire basket from beaker and place coated aggregate in a pan. Allow aggregate to cool to room temperature.
10. Individually inspect each aggregate particle and rate the extent of coating based on the scale established by UNI EN 12697-11 2012 (E), this scale is provided in Figure 28.

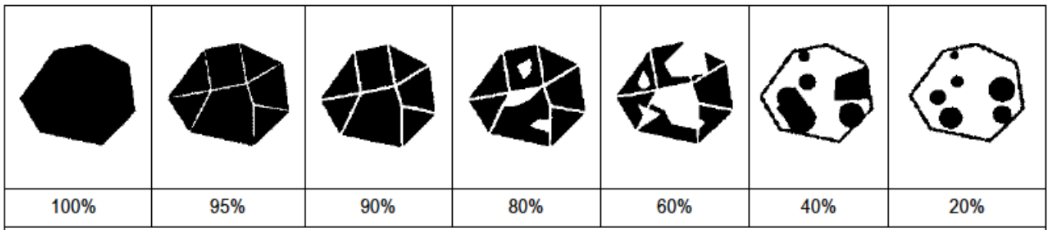


Figure 28. Scale for Determination of Degree of Asphalt Binder Coverage as provided in UNI EN 12697-11 *(15)*

11. Calculate the Coating Index using Equation 3

$$C.I.[\%] = \sum_{i=1}^{8}\left(\left(\frac{n_i+n_{i+1}}{N}\right)*(\Delta_{i+1}-\Delta_i)*0.5\right) \tag{3}$$

Where:

- $\mathbf{n_i}$ – number of particles in the i^{th} category represented by the amount of uncoated surface after boiling (i=[1-8]);
- **N** – sample size;
- **Δ** – Category label (Δ(1)=0, Δ(2)=5, Δ(3)=10, Δ(4)=20, Δ(5)=40, Δ(6)=60, Δ(7)=80, Δ(8)=100; this represents the percentage of uncoated surface post boiling.

Detailed experiments were conducted in Reference 15 to investigate and select appropriate times for mixing, storage, and boiling. Test conditions were selected based on observed sensitivity to changes in aggregate type and binder modification.

3.3.3.2 Experimental Plan

Upon establishing the test procedure and defining appropriate sample conditioning times an experimental plan was developed with the following objectives.

1. Establish the sensitivity of the Coating Index, as determined by the modified boiling test procedure on changes in materials types and properties, specifically aggregate source, asphalt binder modification, and asphalt binder viscosity.
2. Validate the visual inspection criteria adapted from European Norms for the test by use of the Acid-Base Titration method as defined in UNI EN-12697-2011.

3. Investigate the relationship between the Coating Index and mixture moisture damage as measured by the Tensile Strength Ratio (ASTM D4867) to assess possible applications of the boiling test as a screening test in the current mixture design process.

The materials and levels of asphalt binder viscosity selected in the study are summarized in Table 11. A shear rate of 0.01 s^{-1} was used to select the mixing temperatures associated with each viscosity level based on the hypothesis that coating quality is established during storage as the asphalt binder is absorbed and creates chemical bonds with the aggregate. This was assumed to be a low shear process. To obtain viscosity measurements at these low shear rates, tests were conducted using the standard bob and cup geometry in a dynamic shear rheometer (DSR).

Table 11. Summary of Materials and Levels of Asphalt Binder Viscosity (at $\gamma = 0.01\ s^{-1}$) used in for Boiling Test Evaluation

Factor	Levels
Aggregate Source (2)	Granite – North Central WI Limestone – South Eastern WI
Asphalt Binder Modification (5)	Base – PG 64-22 Base + 1% Elastomer 1 and 0.17% PPA Base + 2% Plastomer 1 Base + 2% Plastomer 2 Base + 1% Chemical WMA Additive (CWM)
Asphalt Binder Viscosity at 0.01 s^{-1} (3)	0.17 Pa•S 1.0 Pa•S 3.0 Pa•S

The comparison of boiling test results to the TSR was conducted using an expanded set of asphalt binders including additional modifiers and the presence of anti-stripping additives. A total of six mixtures were prepared with the granite aggregate source using the same gradation. The mix design had a nominal maximum aggregate size of 12.5 mm and met WisDOT requirements for an E-10 traffic level (N_{des} = 100 gyrations). The experiment included one base asphalt (PG 64-22) and five different modified binders formulated to achieve a two PG grade increase, amine based anti-stripping additive was included at a concentration of 0.1% by weight of the asphalt binder for some of the modified binders. The specific modifications used were:

- 3.5% Elastomer 2

- 2.0% Elastomer 2 + 1.5% Plastomer 2 (Hybrid) +0.3% Anti-stripping additive
- 4% Plastomer 1
- 4.5% Plastomer 2
- 4.5% Plastomer 2 + 0.3% Anti-stripping additive

3.3.3.3 Summary of Results

As shown in Table 11, viscosity was controlled as a factor in the boiling test evaluation experiment. The mixing temperatures associated with each viscosity level are provided in Table 12. For all mixes the storage temperature was held 10°C lower than the mixing temperature. As shown in the table, relative to the base binders similar viscosities were observed for the chemical warm mix additive at all temperatures. The most significant effect of modification was observed for the Elastomer across all viscosity levels. Increases in the temperature required to reach the viscosity threshold was also higher for both plastomers, particularly below the melting point of the polymer.

Table 12. Summary of Mixing Temperatures Associated with Selected Viscosity Levels *(15)*.

Asphalt Binder Modification	η @ γ =0.01 s^{-1}[Pa•s]		
	0.17	1.0	3.0
Base (PG 64-22)	158	124	103
1% Elastomer 1 + 0.17% PPA	185	155	137
2% Plastomer 1	164	145	134
2% Plastomer 2	166	127	119
1% Chemical Warm Mix Additive (CWM)	155	121	99

The relationship between coating index and asphalt binder viscosity for the limestone aggregate are provided in Figure 29. For most materials a decrease in coating quality with increasing binder viscosity is observed with the most drastic change in coating index realized when viscosity is increased from 0.17 Pa•S to 1.0 Pa•S. The elastomer modified binder does not follow this trend as full coating is achieved across all levels of asphalt binder viscosity selected. Furthermore, the worst coating quality results at a the 1.0 Pa•S viscosity level were observed for the chemical warm mix additive, the mixing temperature that corresponds to this viscosity was 127°C, which is within the range at which WMA is currently produced in the field. The results indicate that for this aggregate source there is risk of premature loss of coating if production temperatures are reduced. Assuming mixing temperatures ranging from 155 to 165 °C for conventional HMA, the results indicate that a quality level of coating (coating index above 80%) can be achieved for all materials evaluated. To evaluate the effects of aggregate type, coating index values for granite and limestone aggregates for a viscosity of 1.0 Pa•S are compared in Figure 30. Similar comparisons for other viscosity levels are available in Reference 15, but were not presented here because no effect of aggregate type was observed at the low level of viscosity and coating evaluation at the high level of viscosity is not relevant because the mixing temperatures used are lower than those that would be expected in the field *(15)*.

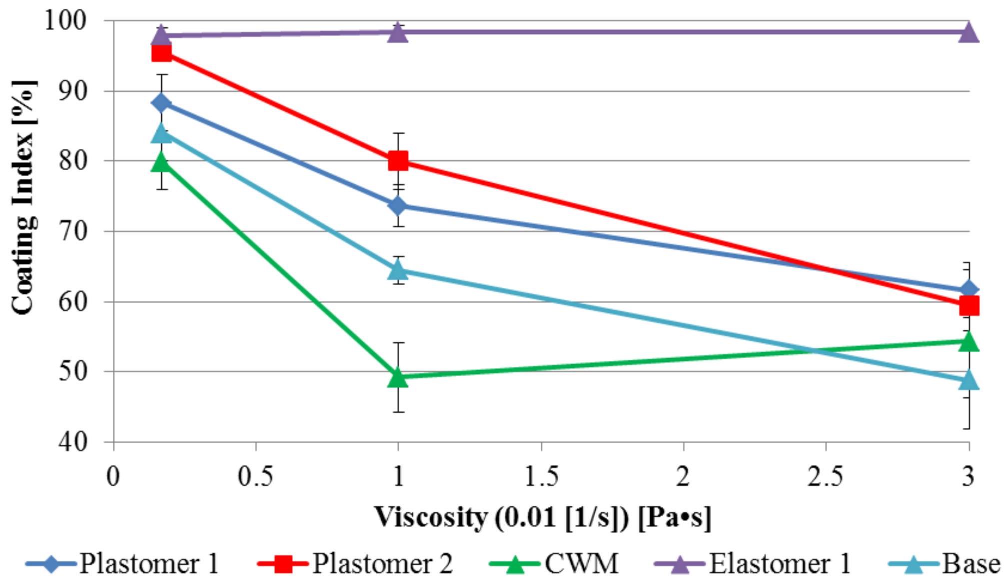
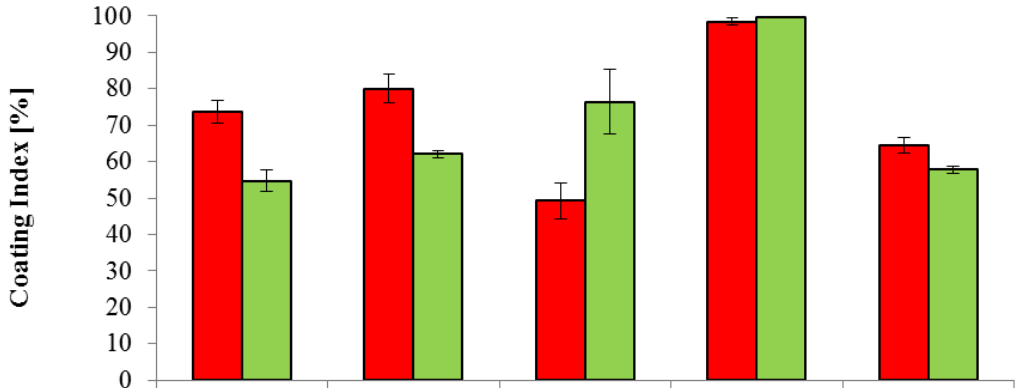


Figure 29. Coating Index vs. Viscosity Relationship for Conventional and Modified Binders Combined with Limestone Aggregate *(15)*.



	Plastomer 1	Plastomer 2	CWM	Elastomer 1	Base
Limestone	73.7	80.0	49.2	98.4	64.5
Granite	54.8	62.2	76.5	99.7	57.8

Limestone Granite

Figure 30. Effect of Aggregate Source on Coating at 1.0 Pa•S *(15)*.

In regards to the effect of aggregate type, an improvement in coating quality on the order of 20 percent is observed for the limestone aggregate used in combination with the plastomer modified binders. No effect was observed for the base or elastomer materials. Furthermore, for both aggregate sources the elastomer modified binder experienced no degradation in coating quality. A significant improvement in coating quality was observed when the chemical warm mix additive (CWM) was used with the granite aggregate indicating that the effectiveness of the additive in preventing aggregate coating loss when mixed and stored at lower temperatures is aggregate dependent. A 20 minute boiling time was used in collection of all data, based on the observation of no values of coating index below 50 percent, it was determined that the initial conditioning time of 20 minutes was insufficient to cause damage, thus a 60 minute boiling time was recommended in the final procedure.

The variation in results due to the use of different modifiers for a given level of viscosity indicates that controlling viscosity in the mixing and storage process does not necessarily guarantee that quality coating will be achieved. These results are in contrast to the previous results presented in Figure 26, which based on the relationship between viscosity and absorption found that the extent of coating achieved during the mixing process can be effectively controlled by selecting the correct viscosity, particularly at lower asphalt contents. Possible mechanisms preventing a direct relationship between coating index and viscosity were cited as: 1) The asphalt content used in the boiling test procedure; and 2) Interactions between the various modifications and aggregate sources used causing differing levels of resistance to moisture damage mechanisms of debonding and detachment. In regards to the effect of asphalt content, absorption results presented in Figure 26 indicate diminishing sensitivity of absorption to viscosity as asphalt content increases. There is potential that this trend remains in coating quality evaluation as more asphalt is available to achieve a sufficient film thickness around the aggregate.

For coating degradation (decrease in coating index) to occur the affinity of water to aggregate must be greater than the physical and chemical bonding between the asphalt and aggregate surface. The results indicate that for a given base asphalt, modification can improve the resistance to degradation through both physical (i.e. increase in stiffness) and chemical means. An example of chemical improvement is observed for the warm mix additive, which makes use of surfactants to improve wetting between the asphalt and aggregate. The results indicate that the effectiveness of this chemical modification is aggregate type dependent. Overall the boiling tests results indicate that the sole use of coating extent tests such as AASHTO T195 or the absorption method are insufficient to diagnose moisture damage potential.

3.3.3.4 Validation of the Visual Inspection Scale Using Acid Base Titration

The modified boiling test method introduced a refined scale for evaluating coating quality; however, the output of the test is still reliant on visual inspection. To validate the proposed visual inspection the acid-base titration methodology recommended in the UNI EN 12697 – 11 (2012) (Part E) was adapted as an additional measure of coating quality. The titration procedure was used with samples prepared in the previously detailed experiment using the limestone aggregate. The test is based on the chemical reaction between hydrochloric acid (HCl) and calcium carbonate ($CaCO_3$), which results in dissolving the calcium carbonate into the components as shown in Equation 4. A similar procedure can be used for siliceous aggregates, such as granite, by using hydrofluoric acid (HF).

$$CaCO_3 + 2 \cdot HCl \rightarrow CaCl_2 + H_2O + CO_2 \qquad (4)$$

During the reaction, the salt $(CO_3)^{2-}$ of Calcium Carbonate reacts with the hydrogen ion (H^+) of the hydrochloric acid forming carbonic acid H_2CO_3 which in presence of water dissolves into H_2O and CO_2. This reaction reduces the concentration of H+ ions causing an increase in the pH of the solution; which represents the amount of consumed acid during the reaction. The increase in pH is proportional to the amount of salt $(CO3)^{2-}$ involved in the reaction; this relates to the amount of aggregate surface exposed to the acid. As a result, a higher surface area of exposed aggregate corresponds to a higher volume of consumed acid during the reaction. Acid base titration is then applied to quantitatively measure the amount of consumed acid through measuring the volume of base (NaOH), necessary to neutralize the acid (HCl) after the reaction with the calcium carbonate (which is now a solution). In this method use of a higher volume of base to neutralize the acidic solution corresponds to less hydrogen ions consumed during the reaction with calcium carbonate and thus represents a higher quality of coating (less aggregate surface area exposed).

The procedure can be summarized as follows: a) after boiling, once the sample is cooled and dried at room temperature, it is put in contact with an amount of acid equal to the sample's weight (200g) and reacted for 1 hour; b) after reaction the solution is poured in a graduated cylinder; c) a volume of 25 ml of solution is neutralized with the base and the volume of base is recorded, in this study the base used for neutralizing the solution was Sodium Hydroxide (NaOH); d) the volume consumed as well as residual acid is computed. A significant deviation from the standard procedure was the duration of reaction time, the European Norm recommends a time of 5 minutes, however 60 minutes was used for this study. The extended reaction time was selected to account for the larger sample size used during the test and the increased asphalt absorption observed for longer mixture curing times. These factors are not addressed directly in the standard, so it was necessary to account for them in establishing a new reaction time. A schematic of the procedure is provided in Figure 31.

The volume of consumed acid resulting from the acid base titration method were compared to the coating index values for the asphalt binders and viscosity levels in Figure 29. The results provided in Figure 32 demonstrate a moderate relationship between the volume of acid consumed and the coating index. The comparison is also consistent with expectations as both lower coating index and lower volume of final acid correspond to more exposed surface area of bare aggregate. Recall that lower volume of final acid indicates that more acid was consumed in reaction with the aggregate surface. Based on these results the qualitative scale used for coating evaluation was confirmed.

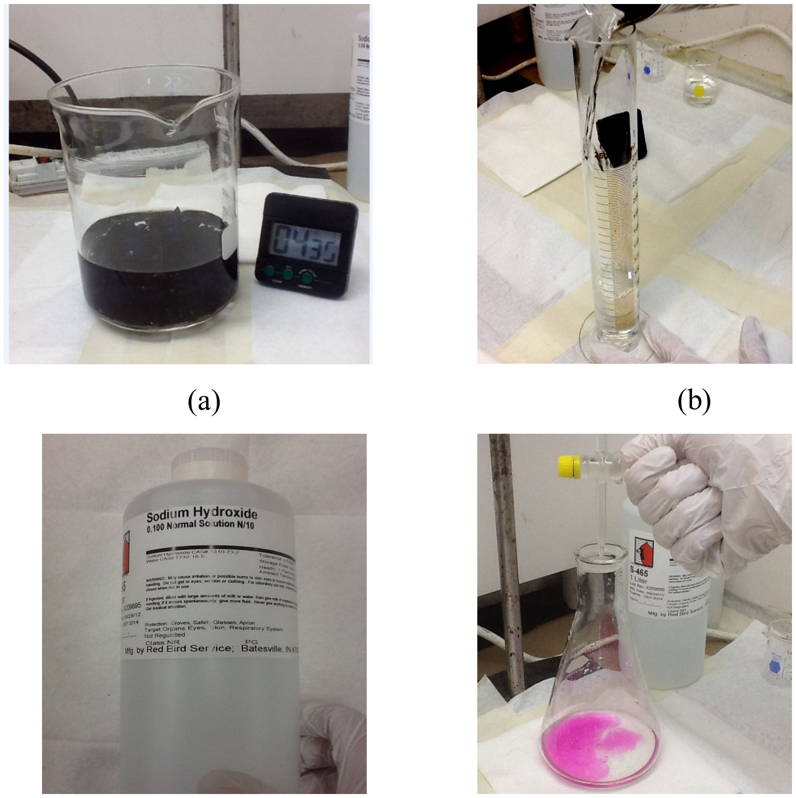


Figure 31. Schematic of Acid-Base Titration Procedure for Limestone Aggregates *(15)*.

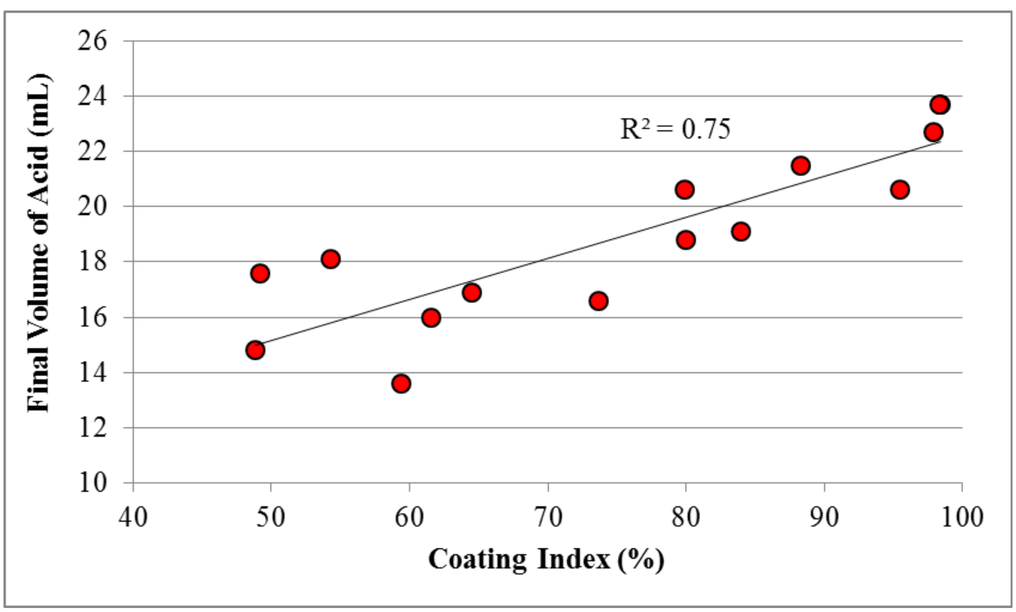


Figure 32. Validation of Coating Index Parameter through Comparison to Volume of Consumed Acid by Titration *(15)*.

3.3.3.5 Comparison to Mixture Performance

A fine graded E-10 mix design from the granite aggregate source was used to compare the coating index parameter to mixture moisture damage as measured by the tensile strength ratio (TSR); the NMAS of the mix was 12.5 mm. Six different asphalt binders were used to in the verification mixes including a control, different types of modification, and also use of liquid anti-strip. The mixing temperature was held constant at 155 °C. All samples were compacted to a target of 7 percent air voids and saturated and conditioned according to the ASTM D4867 test procedure. The boiling test was conducted on the coarse aggregate fraction of the mix design gradation for each binder selected in this portion of the study. As previously discussed, the boiling time was extended to 60 minutes to ensure sufficient conditioning for observation of sensitivity to changes in materials. Comparison between the TSR and Coating Index is provided in Figure 33.

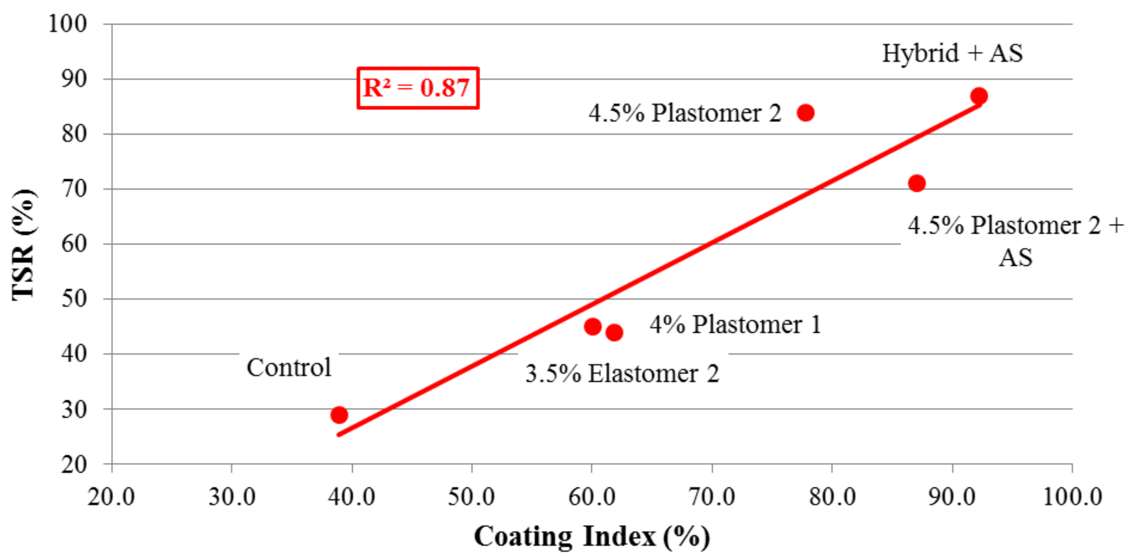


Figure 33. Comparison between Mixture Moisture Damage (TSR) and Coarse Aggregate Coating Quality *(15)*.

The results presented in Figure 33 demonstrate a moderate relationship between coating index and TSR that includes a clear distinction between poor performing (TSR<50) and those that perform well (TSR >70). The data also indicate that opportunities to improve moisture damage exist through both changing modification types or using liquid anti-strip additives. It is also interesting to note the performance differences between different types of modification. Without considering the use of anti-strip or hybrid formulations changing plastomer type results in improvements in both TSR and Coating Index on the order 20 – 30 percent. Hybrid (Plastomer 2 + Elastomer 2) formulations also significantly impact moisture damage resistance as the performance of the hybrid in regards to both coating index and TSR exceeds that of all other components.

In general, the Coating Index under predicts the TSR by approximately 10 percent (i.e. Coating Index of 40 percent corresponds to a TSR of 30 percent). This finding is not unexpected as stripping of the coarse aggregate represents only one of many mechanisms for moisture damage in mixtures. Specific mechanisms include: loss of strength in the mastic due to the presence of moisture, which causes a corresponding decrease in mixture strength; or stripping in the natural sand component of the fine aggregate portion. Furthermore, recall that the information for the boiling test was added based on related work and not as part of the original work plan approved by WHRP. Therefore information related to the effects of WMA additives, foaming, or the presence of RAP on boiling or moisture damage testing results are not available.

3.3.4 Summary of Findings and Conclusions

The objective of the coating study was to develop an objective method for laboratory evaluation of coating as a substitute for current guidance specified in AASHTO T195. Two developmental methods were evaluated to measure the extent of coating, percent uncoated area from digital image processing and percent water absorption. The concept of measuring the quality of coating through the use of a boiling test was also introduced. The motivation for evaluating these tests was to ensure that the lower production temperatures and use of additives/processes associated with WMA do not result in inadequate mixture coating extent or quality and thus a decrease in durability. The following are a summary of the findings from the coating study:

1. The use of digital imaging to measure the extent of coating yielded unreliable results that were attributed to variation in light source and reflection of light from the surface of coated particles. Based on the need to standardize ambient lighting and methods used to capture the image, the decision was made to not pursue further development of the test procedure as considering these effects deviates from the project objective of providing a simple, reliable measurement of coating.

2. It was not possible to evaluate coating based on water absorption using retained 3/8" material sampled from laboratory or field produced loose mix due to entrapment of moisture on the surface of the mastic that coats the aggregate. Instead it is necessary to evaluate

absorption of coarse aggregates coated only with asphalt binder. This precludes the use of water absorption as a field acceptance parameter.

3. The coating experiment introduced the concept of considering the quality of coating from the boiling test to better relate to the potential for moisture damage. The results found that although equal coating extent was achieved during mixing, the quality of coating was influenced by viscosity for most conventional and modified binders tested. A moderate relationship between coating quality as measured by the coating index and mixture moisture damage was also observed. However, additional testing including more binder and aggregate sources is needed to confirm this relationship.

4. Preliminary results indicate that the boiling test has potential for screening new materials to ensure that new additives or binder modifiers are compatible with the aggregate selected in the mix design. Further research is needed to assess the benefits of including the boiling tests as an initial screening test in the current WMA or HMA mix design process versus current practice which assess compatibility based solely on TSR results.

The coating experiment demonstrated that it is not possible to develop a simple imaging or absorption based test that can be used to evaluate coating during mixture design and production. Considering this and the recommendations from the TOC that AASHTO T195 is too subjective for mixture design, quality control and acceptance, a coating evaluation was not included in the draft specifications. Instead, minimum production temperatures for various processes were included based on temperatures that have been successfully used in various monitored WMA demonstration projects. The boiling test appears promising as a measure of coating quality, but more research is required before this test can be recommended as an alternative to the TSR testing currently included in WisDOT specifications.

3.4 Asphalt Thermal Cracking Analyzer Experiment

The increased use of RAP and RAS and the use of WMA additives to extend the range of production temperatures used in the field have introduced the possibility of significant differences between the as-built mixture properties and the properties considered in design by asphalt binder grade selection. To address this issue the research team introduced the concept of controlling mixture resistance to rutting and thermal cracking by incorporating the flow number and Asphalt

Thermal Cracking Analyzer tests into mix design and quality control. The potential impacts of the use of WMA additives and increased recycled materials on mixture thermo-volumetric properties are summarized in Table 13.

Table 13. Summary of Potential WMA/RAP/RAS Related Factors that Impact on Mixture Thermo-volumetric Properties.

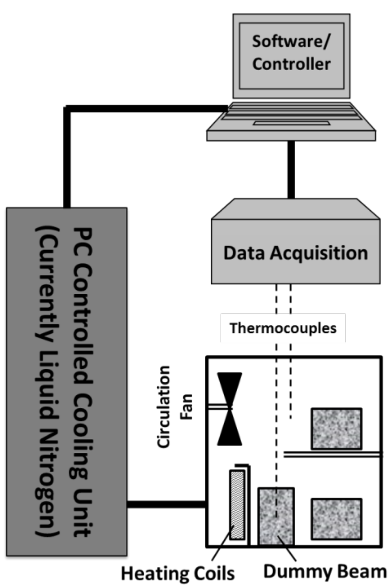
Factor	Effect on Thermal Cracking	Reason for Effect
Increased RAP/RAS Binder Replacement	Increase	1. Blending of virgin/recycled binder causes embrittlement at low PG temperatures (higher S and lower m-value).
		2. Actual mixture asphalt content is less than design %AC due to incomplete blending of virgin/recycled binder.
Decreased Production Temperatures	Increase	1. Extent of blending decreases at lower temperatures, reducing effective asphalt content of mix.
	Decrease	2. Reduced binder oxidation during production due to lower temperatures.
Use of WMA Additives	No effect or Increase	3. Additive dependent. Some additives have an effect on binder PG grade, others do not.

As demonstrated in Table 13, the use of high RAP or RAS contents in combination with WMA introduces many competing mechanisms that have different influences on cracking. Furthermore, the only factor that can be addressed directly by AASHTO M320 binder grading specifications is the WMA additive effect. The other factors are RAP/RAS source dependent as they are related to the rheological properties of the recycled binder and the extent of blending that occurs during mixing and storage (*16, 17*). As a result, it is most effective to measure cracking resistance directly on asphalt mixtures as it allows for consideration of all factors through use of the actual recycled materials sources and conditioning times and temperatures can be adjusted to simulate storage conditions in the field. The test selected to conduct this evaluation was the Asphalt Thermal Cracking Analyzer test. One property that can be measured with the Asphalt Thermal Cracking Analyzer test is the glass transition temperature, T_g, which is determined through monitoring volume change with decreasing temperatures.

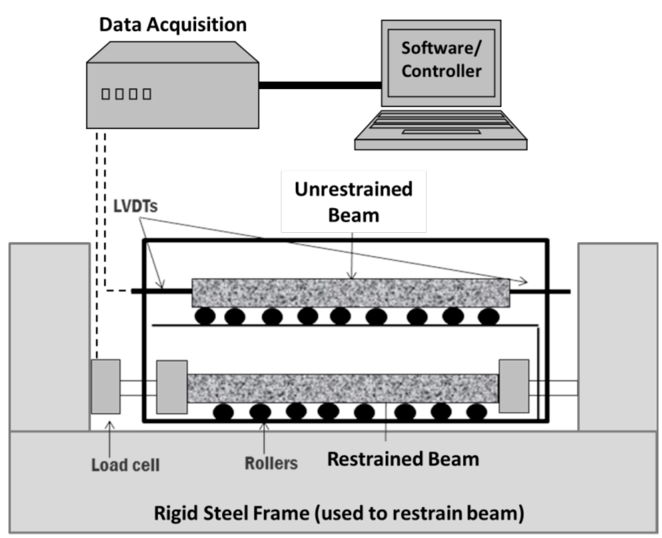
3.4.1 Test Procedure

Determining the mixture glass transition, T_g, with the Asphalt Thermal Cracking Analyzer involves subjecting an asphalt mixture beam (50±5 mm x 50±5 mm x 300±10 mm) to cooling and then heating in a range from 30°C to -70°C at a rate of 0.5°C/min in an environmental chamber. Thermo-volumetric properties are measured through monitoring the change in length of an unrestrained beam due to a decrease in temperature. The length measurement is obtained through instrumentation of the sample ends with linear variable differential transducers (LVDTs) and the unrestrained condition is achieved by placing the beam on rollers to prevent friction with the bottom of the environmental chamber. A schematic of the chamber is provided in Figure 34. As shown in the schematic, the chamber is also capable of measuring the thermal cracking resistance of restrained samples using an adaptation of the thermal stress restrained specimen test (TSRST).

The test is fully automated as the temperature is computer controlled and data acquisition is used to collect LVDT readings for the Mixture T_g test and/or load cell readings for the TSRST test. A circulation fan is used to further regulate the temperature throughout the chamber. The “Dummy Beam” shown in Figure 34a is used to monitor the core temperature of the asphalt beam to ensure that only data collected when the temperature is consistent throughout the beam is used in the analysis. A picture of the device set up prior to starting the test is provided in Figure 35.



(a) Front View



(b) Side View

Figure 34. Schematic of the Test Apparatus for Measurement of Mixture Thermo-Volumetric Properties.

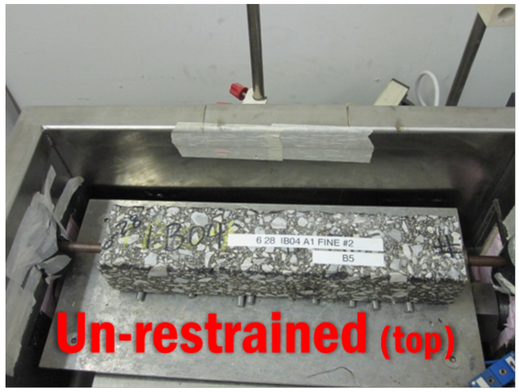


Figure 35. Picture of the Instrumented Asphalt Mixture Beam Prior to Mixture T_g Testing.

The mixture T_g procedure consists of the following heating and cooling steps:

1. Heating the beam to 30°C and maintaining the temperature for 30 minutes.
2. Cooling the beam to -70°C at a rate of 0.5°C/min and maintaining the temperature for 30 minutes.
3. Heating the beam back to 30°C at the same rate.

The total duration of the procedure is approximately 3 hours. Length measurement data is acquired from the LVDTs at a rate of one data point every 30 seconds. An example output of the test is provided in Figure 36.

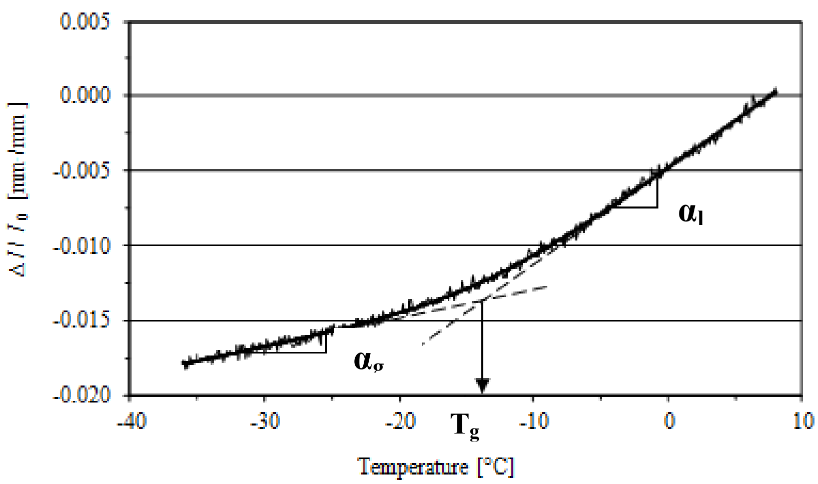


Figure 36. Example of Determination of HMA Thermo-Volumetric Properties Based on Change in Length vs. Temperature.

The thermo-volumetric properties obtained from the test are defined as follows:

- *Glass Transition Temperature (Tg)* – At the glass transition temperature the material undergoes a transition from "liquid" behavior to "glassy behavior." The glass transition temperature is defined as the temperature at the intersection of the extension of the linear contraction/expansion trends on the volume/length versus temperature curve.
- *Liquid Coefficient of Contraction (α_l)*– Defined as the slope of the volumetric or linear change of dimensions with temperature, when the sample is at temperatures sufficiently higher than the T_g to result in a linear rate of volumetric or linear dimensional change with temperature.
- *Glassy Coefficient of Contraction (α_g)* – Defined as the slope of the volumetric or linear change of dimensions with temperature, when the sample is at temperatures sufficiently lower than the T_g to result in a linear rate of volumetric or linear dimensional change with temperature.

In this study all samples were prepared from cylindrical samples compacted in the SuperPave gyratory compactor (SGC). Sufficient material was placed in the SGC mold to achieve a final compacted sample height of 180 mm. Samples were cut into prismatic pieces and assembled according to the schematic provided in Figure 37. The ends of the sample were glued using fast curing epoxy (3M DP-100 Scotch-Weld). The test procedure is included in Appendix D. The test procedure was developed through the Asphalt Research Consortium (ARC) project funded by FHWA. A deliverable of that project is a draft AASHTO standard that was submitted for consideration during the 2013 meeting of the AASHTO Subcommittee on Materials. Further information regarding the test is available in various publications and conference proceedings (*18, 19,20*).

3.4.2 Experimental Design and Materials

The objective of the glass transition test experiment was to evaluate the effects of the high percentage of RAP binder replacement and the presence of WMA additives on mixture thermo-volumetric properties. The experimental design and justification for selection of factors is provided in Table 14.

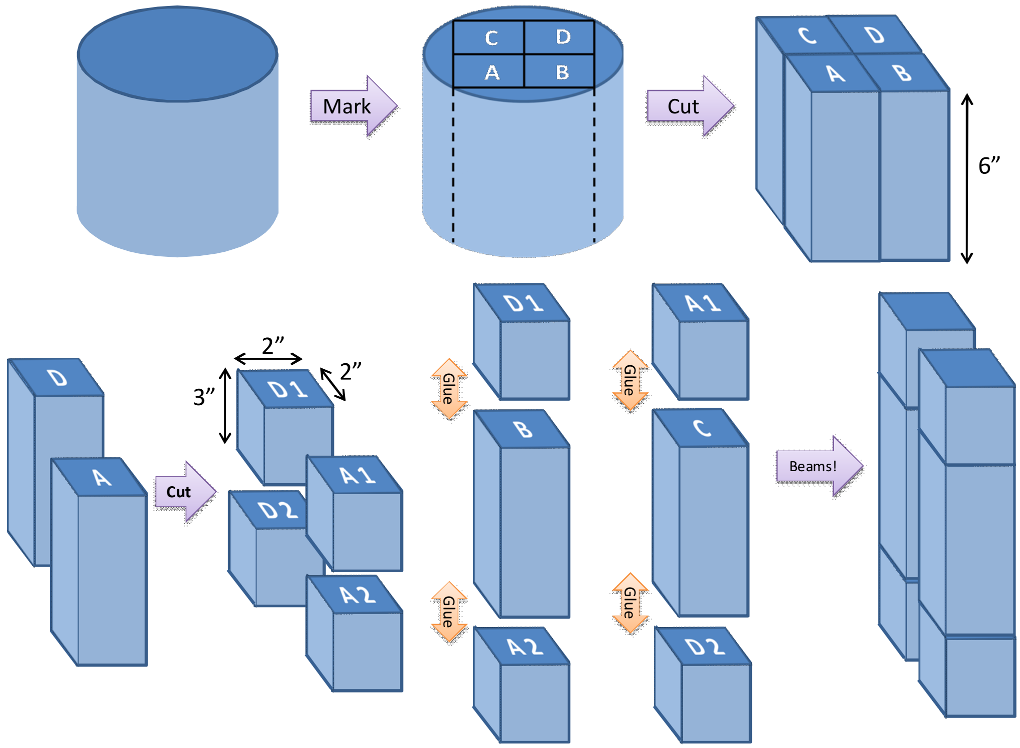


Figure 37. Schematic for Assembly of Beams for Thermal Volumetric Mixture Testing from SGC Samples.

Table 14. Experimental Design for Mixture Thermo-Volumetric Evaluation.

Factor	Description	Justification
Mix Design (1)	E-10 WisDOT Mix Design ID 250-0186	E* and FN values measured in WHRP 0092-08-06 (*6*)
Binder PG Grade (2)	PG 58-34 PG 70-28	Represents range of PG grades used by WisDOT
% RAP Binder Replacement (2)	0% (Control) 24%	Percent binder replacement approximately 10% above current maximum for surface mixes.
WMA Additives (3)	0% (Control) 2% W1* 0.5% W2*	Commercially available WMA additives.

*Dosage levels based on weight of asphalt binder.

The gradation for the E-10 WisDOT Mix Design 250-0186 is presented in Figure 38. The original JMF gradation based on the 100 percent virgin aggregate mix was maintained for the RAP mixtures. The RAP was a single source from northern Wisconsin with an asphalt content of 6.1 percent. The total binder content for all mixes was held constant at 5.1 percent for all mix designs.

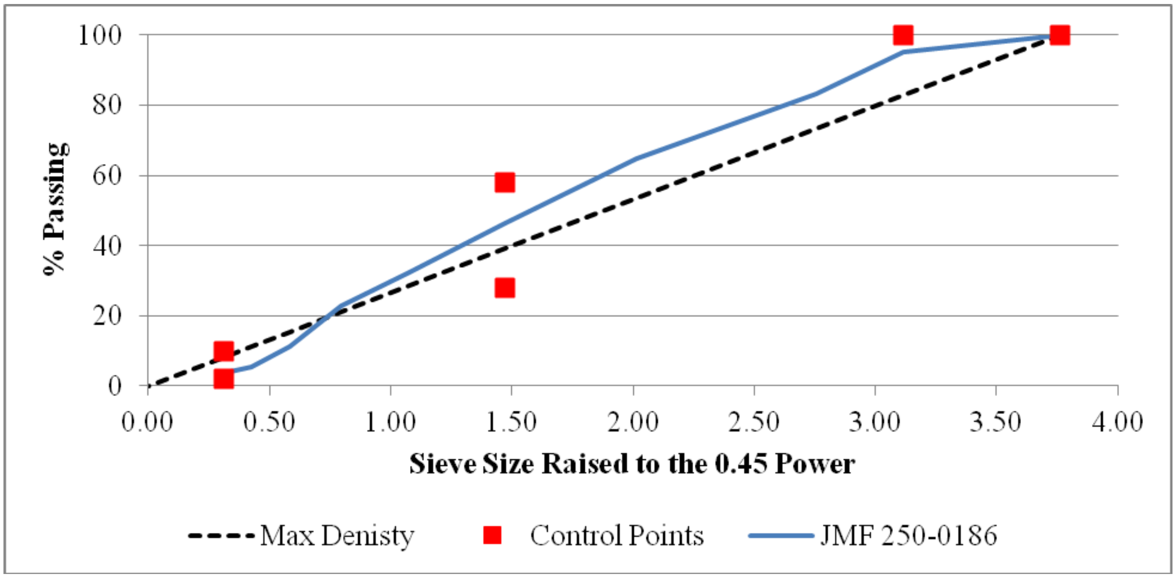


Figure 38. Gradation Curve for WisDOT Mix Design 250-0186 Plotted on 0.45 Power Chart.

To serve as a control, mixes were prepared at both RAP contents for the PG 58-34 and PG 70-28 binder grades. The WMA mixes were prepared at only 24 percent RAP binder replacement. The compaction temperature for each binder grade was 141 °C and 168 °C for the PG 58-34 and PG 70-28 binders, respectively. For a given binder grade, the compaction temperature was held constant for HMA and WMA mixes to isolate the effects of WMA additives on the thermo-volumetric properties of mixes that included RAP. All mixes were prepared to a target core air void content of 4 percent and beams were assembled according to the schematic provided in Figure 37.

3.4.3 Results and Analysis

Typical results for the thermal strain versus temperature relationship are provided in Figure 39. In the presentation of the data, 20 percent RAP indicates the amount of RAP by mixture weight, this corresponds to the 24 percent binder replacement specified in the experimental design. Contrary to the example provided in Figure 36, the actual data collected is lacking a clear transition from liquid to glassy behavior, complicating estimates of glass transition temperature. This result is attributed to the presence of RAP or the gradation of the mixture used in the study. Overall, the mixture glass transition temperature is a function of the aggregate structure developed during compaction (gradation) and the glass transition temperature of the bituminous components of the mix. Addition of a material with a different glass transition temperature than that of the neat asphalt such as reclaimed asphalt binder or WMA additives increases the distribution of glass transition temperatures in the composite material, thus broadening the range at which the transition from liquid to glassy behavior occurs. Qualitatively, both the effects of RAP and WMA additives are observed as the control mix (PG 70-28) undergoes a more distinct transition relative to other mixes. Furthermore, the WMA additive effect is observed for W1 as it accumulates marginally less strain relative to the control and W2 modified mixes.

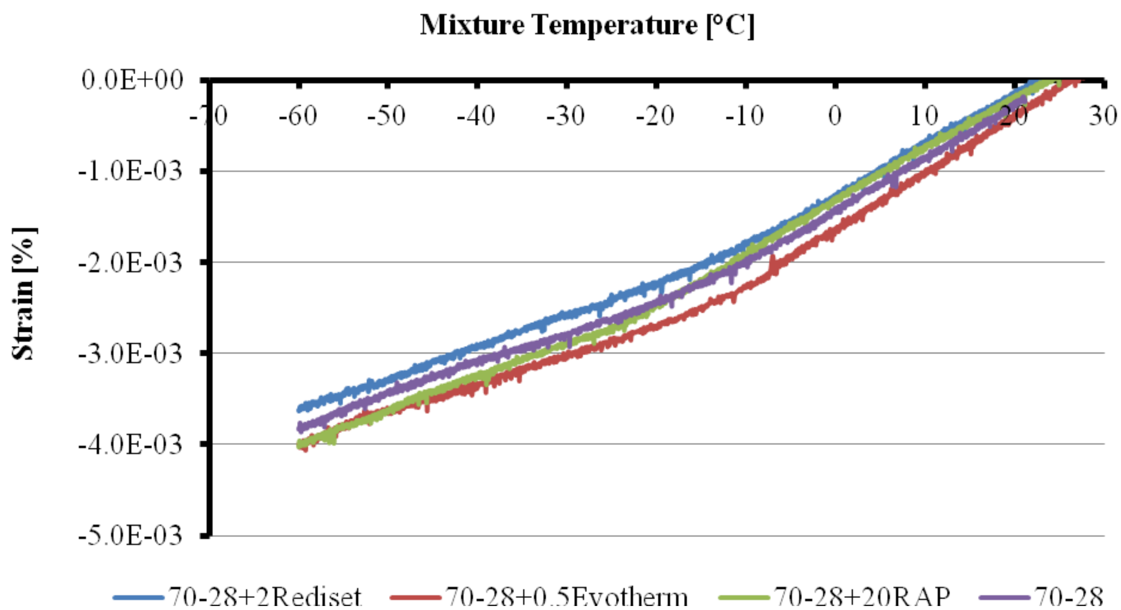


Figure 39. Trend of Sample Contraction With Temperature.

The thermal strain versus temperature plots were used to determine the aforementioned mixture thermo-volumetric properties. The objective of this study was to assess the potential for using these properties as a performance-based mix design or quality control tool to mitigate the potential for thermal cracking by evaluating the sensitivity to the presence of RAP and WMA additives. Mixture glass transition temperature results are presented in Figure 40. In the presentation of the data for Figure 40 and subsequent plots the error bars represent the pooled standard deviation of test results multiplied by a factor of 2 to obtain a 95 percent confidence intervals.

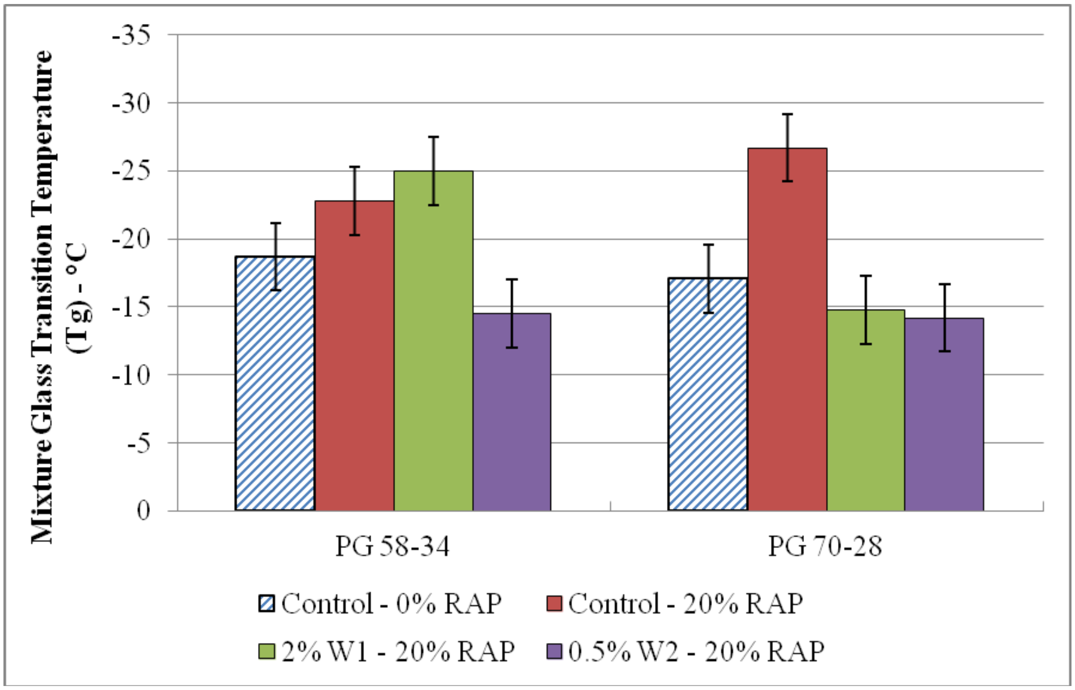
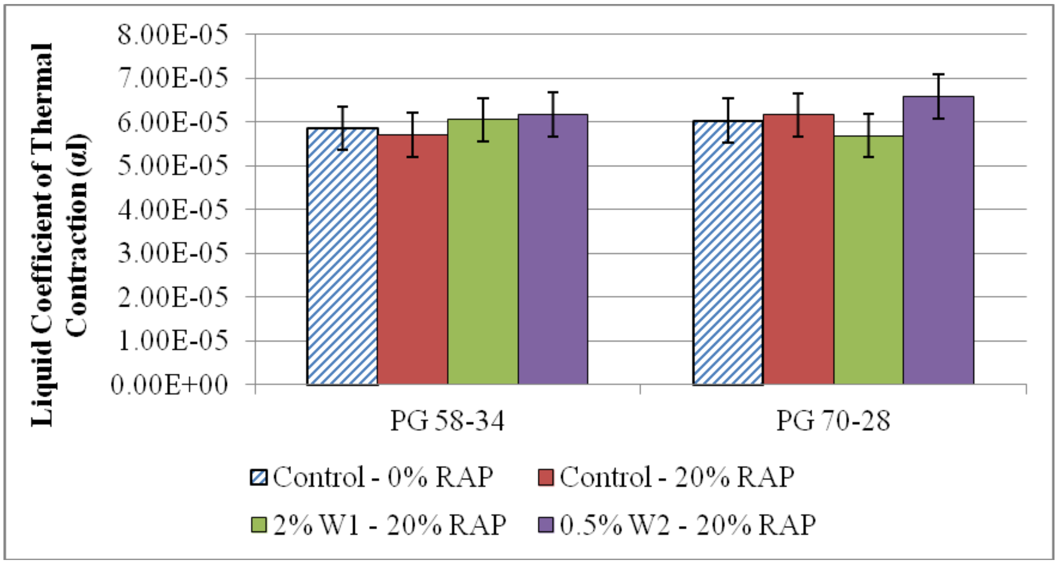


Figure 40. Variation in Mixture Glass Transition Temperature (T_g) due to Presence of RAP and WMA Additives for PG 58-34 and PG 70-28 Binders.

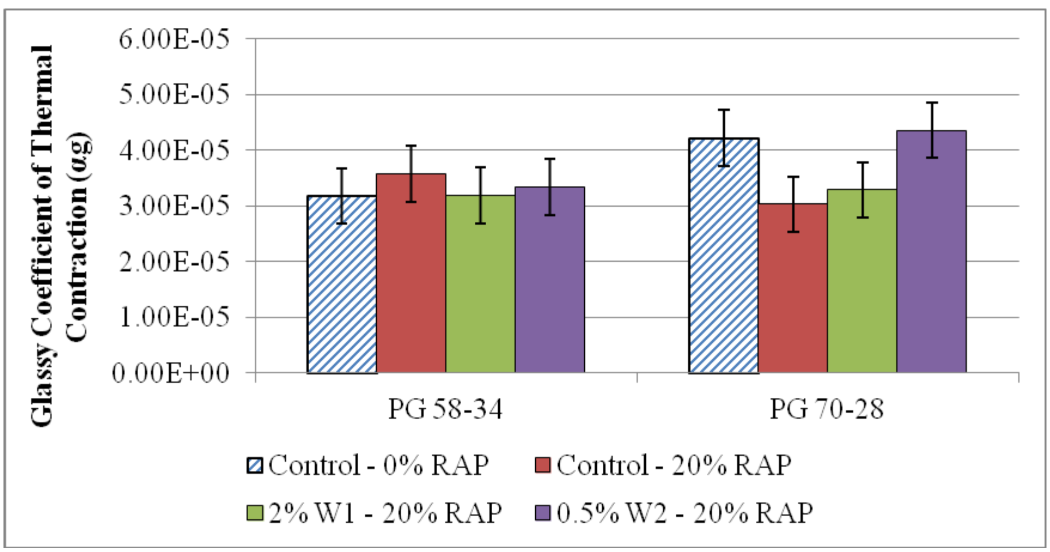
The results presented in Figure 40 demonstrate marginal sensitivity between mixes and inconsistent trends in the effects of experimental factors on the T_g parameter. The lack of sensitivity is shown by the presence of only two mixes for the PG 58-34 binder and one mix for the PG 70-28 with values of T_g statistically different than the control (0% RAP) mix. In both instances the addition of RAP generally decreases the mixture glass transition temperature, possibly indicating improved performance. Between binders trends regarding the effects of WMA and RAP are generally inconsistent. Specifically, the W2 additive with 20 percent RAP is the only combination that demonstrates a consistent increase in mixture $T_{g,}$ between binders, conversely differing trends are observed between binder grades for the effects of both the effect of RAP only and the effects of RAP + W1.

Test data for the liquid and glassy coefficients of thermal contraction are presented in Figure 41. The results presented in Figure 41 indicate that both the liquid and glassy coefficients of thermal contraction are insensitive to mixture type for most of the combinations evaluated in this study. As previously stated mixture volume change with temperature is dependent on both aggregate structure and asphalt binder properties. Given that the same aggregate gradation was used for all combinations and the relative proportions by volume of aggregate (85%) and asphalt binder (15%)

in a mixture, the results imply that the changes in binder properties due to the use of RAP and WMA additives are insufficient to overcome the similarities in mixture performance due to use of the same gradation. This observation is based on the assumption that the use of the same gradation implies that all mixes have a similar aggregate structure at 4 percent air voids.



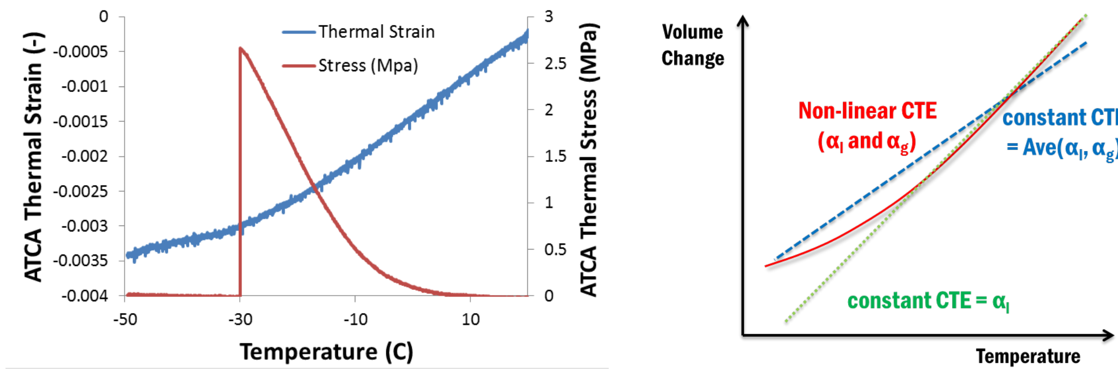
(a)



(b)

Figure 41. Variation in Mixture (a) Liquid Coefficient of Thermal Contraction (α_L) and (b) Glassy Coefficient of Thermal Contraction (α_G) due to Presence of RAP and WMA Additives for PG 58-34 and PG 70-28 Binders.

Initial findings presented in the interim report recommended measurement of mixture fracture strength and temperature based on the insensitivity to changes in materials types observed for mixture thermo-volumetric properties. The schematic of the relationship between mixture thermo-volumetric and fracture properties is presented in Figure 42.

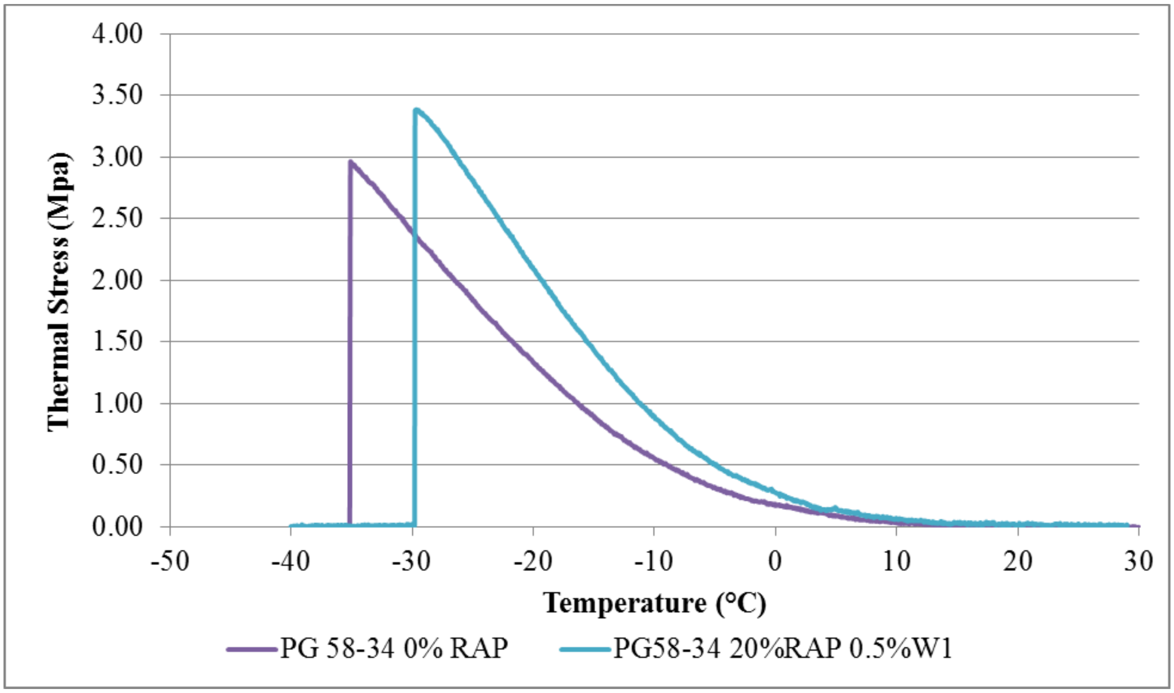


(a) **(b)**

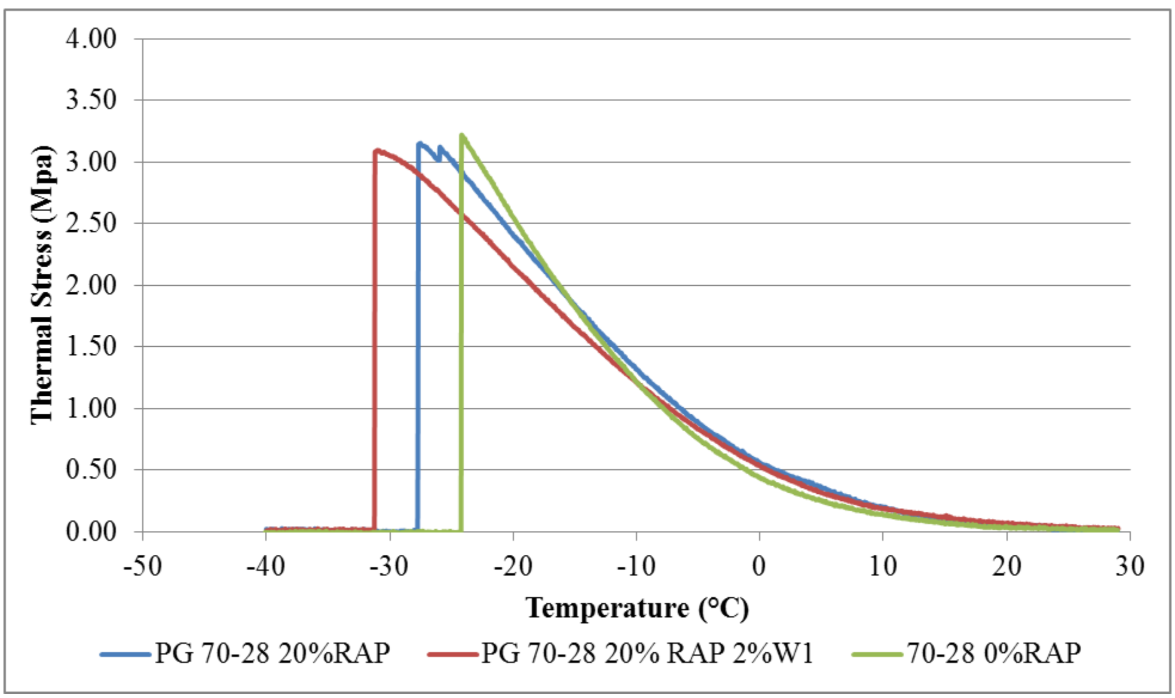
Figure 42. Relationship between Thermal Stress and Strain (a), Effect of Assuming a Constant Coefficient of Thermal Contraction on Predicted Volume Change (b)

As shown in Figure 42 fracture occurs within the glass transition region, indicated by a change in slope of the temperature versus thermal strain relationship. In application to design the potential value introduced by considering the bi-linear relationship between mixture volume change (thermal strain) and temperature as opposed to assuming constant values of coefficient of thermal contraction based on α_l or the average of α_g and α_l is demonstrated in Figure 42b. Specifically, assuming a constant coefficient of thermal contraction will result in an over-prediction or under-prediction of thermal stresses on the order of 25 percent *(21)*.

The original experiment was developed based on the assumption that the presence of WMA additives or changing binder grade would significantly influence thermo-volumetric properties and thus could be used as a discriminating test to evaluate the performance implications of using RAP in conjunction with WMA. Given the results published in the interim report it was deemed necessary to expand this concept to evaluation of mixture fracture resistance through restrained testing of available beams. The thermal stress versus temperature relationships for the beams tested are provided in Figure 43.



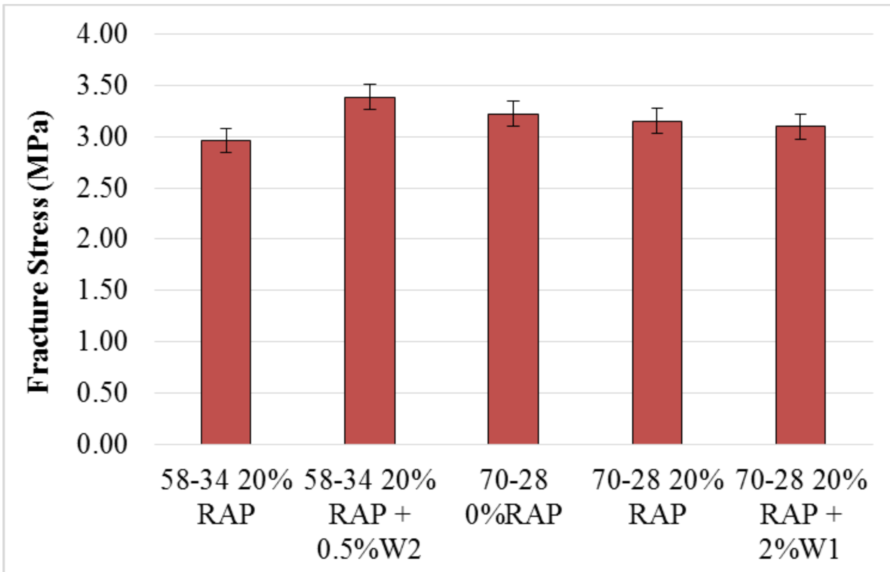
(a)



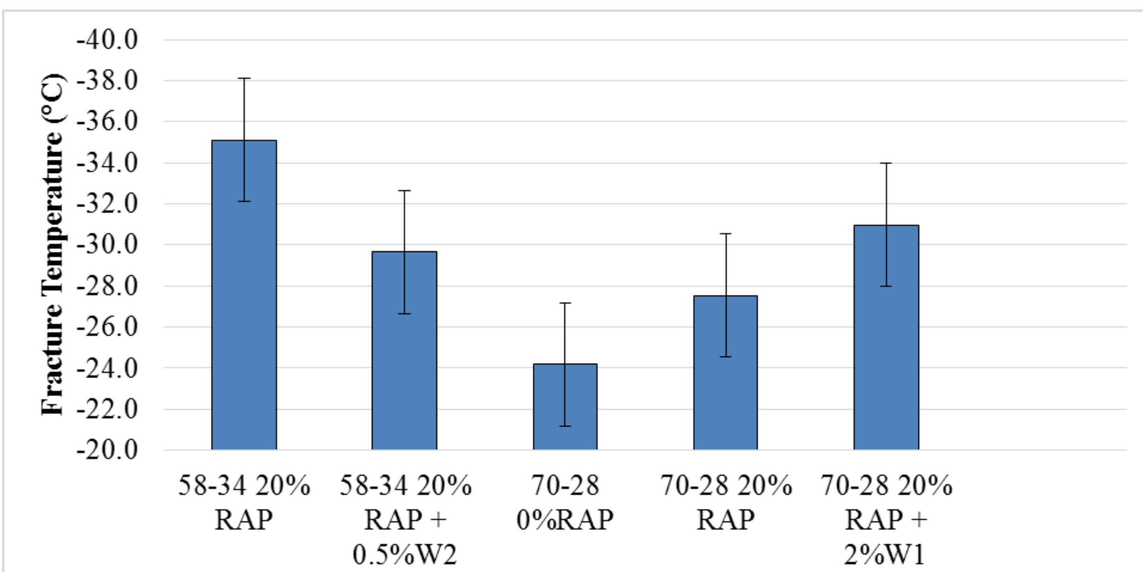
(b)

Figure 43. Thermal Stress vs. Temperature Relationship for PG 58-34 (a) and PG 70-28 (b) mixes

The outputs of the restrained fracture testing are the fracture temperature and stress at fracture. These parameters are summarized in Figure 44. Due to the limited amount of beams available for re-testing the error bars represent the 95% confidence interval based on the laboratory compacted beam results from field project #2. As shown by the error bars, the variation in fracture stress and fracture temperature were approximately 0.12 MPa and 3°C respectively.



(a)



(b)

Figure 44. Summary of Fracture Stress (a) and Fracture Temperature (b) Results for Beams Available after Phase I Study.

As demonstrated in Figure 44a, little variation in fracture stress was observed due to changing binder grade, the addition of RAP, or WMA additives as all values were within approximately 0.5 MPa, indicating that fracture stress was not sensitive to the factors varied in the study. A variation of approximately 10 °C was observed for fracture temperature with the mixture prepared with 100 percent virgin PG 70-28 binder resulting in the highest fracture temperature. Furthermore, fracture temperature was improved marginally due to the addition of both RAP and WMA additive #1. While efforts were made to maintain similar gradations between the control mixes and those containing RAP, there is potential that both the aggregate shape and angularity were different between mixes, resulting in different aggregate orientation achieved after compaction. In combination thermo-volumetric and fracture measurements indicate that for this particular mix design the less aggregate packing was achieved for the PG 70-28 mix prepared with 100 percent virgin binder resulting in a more rapid rate of volume change in the glassy region (high glassy coefficient of thermal contraction) and a corresponding decrease in fracture temperature relative to the mixes prepared with RAP. Mixture fracture testing was conducted after the experiment, limiting the data set available. Given these limitations additional testing is needed to further evaluate these concepts

Focusing on the mixes prepared with RAP, trends are consistent with expectations regarding the effects of binder grade as the PG 58-34 mix exhibited a fracture temperature approximately 6 °C lower than that of the PG 70-28 mix. Varying effects of WMA additives #1 and #2 were observed, in both cases the WMA additive effect on fracture temperature was within the experimental error observed for the test. Furthermore, the values of fracture temperature observed are consistent with the base binder grades selected indicating that the 24 percent binder replacement used for this portion of the study did not result in significant deviations from the base binder grade selected. It is expected that this finding is specific to the properties of the RAP (i.e. age and proportion) and may not hold if RAS is used alone or in combination with RAP.

3.4.4 Summary of Findings and Conclusions

The objective of this study was to assess the feasibility of incorporating the mixture thermo-volumetric and fracture properties measured by the Asphalt Thermal Cracking Analyzer test into mix design and/or quality control testing protocols to mitigate the risk of thermal cracking in WMA mixes that use high RAP contents. The primary finding of this study was the glass transition temperature and the coefficients of thermal contraction do not show sufficient sensitivity to be used as measures of resistance to low temperature cracking for mixture design and acceptance. Instead it is necessary to include both development of thermal strain in an unrestrained sample and thermal stress build up in a restrained sample to obtain a complete evaluation of thermal cracking performance. The draft specification with performance tests was revised to include parameters from both unstrained and restrained testing using the Asphalt Thermal Cracking Analyzer.

Chapter 4 Draft Specifications and Field Validation Plan

4.1 Draft Specifications

Based on comments received on the initial straw-man specification presented to the TOC in Task 3 and the findings of the laboratory experiments, two versions of the draft specification were prepared. Appendix B presents the first version titled, "*WHRP Project 0092-12-02 Draft Specification With Performance Tests*." This version of the draft specification includes the use of mixture performance tests for rutting resistance and low temperature cracking resistance during both design and production. Additionally, it provides the producer the flexibility to select appropriate virgin and recycled binders, production temperatures, and warm mix processes or additives such that the specified performance criteria are met. Appendix C presents the second version titled, "*WHRP Project 0092-12-02 Draft Specification Without Performance Tests.*" This version of the draft specification includes flow number testing for rutting resistance during design only. It uses the recycled binder replacement criteria developed in WHRP Project 0092-10-06 to control the low temperature cracking resistance of the mixture (*3*). Table 15 summarizes how the two draft specification differ from Section 460 of the current WisDOT specifications.

Table 15. Summary of Draft Specification Changes.

Section	Title	¶	With performance test	Without performance test
460.1	Description	1	Reworded to provide general definition of HMA that includes approved WMA processes	Reworded to provide general definition of HMA that includes approved WMA processes
460.2	Materials	NA	None	None
460.2.1	Materials General	1	Added reference to warm mix additive	Added reference to warm mix additive
460.2.2	Materials Aggregates	NA	None	None
460.2.2.1	Materials Aggregates General	1	None	None
460.2.2.1	Materials Aggregates General	2	None	None
460.2.2.2	Materials Aggregates Freeze-Thaw Soundness	1	None	None
460.2.2.3	Materials Aggregates Aggregate Gradation Master Range	1	None	None
460.2.3	Asphaltic Binders	1	Changed to remove reference to designated binder grade and instead reference flow number and thermal coefficient testing.	Changed recovered binder to recycled binder.
460.2.4	Additives	NA	None	None
460.2.4.1	Hydrated Lime Antistripping Agent	1	None	None
460.2.4.3	Liquid Antistripping Agent	1	None	None
460.2.4.3	Stone Matrix Asphalt Stabilizer	1	None	None
460.2.4.4	Warm Mix Asphalt Additive or Process	1	Section added to department approval of WMA additives or processes	Section added to department approval of WMA additives or processes
460.2.5	Recycled Asphaltic Materials	1	None	None
460.2.5	Recycled Asphaltic Materials	2	Modify to place an upper limit on recycled binder in mixtures. Delete the binder replacement table.	Modified section to replace binder replacement table with binder replacement recommendations developed in WHRP Project 0092-10-06. No change in virgin binder required when complying with binder replacement table. Numbered the new table as Table 460-2.

Table 15. Summary of Draft Specification Changes Continued.

Section	Title	¶	With performance test	Without performance test
460.2.5	Recycled Asphaltic Materials	3	Not used	Added to address binder replacement exceeding binder replacement table. Requires blending charts during design and recovered binder grading during production when binder replacement limits are exceeded.
460.2.6	Recovered Asphaltic Binders	NA	Rename Recycled Asphaltic Binders	Rename Recycled Asphaltic Binders
460.2.6	Recovered Asphaltic Binders	1	Reword to use recycled asphaltic binder and to address change in virgin binder added.	Reword to use recycled asphaltic binder and to address change in virgin binder added.
460.2.6	Recovered Asphaltic Binders	2	Deleted	Deleted
460.2.7	HMA Mixture Design	NA	None	None
460.2.7	HMA Mixture Design	1	Modified Table 460-2 to include: (1) compactability, (2) flow number (3) Asphalt Thermal Cracking Analyzer, and (4) reheat correction factor reporting.	Modified Table 460-2 to include: (1) compactability, (2) flow number, and (3) reheat correction factor reporting. Renumbered as Table 460-3
460.2.7	HMA Mixture Design	2	Added Table 460-3 to provide minimum for various processes.	Added Table 460-4 to provide minimum for various processes.
460.2.8	Quality Management Program	NA	None	None
460.8.2.1	General	1	None	None
460.8.2.1	General	2	None	None
460.8.2.1	General	3	None	None
460.2.8.2	Contractor Testing	NA	None	None
460.2.8.2.1	Required Quality Control Program	NA	None	None
460.2.8.2.1.1	Personnel Requirements	1	None	None
460.2.8.2.1.1	Personnel Requirements	1	None	None
460.2.8.2.1.1	Personnel Requirements	3	None	None
460.2.8.2.1.1	Personnel Requirements	4	None	None
460.2.8.2.1.2	Laboratory Requirements	NA	None	None
460.2.8.2.1.2	Laboratory Requirements	1	None	None

Table 15. Summary of Draft Specification Changes Continued.

Section	Title	¶	With performance test	Without performance test
460.2.8.2.1.3	Required Sampling and Testing	NA	None	None
460.2.8.2.1.3.1	Contracts with 5000 Tons of Mixture or Greater	1	Modified to allow off-site flow number and glass transition temperature testing	Modified to allow offsite grading of recovered binder
460.2.8.2.1.3.1	Contracts with 5000 Tons of Mixture or Greater	2	Modified to require immediate testing of QC samples.	Modified to require immediate testing of QC samples.
460.2.8.2.1.3.1	Contracts with 5000 Tons of Mixture or Greater	3	None	None
460.2.8.2.1.3.1	Contracts with 5000 Tons of Mixture or Greater	4	Modified to add testing of asphalt content and gradation of each recycled material in QC testing	Modified to add testing of asphalt content and gradation of each recycled material in QC testing
460.2.8.2.1.3.1	Contracts with 5000 Tons of Mixture or Greater	5	None	None
460.2.8.2.1.3.1	Contracts with 5000 Tons of Mixture or Greater	6	None	None
460.2.8.2.1.3.1	Contracts with 5000 Tons of Mixture or Greater	7	Added to require flow number and glass transition temperature testing at the rate of 1 test per 10,000 tons.	Added to require recovered binder testing on mixture that exceed the binder replacement in the new Table 460-2 at the rate of 1 test per 10,000 tons.
460.2.8.2.1.3.2	Contracts with Less Than 5000 Tons of Mixture	1	Modified to require one flow number test, one glass transition test, and one field tensile strength ratio test	Modified to require one field tensile strength ratio test and one recovered binder test.
460.2.8.2.1.3.3	Contracts with Less that 500 Tons of Mixture	1	None	
460.2.8.2.1.3.3	Contracts with Less that 500 Tons of Mixture	2	None	
460.2.8.2.1.3.4	Temporary Pavements	1	None	
460.2.8.2.1.4	Documentation	NA	None	
460.2.8.2.1.4.1	Records	1	None	
460.2.8.2.1.4.1	Records	2	None	
460.2.8.2.1.4.2	Control Charts	1	Modified to include plots of binder replacement.	Modified to include plots of binder replacement.

Table 15. Summary of Draft Specification Changes Continued.

Section	Title	¶	With performance test	Without performance test
460.2.8.2.1.4.2	Control Charts	2	None	None
460.2.8.2.1.5	Control Limits	1	Modified to include limits for binder replacement.	Modified to include limits for binder replacement.
460.2.8.2.1.6	Job Mix Formula Adjustment	1	None	None
460.2.8.2.1.6	Job Mix Formula Adjustment	2	None	None
460.2.8.2.1.6	Job Mix Formula Adjustment	3	None	None
460.2.8.2.1.7	Corrective Action	1	None	None
460.2.8.2.1.7	Corrective Action	2	None	None
460.2.8.2.1.7	Corrective Action	3	None	None
460.2.8.2.1.7	Corrective Action	4	None	None
460.2.8.2.1.7	Corrective Action	5	None	None
460.2.8.2.1.7	Corrective Action	6	Add pay factors for binder replacement. Pay adjustment for binder replacement waived if flow number and glass transition temperature testing provide acceptable properties.	Add pay factors for binder replacement. Pay adjustment for binder replacement waived if recovered binder grading indicates the binder meets the binder grade specified in the contract.
460.2.8.2.1.7	Corrective Action	7	None	None
460.2.8.2.1.7	Corrective Action	8	None	None
460.2.8.2.1.7	Corrective Action	9	None	None
460.2.8.2.2	Optional Contractor Assurance	NA	None	None
460.2.8.2.2.1	General	1	None	None
460.2.8.2.2.2	Personnel Requirements	1	None	None
460.2.8.2.2.3	Laboratory Requirements	1	None	None
460.2.8.2.2.4	Testing	1	None	None
460.2.8.2.2.4	Testing	2	Modified to include reheat factors in air void calculation and to add asphalt content, binder replacement, flow number, and glass transition testing.	Modified to include reheat factors in air void calculation and to add asphalt content, binder replacement, and if the binder replacement exceeds Table 460-2, recovered binder grading.

Table 15. Summary of Draft Specification Changes Continued.

Section	Title	¶	With performance test	Without performance test
460.2.8.2.2.4	Testing	3	None	None
460.2.8.2.2.4	Testing	4	None	None
460.2.8.2.2.5	Documentation	1	None	None
460.2.8.2.2.6	Allowable Differences	1	Modified to include asphalt content, binder replacement, coating, flow number, and glass transition limits.	Modified to include limits for asphalt content, binder replacement and recovered binder grading if required.
460.2.8.3	Department Testing	NA	None	None
460.2.8.3.1	Quality Verification Program	NA	None	None
460.2.8.3.1.1	General	1	None	None
460.2.8.3.1.2	Personnel Requirements	1	None	None
460.2.8.3.1.2	Personnel Requirements	2	None	None
460.2.8.3.1.2	Personnel Requirements	3	None	None
460.2.8.3.1.2	Personnel Requirements	4	None	None
460.2.8.3.1.3	Laboratory Requirements	1	None	None
460.2.8.3.1.4	Department Verification Testing Requirements	1	None	None
460.2.8.3.1.4	Department Verification Testing Requirements	2	None	None
460.2.8.3.1.4	Department Verification Testing Requirements	3	Modified to include reheat factors in air void calculation, flow number, and glass transition testing	Modified to include reheat factors in air void calculation and recovered binder grading if the binder replacement exceeds the limits in Table 460-2.
460.2.8.3.1.4	Department Verification Testing Requirements	4	None	None
460.2.8.3.1.5	Documentation	1	None	None
460.2.8.3.1.6	Acceptable Verification Parameters	1	Modified to include flow number, and glass transition limits	Modified to include recovered binder grading if binder replacement exceeds the limits in Table 460-2

Table 15. Summary of Draft Specification Changes Continued.

Section	Title	¶	With performance test	Without performance test
460.2.8.3.1.6	Acceptable Verification Parameters	2	None	None
460.2.8.3.1.6	Acceptable Verification Parameters	3	None	None
460.2.8.3.1.7	Dispute Resolution	1	None	None
460.2.8.3.1.7	Dispute Resolution	2	None	None
460.2.8.3.1.7	Dispute Resolution	3	None	None
460.2.8.3.1.8	Corrective Action	1	None	None
460.2.8.3.1.8	Corrective Action	2	None	None
460.2.8.3.2	Independent Assurance Testing	1	None	None
460.3	Construction	NA	None	None
460.3.1	General	1	None	None
460.3.2	Thickness	1	None	None
460.3.3	HMA Pavement Density Maximum Density Method	NA	None	None
460.3.3.1	Minimum Required Density	1	None	None
460.3.3.2	Pavement Density Determination	1	None	None
460.3.3.2	Pavement Density Determination	2	None	None
460.3.3.2	Pavement Density Determination	3	None	None
460.3.3.2	Pavement Density Determination	4	None	None
460.3.3.2	Pavement Density Determination	5	None	None
460.3.3.3	Waiving Density Testing	1	None	None
460.3.3.3	Waiving Density Testing	2	None	None
460.3.3.3	Waiving Density Testing	3	None	None
460.4	Measurement	1	None	None
460.5	Payment	NA	None	None
460.5.1	General	1	None	None
460.5.2	HMA Pavement	NA	None	None
460.5.2.1	General	1	None	None

Table 15. Summary of Draft Specification Changes Continued.

Section	Title	¶	With performance test	Without performance test
460.5.2.1	General	2	Modified to include WMA additive or process.	Modified to include WMA additive or process.
460.5.2.1	General	3	Modified to include WMA additive or process.	Modified to include WMA additive or process.
460.5.2.1	General	4	None	None
460.5.2.1	General	5	None	None
460.5.2.1	General	6	None	None
460.5.2.1	General	7	None	None
460.5.2.2	Disincentive for HMA Pavement Density	1	None	None
460.5.2.2	Disincentive for HMA Pavement Density	2	None	None
460.5.2.3	Incentive for HMA Pavement Density	1	None	None
460.5.2.3	Incentive for HMA Pavement Density	2	None	None
460.5.2.3	Incentive for HMA Pavement Density	3	None	None

4.2 Field Sampling Plan

The field sampling plan was developed to collect the data required to validate both versions of the draft specification. The field sampling plan included three sections: (1) mix design sampling and testing, (2) production sampling and testing, and (3) project selections guidelines as discussed below.

4.2.1 Mix Design Sampling and Testing

Table 16 summarizes the sampling and testing required for the mix design phase of each project. This table shows the properties to be measured, the rate of measurement, the responsibility for the data, the test method to be used, and the material requirements. For mix design, the paving contractor performed normal mix design as required by WisDOT. The research team measured design performance test properties, recycled asphalt material properties, virgin binder properties, and reheat correction factors for volumetric analysis of reheated samples during production. The research team's testing required 300 lbs of component materials in the approximate proportion as used in the mix design, plus a 25 lb sample of each recycled asphalt material used in the mixture and one additional quart of the virgin binder used in the mixture.

Table 16. Mix Design Sampling and Testing.

Property	Rate	Responsibility	Methods	Material Requirements
Volumetric Design	1 per project	Contractor/WisDOT	WisDOT 1559	NA
Design Flow Number	1 per project	Research Team	3 replicates per Appendix to AASHTO R35	300 lb of component materials
Design Thermal Coefficient	1 per project	Research Team	2 replicates per UW procedure	
Reheat Correction Factors	1 per project	Research Team	Per WHRP 0092-12-02 procedure	
Recycled Asphalt Material Properties	1 per recycled material	Research Team	Binder content, AASHTO T164	25 lb of each recycled material
			Recycled Binder Properties, Appendix, AASHTO M323 for RAP, WHRP 0092-10-06 for RAS	
Virgin Binder Properties	1 per project	Research Team	AASHTO R35	1 quart

4.2.2 Production Sampling and Testing

Table 17 summarizes the sampling and testing required for the production phase of each project. This table shows the properties to be measured, the rate of measurement, the responsibility for the data, the test method to be used, and the material requirements. During production, normal quality control data collected by the contractor was augmented with performance testing for resistance to rutting, low temperature cracking, and moisture damage; characterization of the binder recovered from the mixture, and volumetric analysis of reheated specimens. The research team also determined the binder content of all recycled asphalt materials used in the mixture on a daily basis. This testing required approximately 325 lbs of mix and 25 lbs of each recycled material daily. A minimum of three days of production were sampled.

Table 17. Production Sampling and Testing.

Property	Rate	Responsibility	Methods	Material Requirements
Asphalt Content	Section 460	Contractor/WisDOT	AASHTO T308	NA
Gradation	Section 460	Contractor/WisDOT	AASHTO T30	NA
Maximum Specific Gravity	Section 460	Contractor/WisDOT	AASHTO T209	NA
Air Voids	Section 460	Contractor/WisDOT	AASHTO T312, T166, T269	NA
VMA	Section 460	Contractor/WisDOT	AASHTO R35	NA
Recycled Binder Content	1 per recycled material per day	Research Team	AASHTO T164	25 lb of each recycled material
Flow Number	1 per day	Research Team	3 replicates per Appendix to AASHTO R35	325 lb of mix
Thermal Coefficient	1 per day	Research Team	2 replicates per UW procedure	
Moisture Sensitivity	1 per day	Research Team	AASHTO T283	
Volumetric Analysis of Reheated Samples	1 per day	Research Team	AASHTO T312, AASHTO T166 with reheat correction	
Recovered Binder Grade	1 per day	Research Team	AASHTO T170, AASHTO R29	

4.2.3 Project Selection Guidelines

The available budget limited the field validation to two projects with three days of sampling and testing per project. This provided four measurements of material properties per project: one for design and three during production. Considering that the objective of the project was to produce a single specification that encompasses asphalt concrete produced as either WMA or HMA with or without recycled asphalt materials, it was recommended that one WMA and one

HMA project be selected. Both of these projects should include recycled asphalt materials with at least 20 percent binder replacement. The mixture to be evaluated should be the surface course to allow future monitoring of the performance of the mixture. The design traffic level and speed, and the underlying pavement conditions should be similar for the two projects. Finally projects close to the University of Wisconsin, Madison should be given priority to costs associated with sampling and transporting materials.

4.2.4 Non-Standard Tests

The proposed field validation plan included a number of AASHTO and WisDOT standard tests and the following non-standard tests:

1. Short-term conditioning,
2. Asphalt Thermal Cracking Analyzer,
3. Reheat correction factors,
4. Recovered RAS binder grading

Detailed procedures for the non-standard tests are presented in Appendix D.

Chapter 5. Field Validation

5.1 Capitol Drive Project

5.1.1 Description

The first project included in the field validation was WisDOT Project 2025-14-70, Capitol Drive, State Highway 190 from Brookfield Road to State Highway 100. The Capitol Drive project was the rehabilitation of approximately 2.7 miles of an urban arterial connecting two Milwaukee suburbs. The section of Capitol Drive included in the project is three lanes in each direction with a 2011 average annual daily traffic volume of 39,800 vehicles. There are several signalized intersections and turn lanes within the project. The existing pavement consisted of an asphalt concrete wearing surface over concrete pavement. The rehabilitation included removing the existing asphalt concrete layer, rubblizing the existing concrete pavement and placing a 4 inch overlay of new asphalt concrete. The overlay consisted of a lower layer of 2.25 in of 19.0 mm mixture with PG 64-22 binder and a surface layer of 1.75 in of 12.5 mm mixture with PG 64-28 binder. Some new turn lanes and extension of existing turn lanes used an asphalt concrete over aggregate base section. The aggregate base in these areas was 12 in thick. The asphalt concrete was 6.25 in thick consisting of two 2.25 in 19.0 mm PG 64-22 lower layers and a 1.75 in 12.5 mm PG 64-28 surface layer. The project included a total of approximately 75,000 tons of asphalt concrete. The surface mixture was sampled for the field validation of the WHRP Project 0092-12-02 draft specifications.

The asphalt mixtures were designed for traffic level E3. Table 18 provides a summary of the design for the 12.5 mm surface; the producer's complete mix design submittal is included in Appendix E. As designed, the mixture included 3 percent RAS and 12 percent RAP, resulting in a design binder replacement of 21.0 percent; 11.5 percent from RAS and 9.5 percent from RAP. Evotherm was added to the mixture as a compaction aid. The target production temperature was 300 °F and the target compaction temperature was 275 °F. Some changes to the aggregate blends were made during production as shown in Table 19. The changes in the recycled material content and target binder content increased the binder replacement to 23.0 percent; 15.7 percent from RAS and 7.3 percent from RAP.

Table 18. Design Properties for Capitol Drive 12.5 mm Mixture.

Property		RAS Mix
Gradation, % passing	Sieve size, mm	
	25	100
	19	100
	12.5	96
	9.5	85
	4.75	64
	2.36	45
	1.18	32
	0.6	20
	0.3	10
	0.15	6
	0.075	4.6
Design Gyrations		75
Total Design Binder content, wt %		5.3
Binder from RAS		0.6
Binder from RAP		0.5
Design Air Voids, vol %		4.0
Design VMA, vol %		14.6
Design VFA, vol %		72.9
Maximum Specific Gravity		2.516
Aggregate Bulk Specific Gravity		2.680
% G_{mm} at N_{ini}		88.3
% G_{mm} at N_{max}		96.9
Tensile Strength Ratio, %		88

Table 19. Capitol Drive 12.5 mm Mixture Blend History.

Date	Binder Content, %	Aggregate Blend, %						G_{sb}
		5/8" Chip	3/8" Chip	MAN Sand	NAT Sand	RAS	RAP	
Design	5.30	16	20	22	27	3	12	2.680
10/9/12	5.15	15	20	21	32	3	9	2.674
10/10/12	5.15	15	20	22	30	4	9	2.674
10/19/12	5.15	14	20	23	30	4	9	2.674
10/20/12	5.15	13	19	25	30	4	9	2.674
10/23/12	5.15	15	19	25	29	4	9	2.674
10/26/12	5.15	13	19	25	30	4	9	2.674
11/13/12	5.15	13	18	25	31	4	9	2.673
12/1/12	5.15	12	18	25	32	4	9	2.673
12/3/12	5.15	12	17	25	33	4	9	2.672
12/5/12	5.15	12	16	26	33	4	9	2.672

5.1.2 Sampling

The surface layer placed on December 4 and December 6, 2012 was sampled for the field validation of the WHRP Project 0092-12-02 draft specifications. These days of paving represented approximately 3,900 tons of asphalt pavement. Sampling was in accordance with the sampling plan given in Table 16 and Table 17 except the sampling of the recycled materials did not coincide with the sampling of the asphalt concrete mixture. Three mixture samples were obtained: Sample 1 on December 4 after 761 tons of production, Sample 2 on December 4 after 2751 tons of production, and Sample 3 on December 6 after 1171 tons of production. Five samples each for the RAS and RAP were collected, but these were not marked with production day or time; therefore, the recycled materials cannot be linked directly to the mix production.

5.1.3 Weather

Weather data during the week that sampling was performed was obtained from the weather station at Timmerman Field which is approximately 3 miles from the State Highway 100 end of the project. Air temperature, precipitation, and wind speed during the week of paving are shown in Figure 45. The shaded areas in Figure 45 are the days that sampling we conducted. The air temperature on the days of paving ranged from 33 to 53 °F with no precipitation and light to moderate breeze.

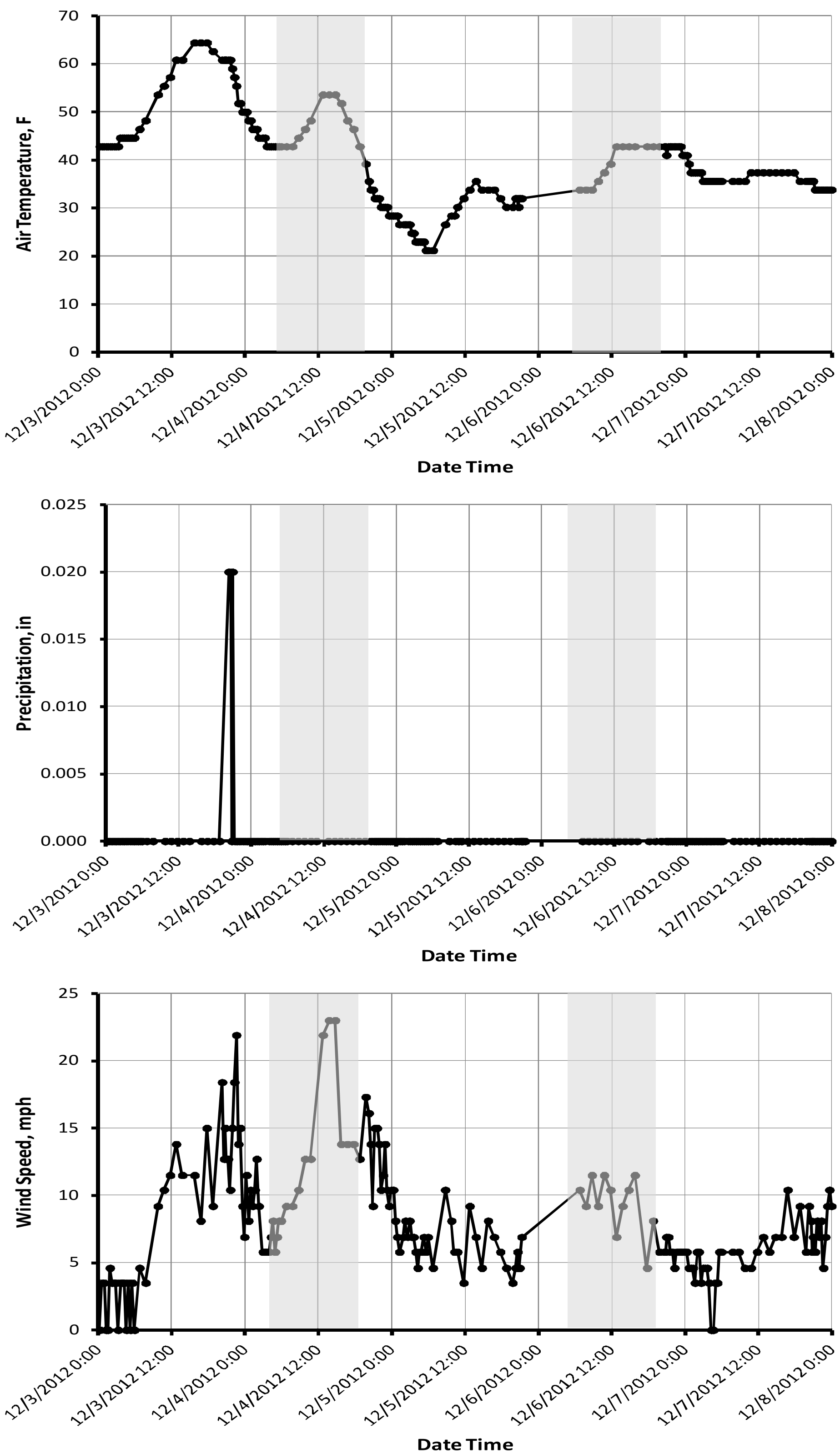


Figure 45. Weather During Week of Capitol Drive Sampling.

5.1.4 Test Results

5.1.4.1 Quality Control

Quality control and WisDOT verification data for the days that the Capitol Drive project was sampled were obtained from the WisDOT Highway Quality Management System. The records did not contain all of the data required by the WisDOT standard specifications. The available data are summarized in Table 20. The available data indicate that the volumetric properties of the mixture were within allowable production tolerances. In-place density measurements of material placed 12/4 and 12/6 indicated lot averages ranging from 93.1 to 93.6 percent. All density measurements were above WisDOT's minimum in-place density requirement of 91.5 percent.

Table 20. Available Capitol Drive Quality Control and Verification Data.

Date	Sample	Type	AC, %	VTM, %	VMA, %	Gradation, % Passing Sieve Size in mm								
						19	12.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
12/4/12	1	QC		3.7										
12/4/12	1+	Ver		3.6	13.3									
12/4/12	2	QC		3.9										
12/4/12	3	QC		3.2										
12/6/12	1	QC		3.3										
12/6/12	2	QC		4.2										
12/6/12	3	QC		4.6										

5.1.4.2 Reheat Correction Factor

The WHRP Project 0092-12-02 draft specifications include the development of a reheat correction factor to account for changes in compactability when reheated samples are used in verification testing. The reheat correction factor is determined during mix design by compacting specimens at the optimum binder content to the design gyration level in the normal manner without reheating, then compacting a second set of specimens to the design gyration level after cooling to room temperature. The difference in the air void content for the two sets of specimens is the reheat correction factor. The procedure is described in detail in Appendix D. Table 21 presents the results of the reheat correction factor determination for the Capitol Drive project. Reheating had no effect on the air void content of the mixture used on this project resulting in a correction factor of zero. Mixtures that are less compactable after reheating because of the transient nature of some WMA additives will have a negative reheat correction factor.

Table 21. Reheat Correction Factors for Capitol Drive 12.5 mm Surface Mixture.

Sample	Reheated?	G_{mb}	G_{mm}	Air Voids, %	Average Air Voids, %	Reheat Correction Factor
1	No	2.440	2.517	3.1	2.7	0.0
2	No	2.456	2.517	2.4		
3	No	2.451	2.517	2.9		
4	No	2.458	2.517	2.3		
5	Yes	2.444	2.517	2.9	2.7	
6	Yes	2.455	2.517	2.5		
7	Yes	2.434	2.517	3.3		
8	Yes	2.444	2.517	2.3		

5.1.4.3 Virgin Binder Properties

Table 22 presents the performance grading properties for the virgin binder used on the Capitol Drive project. The binder grades as a PG 64-28 with a continuous grade of PG 64.7 (17.1) -30.9.

Table 22. Performance Grading for Capitol Drive Virgin Binder.

Condition	Test	Temp, °C	Result
Tank	G*/sinδ, kPa AASHTO T 315	64	1.08
		70	0.54
Rolling Thin Film Residue	Mass Change, % AASHTO T240	163	-0.428
	G*/sinδ, kPa AASHTO T 315	64	2.74
		70	1.40
Pressure Aging Vessel Residue	G*sinδ, kPa AASHTO T 315	16	5730
		19	3930
	Creep Stiffness (MPa)/Slope AASHTO T 313	-24	450 / 0.284
		-18	207 / 0.338
Grade	AASHTO M320	PG 64 – 28	
Continuous Grade		PG 64.7 (17.1) –30.9	

5.1.4.4 Recycled Material Properties

Five samples each for the RAS and RAP were obtained. As discussed previously, the samples were taken at different times between 12/4/12 and 12/6/12, but were not tied to specific production days. The binder content of each sample was measured in accordance with AASHTO T164 to determine the variability in the binder content of the recycled materials. The results are summarized in Table 23. These samples show significant variability in the binder content of the recycled materials. Table 23 also shows binder replacements for the aggregate blend used on 12/4/12 and 12/6/12 and the average binder content of 5.0 percent from the three mixture samples that are discussed in the next section. The production binder replacement is significantly higher than the design due to three factors: (1) lower binder content during production, (2) changes in aggregate blend that increased the RAS content and decreased the RAP content, and (3) differences in the binder content of the recycled materials from the design values. The standard deviation of the binder replacement is quite reasonable at 0.43 percent. The binder replacement for both design and production exceed the limits included in the WHRP Project 0092-12-02 draft specification without performance tests. The limits in the draft specifications were developed in WHRP Project 0092-12-02 with the objective of limiting the change in the low temperature continuous grade of the binder to less than 3 °C (*3*).

Table 23. Binder Content of Capitol Drive Recycled Materials.

Sample	Binder Content, %		Binder Replacement for 5.0 % Total Mix Binder Content, %		
	RAP	RAS	RAP	RAS	Total
1	4.32	25.60	7.8	20.5	28.3
2	4.11	27.08	7.4	21.7	29.1
3	4.15	25.66	7.5	20.5	28.0
4	4.24	26.47	7.6	21.2	28.8
5	4.90	24.80	8.8	19.8	28.6
Average	4.34	25.92	7.8	20.7	28.6
Standard Deviation	0.32	0.88	0.58	0.70	0.43
Design Binder Replacement			9.5	11.5	21.0

One sample of the binder from each recycled material was recovered and graded. The RAP was graded in accordance with the Appendix to AASHTO M323. The RAS was graded using the procedure developed in WHRP Project 0092-10-06 and described in Appendix D (*3*). The virgin binder from the project was used to create the 30/70 blend of recovered RAS and virgin binder that was used to extrapolate the RAS continuous grade properties. The resulting data are presented in Table 24. Per the referenced test methods, the intermediate and low temperature properties for the RAP were determined on Rolling Thin Film Oven Test (RTFOT) conditioned material, while those for the RAS were determined on RTFOT plus pressure aging vessel (PAV) conditioned material.

Table 24. Results of Recovered RAP and RAS Grading.

Property	Test	Temp, °C	RAP	30/70 RAS in PG 64-28
High Recovered	G*/sinδ, kPa AASHTO T 315	82	1.82	1.10
		88	0.88	0.58
High RTFOT	G*/sinδ, kPa AASHTO T 315	82	3.69	2.88
		88	1.74	1.53
Intermediate	G*sinδ, kPa AASHTO T 315	22		5380
		25		3960
		28	5480	
		31	3890	
Low	Creep Stiffness (MPa)/Slope AASHTO T 313	-18		281 / 0.273
		-12	293 / 0.279	142 / 0.307
		-6	145 / 0.332	

Continuous performance grade properties for the RAP and RAS that are needed for blending chart analyses are presented in Table 25. These continuous grade properties are within the range of the RAP and RAS previously tested in WHRP Project 0092-10-06 (*3*).

Table 25. Continuous Performance Grade Properties for Capitol Drive Recycled Materials.

Continuous Grade	RAP	30/70 RAS in PG 64-28	Extrapolated RAS
High	86.1	82.9	125.4
Intermediate	28.8	22.7	35.8
Low	-19.5	-23.2	-2.4

The continuous grading properties of the virgin and recycled materials and the binder replacement values from Table 23 were used in linear blending charts to estimate the change in the grade of the binder in the mixture during production. The results are summarized in Table 26. The low temperature continuous grade of the binder increased 4.4 °C for the design and an average of 6.8 °C for the production samples. The greater increase for the production samples is the result of the aggregate blend changes during production which increased the RAS content and the difference in the binder content of the production RAS compared to that used in the mix design. Based on the blending chart analysis, it is reasonable to expect only small changes in the grade of the blended binder during production as long as the binder replacement is reasonably controlled.

Table 26. Blending Chart Continuous Performance Grades for Capitol Drive Project.

Sample	Blending Chart Continuous Performance Grade, °C		
	High	Intermediate	Low
Design	73.7	20.4	-26.5
Production 1	78.8	21.8	-24.2
Production 2	79.4	22.0	-23.9
Production 3	78.8	21.8	-24.2
Production 4	79.2	21.9	-24.0
Production 5	78.6	21.8	-24.2
Production Average	79.0	21.9	-24.1
Production Standard Deviation	0.34	0.09	0.15

5.1.4.5 Recovered Binder Properties

Binder content and performance graded binder properties were measured on binder recovered from the loose mix samples from the three days of production. The results are summarized in Table 27. These results indicate very consistent asphalt binder content at 5.0 percent and a consistent binder grade of PG 70-22. The high temperature continuous grade ranges from 71.7 to 75.8 °C; the intermediate temperature grade ranges from 21.4 to 22.2 °C, and the low temperature grade ranges from -25.7 to -24.2 °C. The measured high temperature continuous grade is somewhat lower than estimated from the blending charts, averaging 73.4 °C compared to 79.0 °C from the blending chart. The measured intermediate and low temperature grades are within 1 °C of the values estimated from the blending charts. The measured intermediate temperature grade averages 21.7 °C compared to 21.9 °C estimated from the blending charts. The measured low temperature grade averages -25.2 °C compared to -24.1°C from the blending charts. The likely cause of the poorer agreement for the high temperature grades is differences in plant aging of recovered samples compared to RTFOT conditioning for the blending charts. This effect is likely less significant for the intermediate and low temperature grading which includes additional PAV conditioning.

Table 27. Recovered Binder Properties for the Capitol Drive Project.

Test/Condition	Method	Temp, °C	12/4 761 Tons	12/4 2751 Tons	12/6 1171 Tons
Binder Content	AASHTO T164, Method A	NA	4.99	5.04	4.98
As Recovered	G*/sinδ, kPa AASHTO T 315	70	2.70	3.11	4.52
		76	1.29	1.50	2.15
Pressure Aging Vessel Residue	G*sinδ, kPa AASHTO T 315	19	6680	6530	
		22	4790	4700	5080
		25			3790
	Creep Stiffness (MPa)/Slope AASHTO T 313	-18	270 / 0.285	271 / 0.286	287 / 0.273
		-12	139 / 0.325	134 / 0.324	142 / 0.317
Grade	AASHTO M320	NA	70-22	70-22	70-22
Continuous Grade		High	71.7	72.8	75.8
		Intermediate	21.6	21.4	22.2
		Low	-25.7	-25.7	-24.2

Using data from weather station WI 5474, Milwaukee Mount Mary College, and the LTPP low temperature algorithm given in Equation 5 (*22*), the reliability against low temperature cracking ranges from 98.1 percent for the 12/4 samples to 94.8 percent for the 12/6 sample. The 98 percent reliability temperature from LTPPBind 3.1 for this weather station is -25.6 °C.

$$T_{PAV} = -1.56 + 0.75 * T_{AIR} - 0.004 * LAT^2 + 6.26 * \log_{10}(H + 25) - z * (4.4 + 0.52 * S_{AIR}{}^2)^{0.5} \quad (5)$$

Where:

T_{PAV} = pavement temperature for a given reliability, °C

T_{AIR} = low air temperature, °C = -25.6 for WI 5474

LAT = latitude, = 43.07 for WI 5474

H = depth, mm = 0 for surface layers

S_{AIR} = standard deviation of the low air temperature, °C = 3.7 for WI 5474

z = standard normal deviate for desired reliability = 2.055 for 98 % reliability

5.1.4.6 Flow Number

Flow number tests were conducted on test specimens produced from component materials during mix design and test specimens fabricated from the loose mix samples from the two days of production. All test specimens were prepared in accordance with AASHTO PP60 to a target air void content of 7.0 percent except the service conditioning procedure described in Appendix D was used in lieu of short-term conditioning of 4 hours at 135 °C. The specimens were tested in accordance with AASHTO TP79 using the testing conditions recommended in

NCHRP Project 9-33 (*8*); unconfined with a repeated deviatoric stress of 87 psi. The test temperature was 50.5 °C, which is the 50 percent reliability pavement temperature at a depth of 20 mm from LTPPBind 3.1 for weather station WI 5474, Milwaukee Mount Mary College. The flow number test results are summarized in Table 28. Although the coefficient of variation is quite high for the last two sets of samples in Table 28 there was nothing in the test data to indicate errors in the testing. All of the measured data were, therefore, used in the calculation of the average flow number and subsequent analysis of the data.

Table 28. Summary of Flow Number Test Results.

Sample	Air Voids, %	Flow Number	Air Voids, %	Flow Number	Air Voids, %	Flow Number	Average	Coefficient of Variation, %
Design	6.8	106	6.6	81	6.6	102	96	13.9
12/4 @ 761 Tons	6.9	81	6.6	78	6.7	90	83	7.5
12/4 @ 2751 Tons	6.6	90	6.7	271	6.8	228	196	48.2
12/6 @ 1171 Tons	6.8	350	6.6	166	6.6	182	233	43.8

In WHRP Project 0092-09-01 tentative flow number criteria as a function of traffic speed and design traffic level were developed. These tentative criteria recommend a minimum flow number of 90 for intersections with design traffic of 3 million ESAL (*9*). For normal traffic, the recommended minimum flow number is 15 for 3 million ESAL (*9*). As designed, the mixture meets the intersection requirement. Samples from two of the production days exceed the tentative intersection criteria and one is slightly below. All are well above the minimum flow number needed for normal traffic. Figure 46 compares the average flow number and the high temperature continuous grade of the recovered grade of the binder. As shown, the flow number is highly correlated to the continuous high temperature grade of the binder, increasing with increasing high temperature grade.

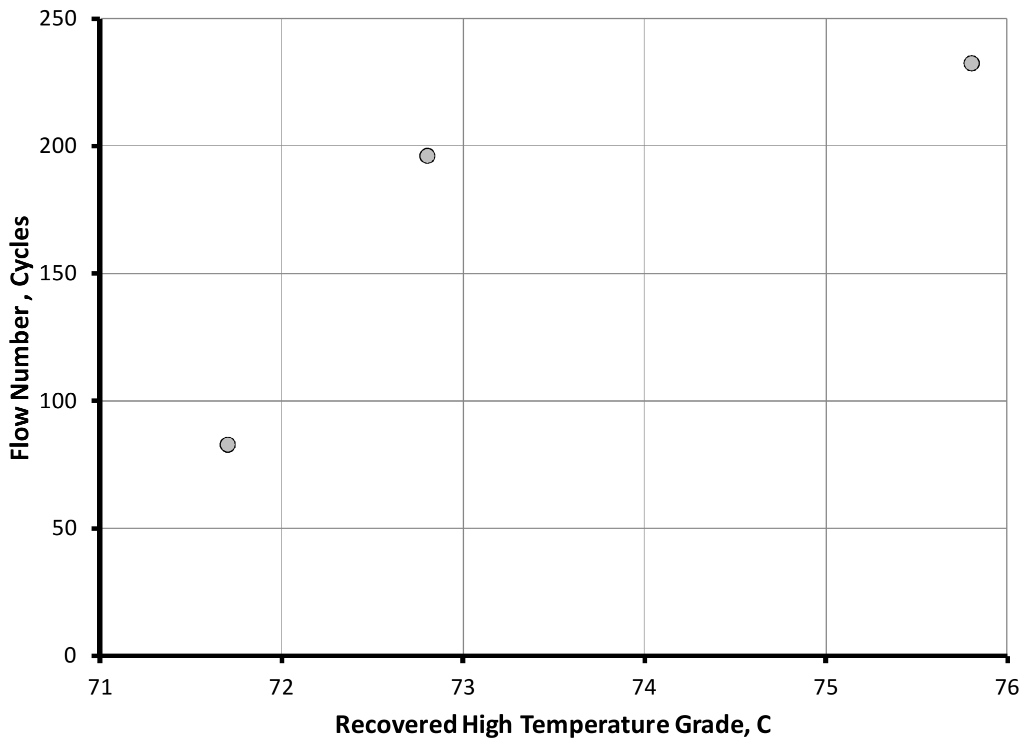


Figure 46. Comparison of Flow Number and Recovered High Temperature Grade.

5.1.4.7 Asphalt Thermal Cracking Analyzer

Unstrained tests in the Asphalt Thermal Cracking Analyzer were conducted on test specimens produced from component materials during mix design and test specimens fabricated from the loose mix samples from the two days of production. All test specimens were prepared in accordance with the procedure described in Appendix D to a target air void content of 4.0 percent after conditioning loose mix per the service condition procedure described in Appendix D. Prior to gluing the air void content of the center portion of the beam was measured. The results are presented in Table 29. The data in Table 29 indicate that the air void content of the beams prepared from the second sample of mix on 12/4/2013 were approximately 2 percent higher relative to other production days.

Thermal strain versus temperature plots for the three production samples are provided in Figure 47. The results presented in Figure 47 indicate that the higher air void content of the beam tested from the second sample from 12/4/2013 resulted in a lower value of accumulated strain across all test temperatures. However, the slopes of the thermal strain versus temperature relationship for all three production days remains similar. The variation in mixture glass transition temperature (T_g) during production is presented in Figure 48. The error bars provided in the figure represent the standard deviation of all six tests multiplied by a factor of two. The average mixture T_g was -18.6°C and the error was ±1.3°C. The higher sample air voids associated with second sample taken on 12/4 resulted in a Mix T_g approximately 1°C higher than samples tested from other production days, verifying the observation that the slopes of the thermal strain versus temperature plots for all three production samples were similar.

Table 29. Summary of Beam Center Air Voids for Samples Prepared for Capitol Drive Project.

Sample	Replicate		Average % Air Voids of Beam	COV
	A	B		
12/4 @ 761 Tons	2.7	2.5	2.60	3.8%
12/4 @ 2751 Tons	4.7	4.7	4.70	0.0%
12/6 @ 1171 Tons	2.8	2.7	2.75	2.6%
Design	2.0	2.0	2.00	0.0%

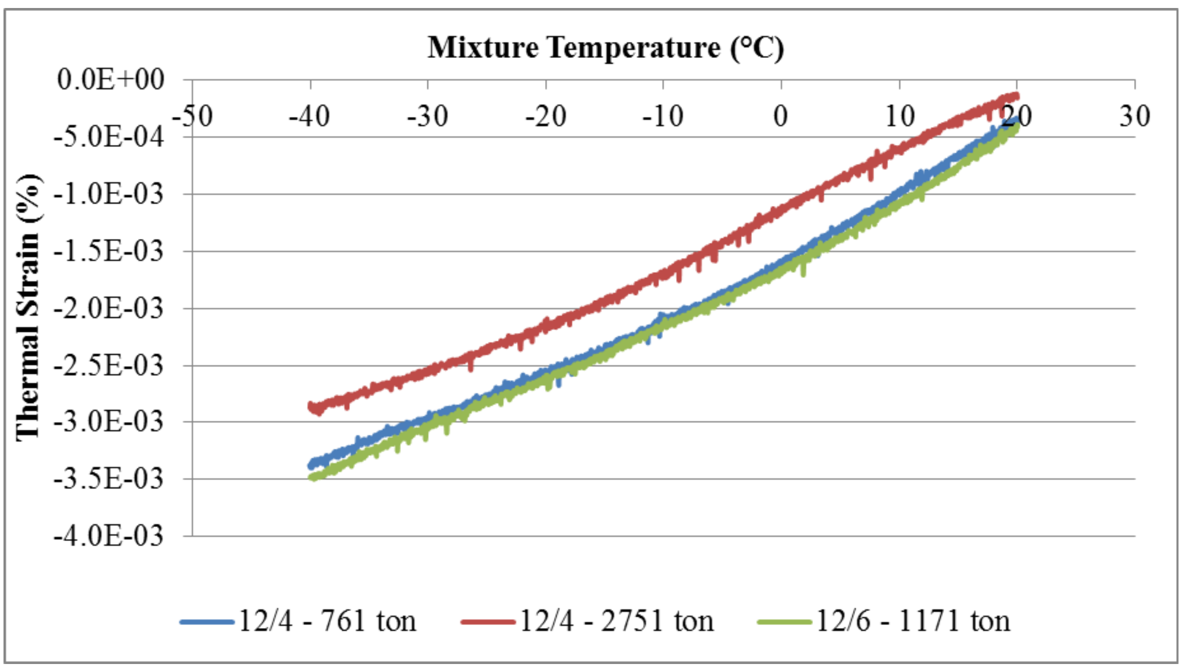


Figure 47. Variation in Thermal Strain vs. Temperature Relationship by Production Day for Capitol Drive Project.

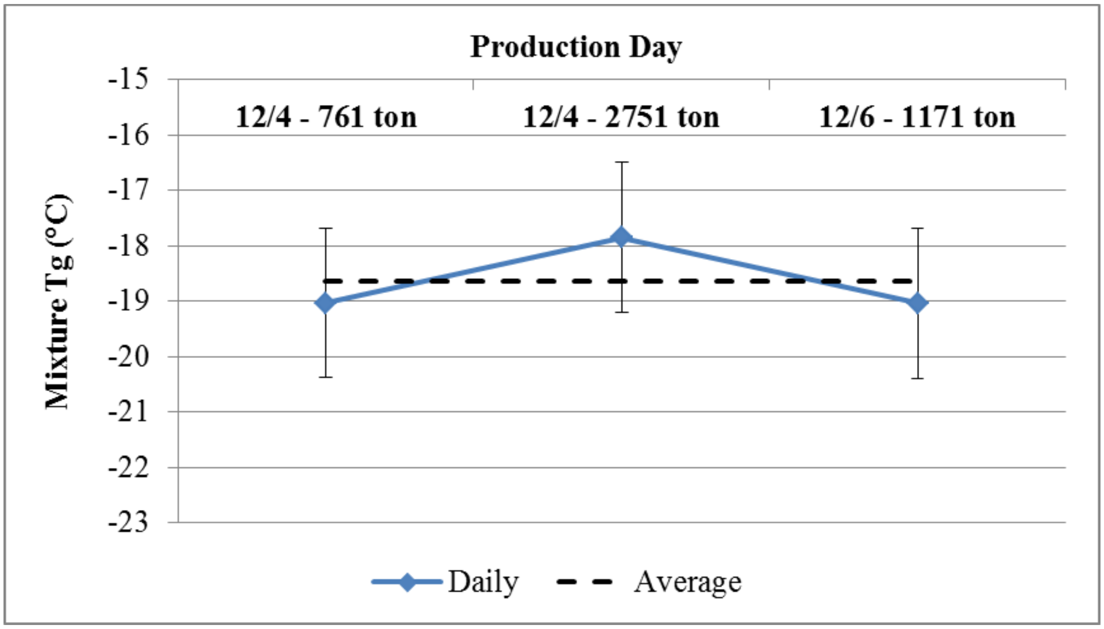


Figure 48. Variation in Mixture Glass Transition Temperature with Production Day and Comparison to Mean Value.

The variation in liquid and glassy coefficients of thermal contraction (α_L and α_G) during production are provided in Figure 49. In presentation of the data a similar convention to the plot of daily variation in mixture T_g is used in which the variation of each parameter is compared to the mean value across all six tests and the error bars represent the standard deviation of all tests multiplied by a factor of two. Average values including experimental error were $5.4 \times 10^{-5} \pm 3 \times 10^{-6}$ and $3.5 \times 10^{-5} \pm 3.3 \times 10^{-6}$ for the α_L and α_G parameters respectively. As demonstrated in Figure 49 variation of both parameters with production day was minimal and near the mean value.

The statistical significance of the observed variation in mixture thermo-volumetric properties with production day was evaluated using one-way analysis of variance at a confidence level of 95 percent. The results summarized in Table 30 indicate that the effect of production sample was found insignificant at the selected level of confidence for all thermo-volumetric properties obtained from the test method. However, both the mixture T_g and α_G parameter would be found statistically significant if the confidence level was lowered to 90%. Given the maximum variation in mixture T_g during of approximately 1 °C and consistent coefficient of contraction measurements the effect of production day is deemed not practically significant.

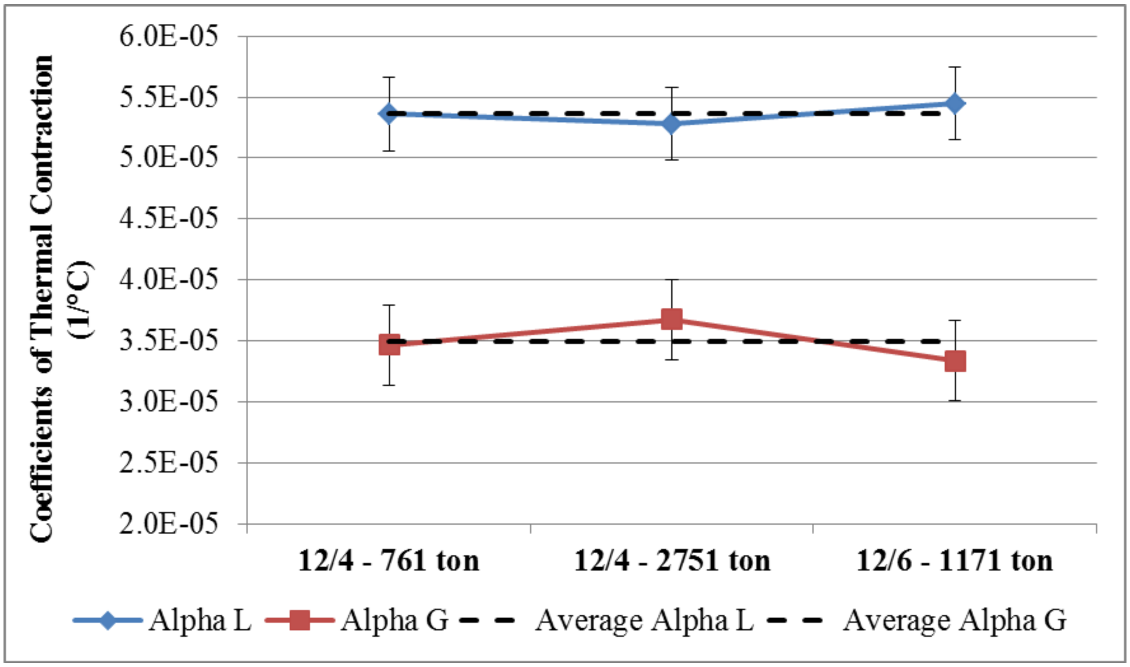


Figure 49. Variation in Mixture Liquid (α_L) and Glassy (α_G) Coefficients of Thermal Contraction with Production Day and Comparison to Mean Value.

Table 30. Summary of One-Way Analysis of Variance to Evaluate the Effect of Production Day on Mixture Thermo-Volumetric Properties.

Factor	Mixture T_g		Liquid Coefficient of Thermal Contraction (α_L)		Glassy Coefficient of Thermal Contraction (α_G)	
Production Sample	**F**	**p-value**	**F**	**p-value**	**F**	**p-value**
	6.87	0.076	0.53	0.635	8.40	0.059

Figure 50 and Figure 51 compare mixture glass transition temperatures and coefficients of thermal contraction between production and mix design samples. The mix design samples were produced using the mix design blend and design binder content which differed from that used in the production samples. The differences are summarized in Table 31. Also in preparing the mix design samples, 2 hours of conditioning at the compaction temperature of 135 °C was used to simulate production aging prior to service conditioning at 100 °C. Only the service conditioning was applied to the production samples.

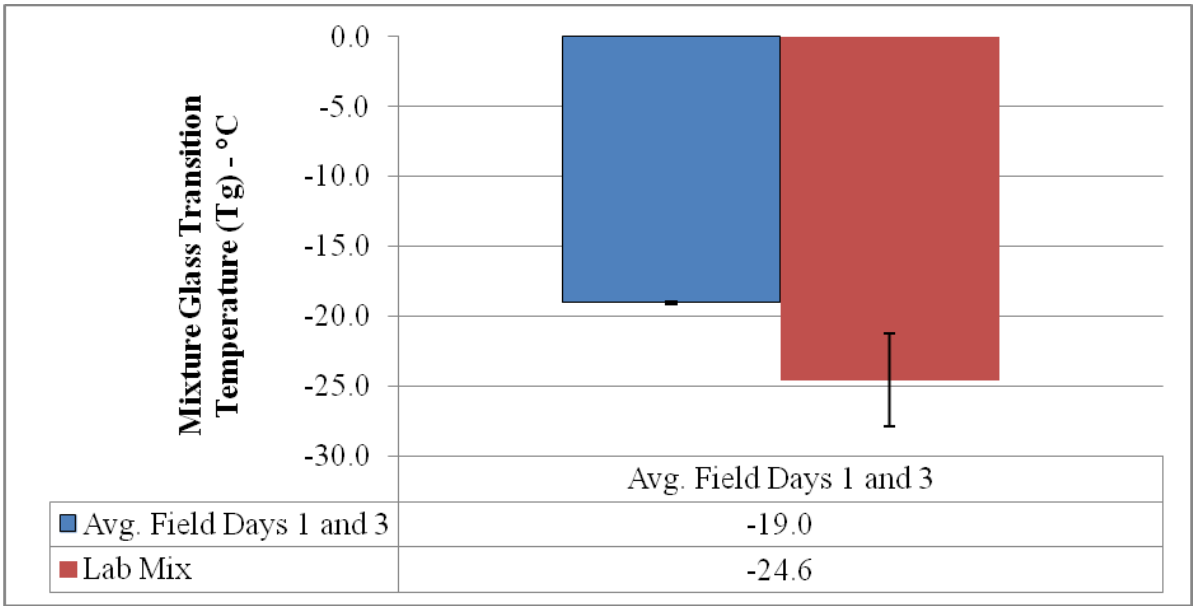


Figure 50. Comparison of Mixture T_g Field Produced (Days 1 and 3) and Laboratory Produced Mixtures.

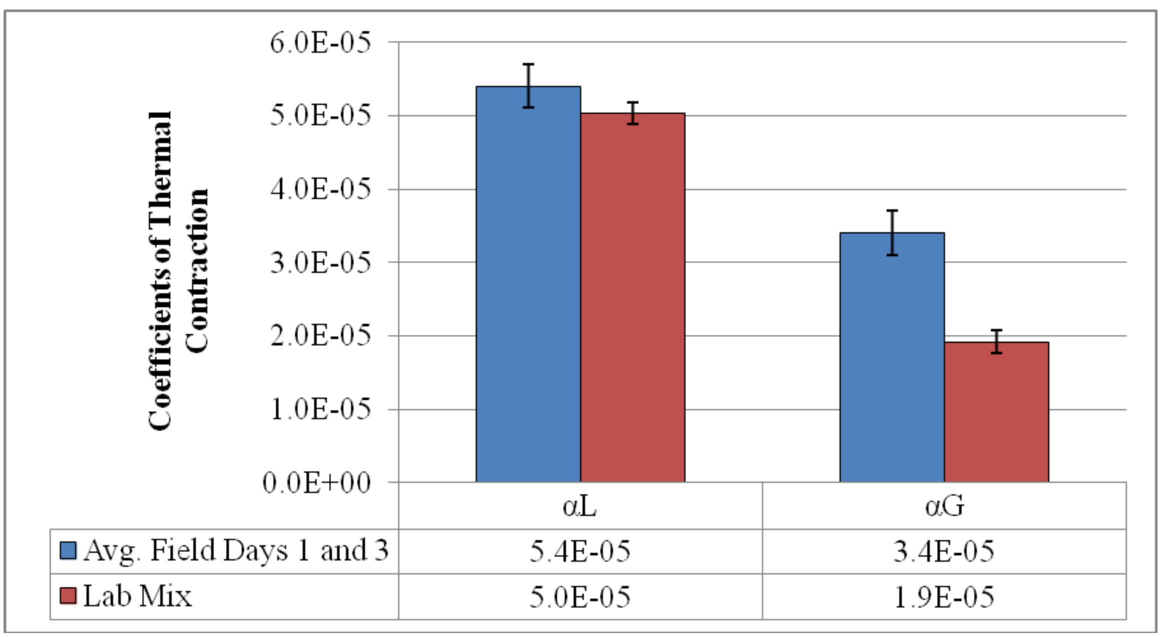


Figure 51. Comparison of Liquid and Glassy Coefficients of Thermal Contraction (α_G and α_L) of Field Produced (Days 1 and 3) and Laboratory Produced Mixtures.

Table 31. Differences Between Design and Production Sample Composition.

Component	Design	Production
Coarse aggregate, % of aggregate	26	28
Manufactured sand, % of aggregate	22	26
Natural sand, % of aggregate	27	33
RAP, % of aggregate	12	9
RAS, % of aggregate	3	4
Binder Content, % of total mixture	5.3	5.0
RAP Binder Replacement	9.8	7.8
RAS Binder Replacement	14.7	20.7

The results in Figure 50 and Figure 51 show a significant difference between the mix design and production samples. The glass transition temperature is 6 °C higher for the production samples compared to the design samples. Both the liquid and glassy thermal coefficients of contraction are higher for the production samples compared to the mix design. Two sample t-testing was conducted to evaluate the significances of the differences shown in Figure 50 and Figure 51. In conducting the t-test the null hypothesis tested was defined as the difference in means between the mix design and field produced mixtures is equal to zero. The test was conducted at a confidence level of 95 percent; therefore, p-values less than 0.05 indicate that the null hypothesis is rejected and that the test results are statistically different. This statistical analysis is presented in Table 32 and confirms that the differences between mix design and production samples are significant. Since multiple factors were changed between design and production (aggregate blend, RAP and RAS binder replacement, field versus lab mixing, and field aging versus lab conditioning) the factor or factors affecting the thermo-volumetric properties cannot be identified.

Table 32. Results of Two Sample t-test to Compare the Effects of Blend Changes on Mixture Thermo-volumetric Properties.

<table>
<tr><th rowspan="2">Thermo-Volumetric Parameter</th><th rowspan="2">Condition</th><th colspan="3">Basic Statistics</th><th rowspan="2">t-Value</th><th rowspan="2">p-value</th></tr>
<tr><th>N</th><th>Mean</th><th>Std Dev.</th></tr>
<tr><td rowspan="2">Mixture T_G</td><td>Field</td><td>4</td><td>-19.0</td><td>0.04</td><td rowspan="2">7.70</td><td rowspan="2">0.002</td></tr>
<tr><td>Lab</td><td>2</td><td>-24.6</td><td>1.66</td></tr>
<tr><td rowspan="2">Liquid Coefficient of Thermal Contraction (α_L)</td><td>Field</td><td>4</td><td>5.4E-5</td><td>1.2E-6</td><td rowspan="2">3.27</td><td rowspan="2">0.031</td></tr>
<tr><td>Lab</td><td>2</td><td>5.0E-5</td><td>1.6E-6</td></tr>
<tr><td rowspan="2">Glassy Coefficient of Thermal Contraction (α_G)</td><td>Field</td><td>4</td><td>3.4E-5</td><td>9.2E-7</td><td rowspan="2">20.41</td><td rowspan="2">>0.0001</td></tr>
<tr><td>Lab</td><td>2</td><td>1.9E-5</td><td>5.2E-7</td></tr>
</table>

The beams were re-tested for evaluation of mixture fracture resistance to assess of how mixture fracture resistance varied with production day. The thermal stress versus temperature plots for the three production days are presented in Figure 52.

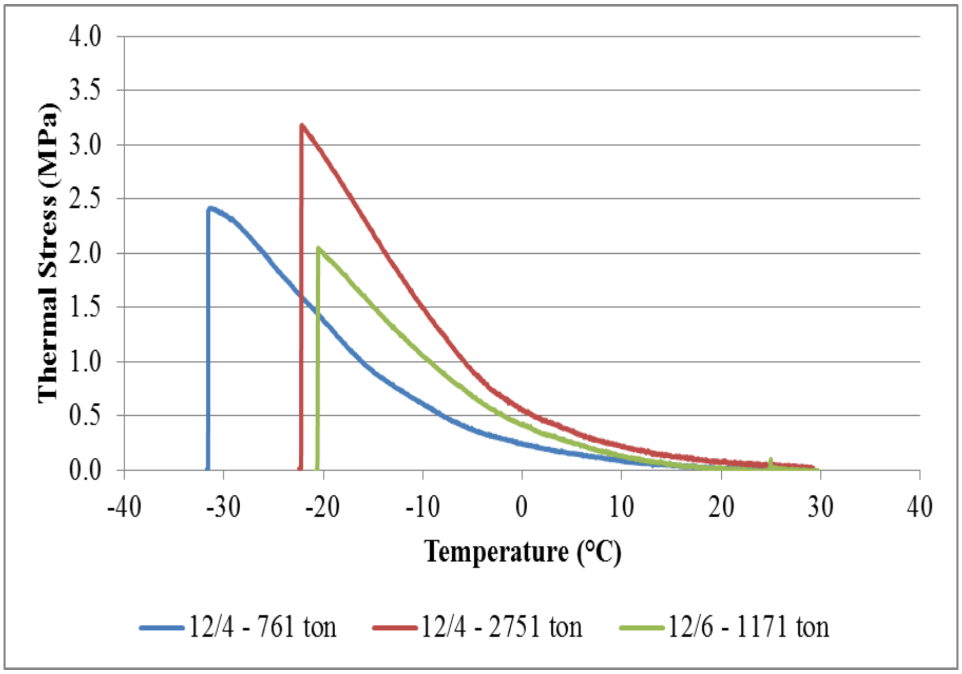
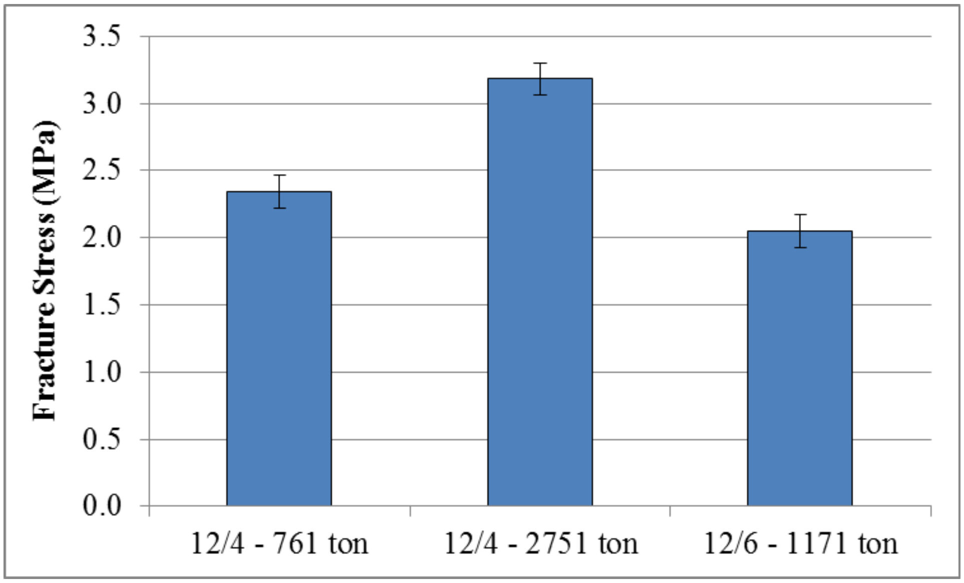
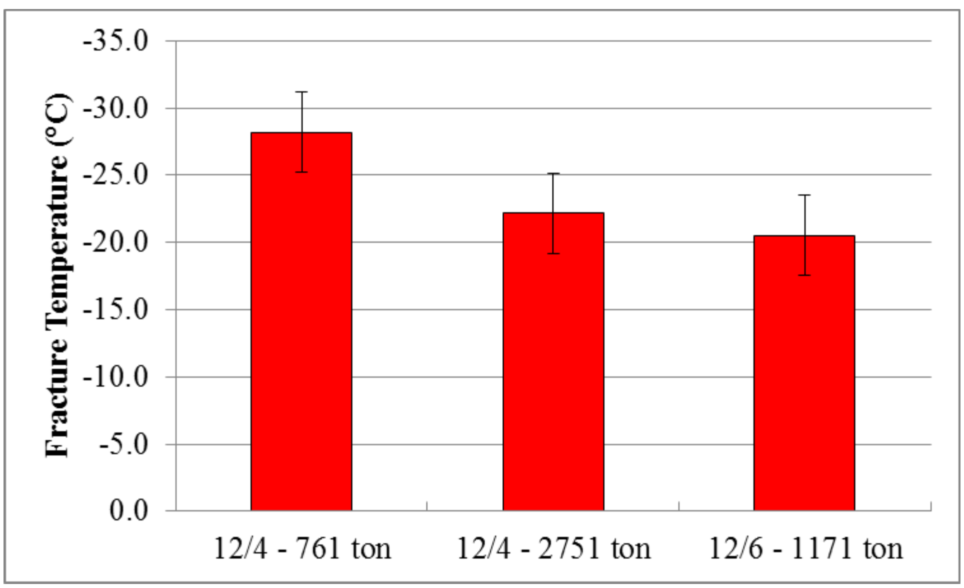


Figure 52. Capitol Drive Project - Thermal Stress vs. Temperature by Production Day.

The outputs of the test, fracture stress and fracture temperature are provided in Figure 53. Contrary to results of thermo-volumetric testing, low temperature fracture testing demonstrates significant variation between production samples in regards to both fracture strength and temperature. The deviation in results for the second sample taken on 12/4 were expected due to the higher air void content of the sample relative to the other production samples. Air void contents for all samples were presented previously in Table 29. In regards to the effects of air voids on thermo-volumetric properties, the results showed that while air void content did not significantly affect the liquid and glassy coefficients of thermal contraction, higher air voids resulted in less thermal strain developed in the sample after the temperature ramp was imposed during the test. This result is consistent with thermal fracture data presented in Figure 53a, which demonstrates a significantly higher value of fracture stress. Values of fracture stress observed for the first sample taken on 12/4 and the mix sampled on 12/6, which had similar air void contents, are within the observed error of the test (±0.3 MPa).



(a)



(b)

Figure 53. Capitol Drive Project – Fracture Strength (a) and Fracture Temperature (b) by Production Day

A significant increase (more positive) in fracture temperature of approximately 6 °C was observed between the first and second samples taken on 12/4, values of fracture temperature are consistent between the second and third samples. Due to the confounding effect of difference in air voids for 12/4 Sample 2 relative to the other samples it is difficult to draw any conclusions for this sample, however, the differences observed between the sample taken after 761 tons of production on 12/4 and the sample taken on 12/6 reveal a significant change in fracture temperature. The difference in fracture temperature of approximately 8 °C is significantly larger than the difference in the low temperature grade of the recovered binder, which as shown in Table 27 was only 1.5 °C.

5.1.4.8 Moisture Sensitivity

AASHTO T283 was conducted on each of the production samples after reheating to the compaction temperature of 149 °C. The results are summarized and compared to the mixture design in Table 33. The production samples are in agreement with the design and indicate a non moisture sensitive mixture. The unconditioned and conditioned strengths of the production samples appear to be weakly related to the intermediate temperature grade of the recovered grade of the binder as shown in Figure 54.

Table 33. Summary of Moisture Sensitivity Testing for the Capital Drive Project.

Property	Design	12/4 @ 761 Tons	12/4 @ 2751 Tons	12/6 @ 1171 Tons
Unconditioned strength, psi	NR	135.8	141.1	161.1
Conditioned strength, psi	NR	121.6	122.4	134.0
Tensile strength ratio	88	89.6	86.7	83.2

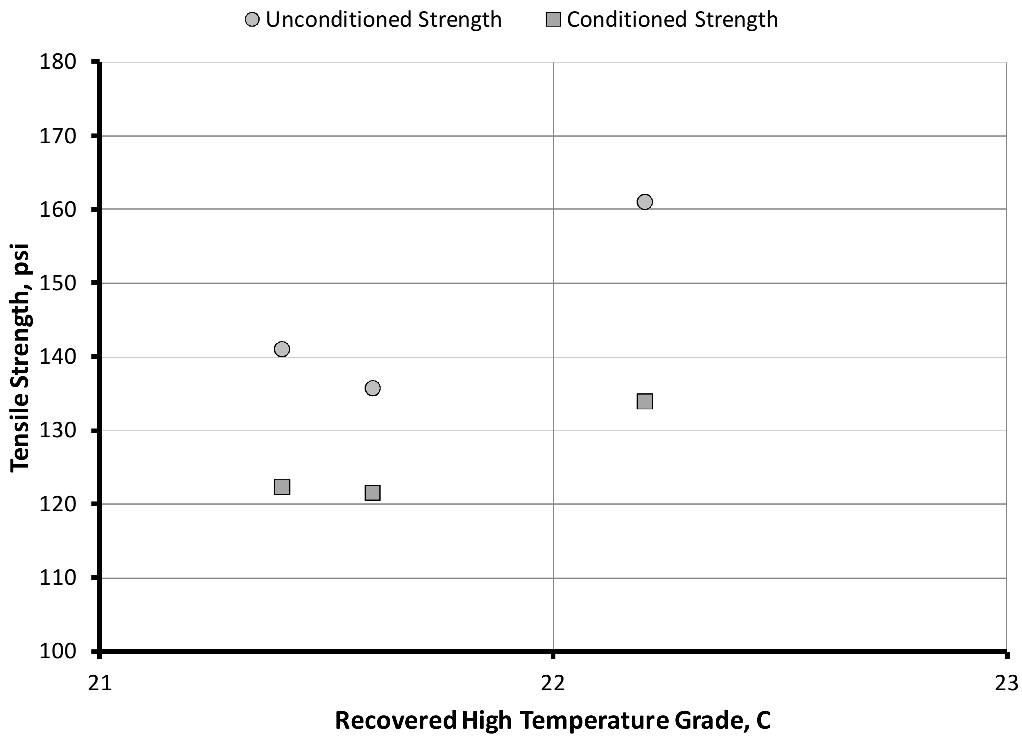


Figure 54. Relationship Between Recovered Binder Intermediate Grade and Tensile Strength for the Capitol Drive Project.

5.2 State Trunk Highway 70 Project

5.2.1 Description

The second project included in the field validation was WisDOT Project 9070-03-60, STH 70 Fifield – Woodruff: North County Line – Morgan Rd. The STH 70 project was classified as a preventative maintenance treatment of STH 70 from Woodruff to the northern Oneida County line, a total length of approximately 6.5 miles. This section of STH 70 runs east to west in north central WI and consists of one lane in each direction travel direction. There are also turn lanes that provide access to ancillary roads located along the project, none of the intersections are signalized. This section of STH 70 experiences average daily traffic of 5000 vehicles (2010), which is expected to grow to 5700 vehicles by the year 2020. For design purposes, it was assumed that 13 percent of the daily traffic is trucks and a design speed of 60 mph was used. The level of traffic and design speed selected indicates that drivers experience free-flow conditions when using this roadway.

The existing pavement consisted of 4.5 in of asphalt concrete over pulverized HMA, this section was built over the existing crushed aggregate base course and granular subgrade layers and was part of the the WisDOT warranty program. As a preventative maintenance measure the current project involves milling 1.75 in of the surface and replacing it with a new HMA overlay of the same lift thickness. The material used in the overlay was a 12.5 mm NMAS mixture with PG 58-28 binder. In addition to mainline paving some new turn lanes and extension of existing turn lanes used an asphalt concrete over aggregate base section. The aggregate base in these areas was 8 in thick. The asphalt concrete was 6.5 in thick, placed in three separate lifts of the same mix design. In total, the project required 120,495 SY of milling and 12,460 tons of hot mix asphalt. The mixture was sampled for the field validation of the WHRP Project 0092-12-02 draft specifications during mainline paving.

The asphalt mixture was designed for traffic level E3. Table 34 provides a summary of the design; the producer’s complete mix design submittal is included in Appendix F. As designed, the mixture included 3 percent RAS and 16 percent FRAP, resulting in a design binder replacement of 25.0 percent; 11.7 percent from RAS and 13.3 percent from FRAP. The mixture was produced with a plant injection foaming process adding water at the rate of 1.15 percent by weight of binder. The plant foaming was used as a compaction aid during production, it was not used as a WMA technology as design mixing and compaction temperatures were 300°F and 265°F respectively.

5.2.2 Sampling

The surface layer placed on September 4, September 5, and September 6 was sampled for field validation of the WHRP Project 0092-12-02 draft specifications. These days of paving represented approximately 6,300 tons of asphalt pavement, all used for mainline paving in the west-bound direction. In-place density measurements of material placed these days indicate that average lot densities of 94.8, 94.3, and 93.4 percent were achieved for production days of 9/4, 9/5, and 9/6 respectively. All density measurements were well above the 91.5 percent minimum in-place density required by WisDOT. Sampling was in accordance with the sampling plan given in Table 16 and Table 17 except the time of sampling for the recycled materials did not exactly coincide with the time of sampling for the HMA mixture. For each production day, the research team visited the HMA plant in the morning and sampled recycled materials from the FRAP and RAS stockpiles. Sampling containers were left onsite for the contractor to collect additional research samples during normal QC sampling.

Table 34. Design Properties for STH 70 12.5 mm Mixture.

Property		Mix
	Sieve size, mm	
Gradation, % passing	25	100
	19	100
	12.5	95
	9.5	83
	4.75	64
	2.36	52
	1.18	42
	0.6	32
	0.3	17
	0.15	8
	0.075	4.6
Design Gyrations		75
Total Design Binder content, wt %		5.4
Binder from RAS		0.63
Binder from FRAP		0.72
Design Air Voids, vol %		4.0
Design VMA, vol %		15.0
Design VFA, vol %		74
Maximum Specific Gravity		2.493
Aggregate Bulk Specific Gravity		2.666
% G_{mm} at N_{ini}		90.5
% G_{mm} at N_{max}		96.7
Tensile Strength Ratio, %		71

5.2.3 Weather

Weather data during the week that sampling was performed was obtained from the weather station at Lakeland Airport which is approximately 3 miles from the east end of the project. Air temperature, precipitation, and wind speed during the week of paving are shown in Figure 55.

The shaded areas in Figure 55 are the days that sampling we conducted. The air temperature on the days of paving ranged from 60 to 80 °F with no precipitation and light breeze.

5.2.4 Test Results

5.2.4.1 Quality Control

Production records for HMA mix properties are summarized in Table 35, each value represents the running average (based on 4 tests) of the third test for each production day, other tests were omitted for the sake of brevity. Days in which three samples were not taken are highlighted. Current WisDOT specifications require the following sampling frequencies: 50 – 600 Ton – 1 test, 601 – 1500 ton – 2 tests, 1501 – 2700 ton – 3 tests. Based on these requirements daily production for a majority of the project was between 1500 and 2700 tons. Similar data is presented in Table 36 for the gradation of the HMA mixture. In combination, the results show that production throughout the project was controlled well within WisDOT requirements.

5.2.4.2 Reheat Correction Factor

The WHRP Project 0092-12-02 draft specifications include the development of a reheat correction factor to account for changes in compactability when reheated samples are used in verification testing. The reheat correction factor is determined during mix design by compacting specimens at the optimum binder content to the design gyration level in the normal manner without reheating, then compacting a second set of specimens to the design gyration level after cooling to room temperature. The difference in the air void content for the two sets of specimens is the reheat correction factor. The procedure is described in detail in Appendix D.

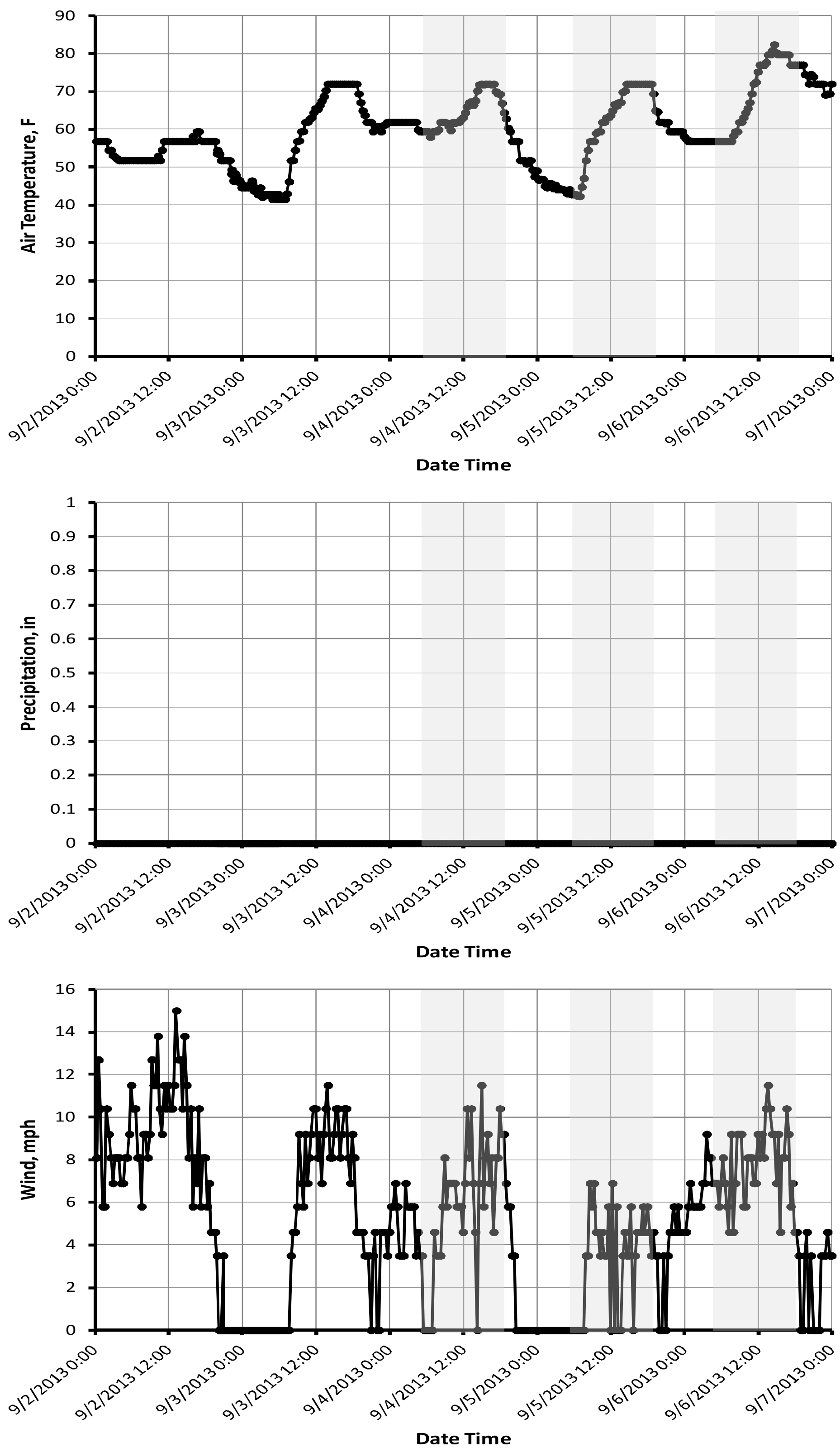


Figure 55. Weather During Week of STH-70 Sampling.

Table 35. Production Records for STH-70 Project – Mixture Properties.

Date	Gmm	Gmb	Va, %	VMA%	Pb,%
JMF	2.493	2.396	3.9	15.0	5.4
8/28/2013	2.480	2.378	4.1	15.7	5.5
8/29/2013	2.486	2.390	4.0	15.3	5.5
9/3/2013	2.482	2.388	3.8	15.3	5.4
9/4/2013	2.487	2.385	4.1	15.4	5.4
9/5/2013	2.502	2.393	4.4	15.2	5.5
9/6/2013	2.497	2.393	4.2	15.2	5.5
9/9/2013*	2.500	2.392	4.3	15.2	5.5
9/10/2013*	2.501	2.391	4.4	15.2	5.5
9/11/2013**	2.507	2.398	4.3	15.0	5.5
9/12/2013*	2.506	2.403	4.1	14.8	5.5
Average	2.495	2.391	4.2	15.2	5.5
ΔJMF	0.002	-0.005	0.3	0.2	0.1
Warning Limit	N/A		+/-1.0	-0.2	+/-0.3
JMF Limit			+/-1.3	-0.5	+/-0.4

*Denotes production days where one QC sample was taken.
**Denotes production days where two QC samples were taken.

Table 36. Production Records for STH-70 Project – Gradation.

Date	19.0 mm ¾”	12.5 mm ½”	9.5 mm 3/8”	2.3 mm #8	75 µm #200
JMF	100.0	94.5	83.4	51.6	4.6
8/28/2013	100.0	94.2	82.8	50.7	5.4
8/29/2013	100.0	94.4	83.0	50.9	5.8
9/3/2013	100.0	94.5	84.1	51.6	5.9
9/4/2013	100.0	95.2	84.3	52.3	5.5
9/5/2013	100.0	94.7	83.9	51.7	5.3
9/6/2013	100.0	94.5	83.0	51.7	5.3
9/9/2013*	100.0	94.2	84.0	52.1	5.3
9/10/2013*	100.0	94.5	83.1	52.4	5.4
9/11/2013**	100.0	95.1	85.3	52.4	5.5
9/12/2013*	100.0	94.7	84.1	51.0	5.3
Average	100.0	94.6	84.1	51.0	5.3
ΔJMF	0	0.1	0.7	-0.6	0.7
Warning Limit	+/-4.0	+/-4.0	+/-4.0	+/-4.0	+/-1.5
JMF Limit	+/-5.5	+/-5.5	+/-5.5	+/-5.0	+/-2.0

Table 37 presents the results of the reheat correction factor determination for the STH 70 project. The project included foaming technology during production. To best replicate this process in the laboratory the asphalt binder was foamed with a water content of 1.15 percent by weight of asphalt binder using a Wirtgen WLB-10 laboratory foaming device. The asphalt binder was foamed at a temperature of approximately 330°F, due to requirements of the foaming device. The mixing temperature specified in the mix design, 300°F, was maintained by controlling the temperature of the aggregates and assuming that based on the relative proportions the temperature of the mix would be controlled by the temperature of the aggregates. As shown in Table 37, reheating had a noticeable effect on the air void content of the mixture used on this project resulting in a correction factor of -0.7 percent. The negative correction factor indicates that mixtures are less compactable after reheating possibly caused by the dissipation of the effect of foaming on mixture workability.

Table 37. Reheat Correction Factors for STH 70 12.5 mm Surface Mixture.

Sample	Reheated?	G_{mb}	G_{mm}	Air Voids, %	Average Air Voids, %	Reheat Correction Factor
1	No	2.399	2.492	3.7	3.6	-0.7
2	No	2.405	2.492	3.5		
3	No	2.407	2.492	3.4		
4	No	2.401	2.492	3.6		
5	Yes	2.389	2.492	4.1	4.3	
6	Yes	2.390	2.492	4.1		
7	Yes	2.386	2.492	4.2		
8	Yes	2.377	2.492	4.6		

5.2.4.3 Virgin Binder Properties

Table 38 presents the performance grading properties for the virgin binder used on the STH 70 project. The binder grades as a PG 58-28 with a continuous grade of PG 59.9 (17.3) –30.0.

Table 38. Performance Grading for STH 70 Virgin Binder.

Condition	Test	Temp, °C	Result
Tank	G*/sinδ, kPa AASHTO T 315	58	1.26
		64	0.60
Rolling Thin Film Residue	Mass Change, % AASHTO T240	163	-0.592
	G*/sinδ, kPa AASHTO T 315	58	3.53
		64	1.61
Pressure Aging Vessel Residue	G*sinδ, kPa AASHTO T 315	16	5960
		19	4030
	Creep Stiffness (MPa)/Slope AASHTO T 313	-24	516 / 0.282
		-18	227 / 0.350
Grade	AASHTO M320	PG 58 – 28	
Continuous Grade		PG 59.9 (17.3) –30.0	

5.2.4.4 Recycled Material Properties

Samples of the mix, RAS and FRAP were obtained on the sampling days. The binder content of each sample was measured in accordance with AASHTO T164 to determine the variability in the binder content of the mix and the recycled materials. The results are summarized in Table 39. These samples show significant variability in the binder content of the RAS. Additionally, the binder content of both the FRAP and RAS from the production samples differs significantly from that used in the design. The production FRAP samples have approximately 1.3 percent lower binder content compared to the design and the RAS samples have approximately 2.7 percent higher binder content than the design. Table 39 also shows the binder replacements based on the measured mix binder content for each production day. The production binder replacement is somewhat lower than the design because of the lower FRAP binder content. The standard deviation of the binder replacement at 1.83 percent is higher than the 0.43 percent observed for the Capitol Drive Project. The binder replacement for both design and production exceed the limits included in the WHRP Project 0092-12-02 draft specification without performance tests. The limits in the draft specifications were developed in WHRP Project 0092-12-02 with the objective of limiting the change in the low temperature continuous grade of the binder to less than 3 °C.

Table 39. Binder Content of STH 70 Recycled Materials.

Sample	Binder Content, %			Binder Replacement, %		
	Mix	FRAP	RAS	FRAP	RAS	Total
9/4/13	5.06	2.88	23.48	9.1	13.9	23.0
9/5/13	5.71	3.43	21.85	9.6	11.5	21.1
9/6/13	5.32	3.33	26.14	10.0	14.7	24.8
Average	5.36	3.21	23.82	9.6	13.4	23.0
Standard Deviation	0.33	0.29	2.17	0.46	1.70	1.83
Design	5.4	4.5	21.1	11.7	13.3	25.0

One sample of the binder from each recycled material was recovered and graded. The RAP was graded in accordance with the Appendix to AASHTO M323. The RAS was graded using the procedure developed in WHRP Project 0092-10-06 and described in Appendix D (*3*). The virgin binder from the project was used to create the 30/70 blend of recovered RAS and virgin binder that was used to extrapolate the RAS continuous grade properties. The resulting data are presented in Table 40. Per the referenced test methods, the intermediate and low temperature properties for the RAP were determined on Rolling Thin Film Oven Test (RTFOT) conditioned material, while those for the RAS were determined on RTFOT plus pressure aging vessel (PAV) conditioned material.

Table 40. Results of Recovered RAP and RAS Grading.

Property	Test	Temp, °C	FRAP	30/70 RAS in PG 58-28
High Recovered		70		1.92
	G*/sinδ, kPa AASHTO T 315	76		0.96
		82	1.68	
		88	0.83	
High RTFOT	G*/sinδ, kPa AASHTO T 315	76		2.59
		82	3.11	1.31
		88	1.51	
Intermediate	G*sinδ, kPa AASHTO T 315	19		6120
		22		4430
		25	5660	
		28	3940	
Low	Creep Stiffness (MPa)/Slope AASHTO T 313	-18	478 / 0/250	249 / 0.296
		-12	244 / 0.304	130 / 0.344

Continuous performance grade properties for the RAP and RAS that are needed for blending chart analyses are presented in Table 41. The continuous grade of the RAP is within the range of the RAP previously tested in WHRP Project 0092-10-06, but the continuous grade of the RAS is softer than the materials tested in WHRP Project 0092-10-06 (*3*).

Table 41. Continuous Performance Grade Properties for STH 70 Recycled Materials.

Continuous Grade	RAP	30/70 RAS in PG 64-28	Extrapolated RAS
High	84.9	75.6	112.2
Intermediate	26.0	23.8	29.3
Low	-22.4	-27.5	-16.3

The continuous grading properties of the virgin and recycled materials and the binder replacement values from Table 39 were used in linear blending charts to estimate the change in the grade of the binder in the mixture during production. The results are summarized in Table 42. The low temperature continuous grade of the binder increased 0.9 °C for the design and an average of 2.0 °C for the production samples. The greater increase for the production samples is the result of higher binder content of the RAS from the production samples compared with that used in design. Based on the blending chart analysis, it is reasonable to expect only small changes in the grade of the blended binder during production as long as the binder replacement is reasonably controlled.

Table 42. Blending Chart Continuous Performance Grades for STH 70 Project.

Sample	Blending Chart Continuous Performance Grade, °C		
	High	Intermediate	Low
Design	69.6	19.9	-29.1
9/4/13	69.6	19.8	-29.2
9/5/13	68.3	19.5	-27.7
9/6/13	70.1	19.9	-27.2
Production Average	69.3	19.7	-28.0
Production Standard Deviation	0.93	0.21	1.02

5.2.4.5 Recovered Binder Properties

Binder content and performance graded binder properties were measured on binder recovered from the loose mix samples from the three days of production. The results are summarized in Table 43. These results indicate reasonably consistent asphalt binder content averaging 5.3 percent and a binder grade of either PG 64-28 or PG 70-22. The high temperature continuous grade ranges from 66.6 to 72.7 °C; the intermediate temperature grade ranges from 18.7 to 20.8 °C, and the low temperature grade ranges from -29.8 to -27.1 °C. The measured continuous grade data compares well with the data from the blending charts. The average measured high temperature continuous grade is 69.6 °C compared to 69.3 °C from the blending chart. The average intermediate temperature grades are almost the same at 19.8 °C for the measured data and 19.7 °C for the blending chart. The average measured low temperature continuous grade is -28.6 compared to -28.0 from the blending chart.

Using data from weather station WI 5516, Minocqua Dam, and the LTPP low temperature algorithm given in Equation 5 (*22*), the reliability against low temperature cracking ranges from 71.6 percent for the 9/6 sample to 86.7 percent for the 9/3 sample. The 98 percent reliability temperature from LTPPBind 3.1 for this weather station is -33.0 °C. Had no recycled binder been used, the reliability against low temperature cracking would have been 88.1 percent based on the properties of the virgin binder.

Table 43. Recovered Binder Properties for the STH 70 Project.

Test/Condition	Method	Temp, °C	9/4/13	9/5/13	9/6/13
Binder Content	AASHTO T164, Method A	NA	5.06	5.71	5.32
As Recovered	G*/sinδ, kPa AASHTO T 315	64	3.40		
		70	1.43	2.19	3.04
		76		1.06	1.48
Pressure Aging Vessel Residue	G*sinδ, kPa AASHTO T 315	16	6920		
		19	4840	5560	6230
		22		4000	4360
	Creep Stiffness (MPa)/Slope AASHTO T 313	-24	488 /0.264	504 / .250	
		-18	245 / 0.322	252 / 0.301	275 / 0.299
		-12			129 / 0.350
Grade	AASHTO M320	NA	PG 64-28	PG 64-28	PG 70-22
Continuous Grade		High	66.6	69.6	72.7
		Intermediate	18.7	20.0	20.8
		Low	-29.8	-28.1	-27.9

5.2.4.6 Flow Number

Flow number tests were conducted on test specimens produced from component materials during mix design and test specimens fabricated from the loose mix samples from the three days of production. All test specimens were prepared in accordance with AASHTO PP60 to a target air void content of 7.0 percent except the service conditioning procedure described in Appendix D was used in lieu of short-term conditioning of 4 hours at 135 °C. The specimens were tested in accordance with AASHTO TP79 using the testing conditions recommended in NCHRP Project 9-33 (*8*); unconfined with a repeated deviatoric stress of 87 psi. The test temperature was 44.5 °C, which is the 50 percent reliability pavement temperature at a depth of 20 mm from LTPPBind 3.1 for weather station WI 5516, Minocqua Dam. The flow number test results are summarized in Table 44.

Table 44. Summary of Flow Number Test Results.

Sample	Air Voids, %	Flow Number	Air Voids, %	Flow Number	Air Voids, %	Flow Number	Average	Coefficient of Variation, %
Design	7.6	64	7.4	71	7.5	62	66	7.2
9/4/13	7.5	98	7.6	71	7.4	69	79	20.4
9/5/13	7.6	106	7.7	89	7.7	103	99	9.1
9/6/13	7.7	62	7.5	78	7.6	88	76	17.2

Table 45 presents an analysis of variance for the measured flow numbers. This analysis indicates that the average flow number for one of the pairs is significantly different at the 95 percent confidence level. Using the Scheffé multiple comparison test, it was concluded that the design differs from the 9/5/13 sample. All other means are not significantly different. Flow numbers for the production samples do not appear to be correlated with the high temperature grade of the recovered binder as shown in Figure 56.

Table 45. Summary of One-Way Analysis of Variance of STH 70 Flow Number Data.

Factor	Flow Number	
	F	**p-value**
Sample	4.42	0.041

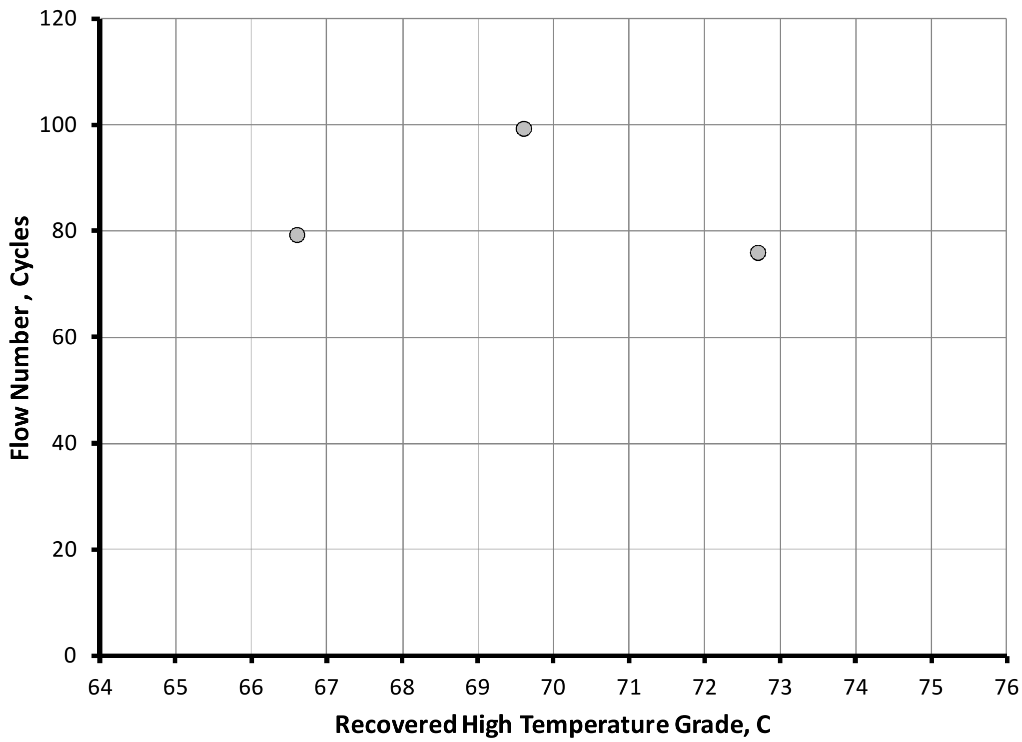


Figure 56. Flow Number Versus Recovered High Temperature Grade for STH 70 Project.

In WHRP Project 0092-09-01 tentative flow number criteria as a function of traffic speed and design traffic level were developed. For normal speed traffic, the recommended minimum flow number is 15 for 3 million ESAL (*9*). As designed, the mixture is well above the normal traffic flow number requirement. The production samples have somewhat higher flow numbers indicating greater resistance to rutting. The 9/5/13 production sample exceeds the flow number requirement for intersection design, which is 90 for 3 million ESAL (*9*).

5.2.4.7 Asphalt Thermal Cracking Analyzer

Unstrained and restrained Asphalt Thermal Cracking Analyzer tests were conducted on test specimens produced from component materials during mix design and test specimens fabricated from the loose mix samples from the three days of production. For this field project, the unrestrained and restrained tests were conducted simultaneously for each sample using beams created from the same compacted sample. This procedure deviates from the Capitol Drive results in which fracture testing was conducted separately from unrestrained testing. Moving forward it is recommended that the unrestrained and restrained tests be conducted concurrently to reduce testing time. Three replicates were tested for all combinations. All test specimens were prepared in accordance with the procedure described in Appendix D to a target air void content of 4.0 percent of the bulk sample after conditioning loose mix per the service condition procedure described in Appendix D.

The results for all three days of production sampled are provided in Figure 57; in the figure and subsequent figures in this section the error bars represent two standard deviations from the mean. The average glass transition temperature for the field samples was -29.3 °C and the error was ± 2.2 °C. As shown, the glass transition temperature for the mix produced on Production Day 3 was approximately 2 °C lower relative to the other mixes sampled. However, based on experimental error, differences in production days were deemed insignificant and statistically similar to the average glass transition temperature.

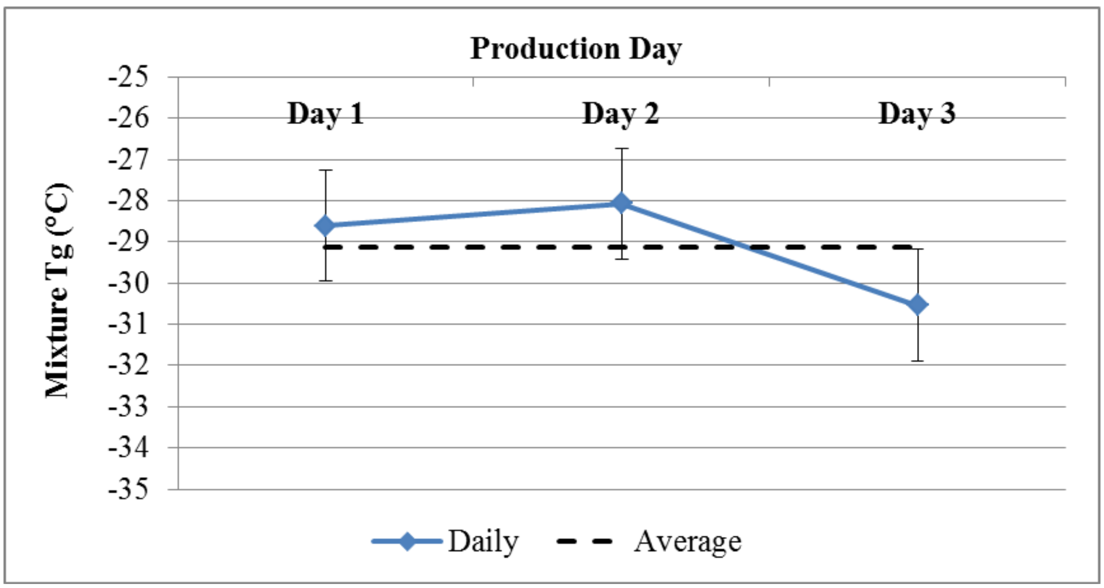


Figure 57. Variation of Glass Transition Temperatures for Field Mixtures Produced for the STH 70 Project.

As previously described the mixture glass transition temperature parameter represents the transition zone from liquid to glassy behavior in the bi-linear mixture thermal strain versus temperature relationship. The liquid (αL) and glass (αG) coefficients of thermal contraction are the slope of the strain versus temperature relationship in their respective zones. The variation in these coefficients with production day is provided in Figure 58. Similar to previous figures, the error bars represent two standard deviations from the mean. As expected based on similarities in mixture glass transition temperature, coefficients of thermal contraction across all three production days were similar.

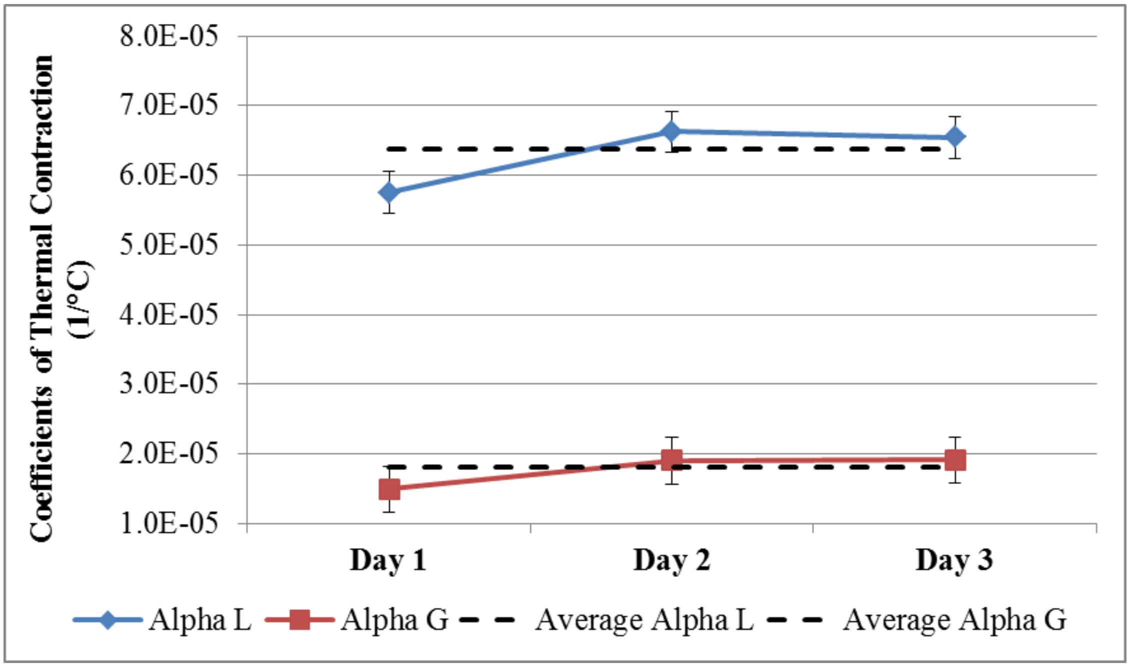


Figure 58. Variation of Liquid (αL) and Glassy (αG) Coefficients of Thermal Contraction for the STH 70 Project Field Sampled Mixtures.

Laboratory produced samples based on the mix design were compared to the field produced samples to verify that the short term aging protocol provided in Appendix D resulted in similar performance properties for laboratory and field produced mixtures. The results are presented in Figure 59 for the liquid (αL) and glassy (αG) coefficients of thermal contraction. These results indicate that the aging protocol developed in Phase I of this research was successful in conditioning laboratory and field produced mixtures to achieve similar performance properties as no difference between laboratory and field αL and αG values was observed. The mixture glass transition (T_g) temperatures for field and lab mixtures as estimated based on coefficients of thermal contraction are provided in Figure 60. As expected no significant difference between laboratory and field data was observed as the difference in Mixture T_g values was less than 1°C.

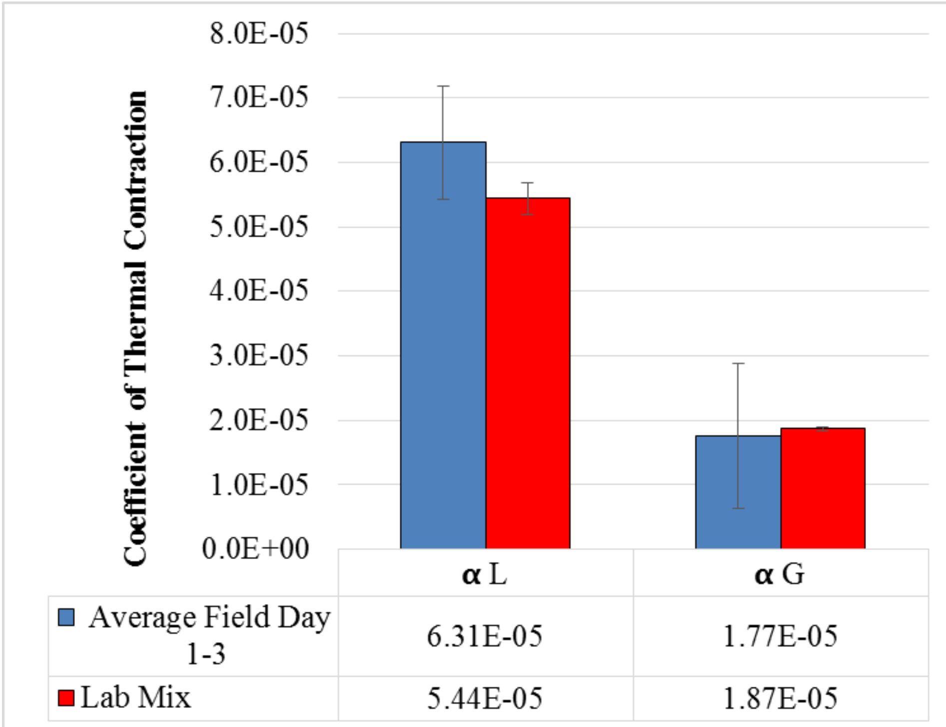


Figure 59. Comparison of Averaged αL and αG Values from Field Production to Laboratory Produced Material for the STH 70 Project.

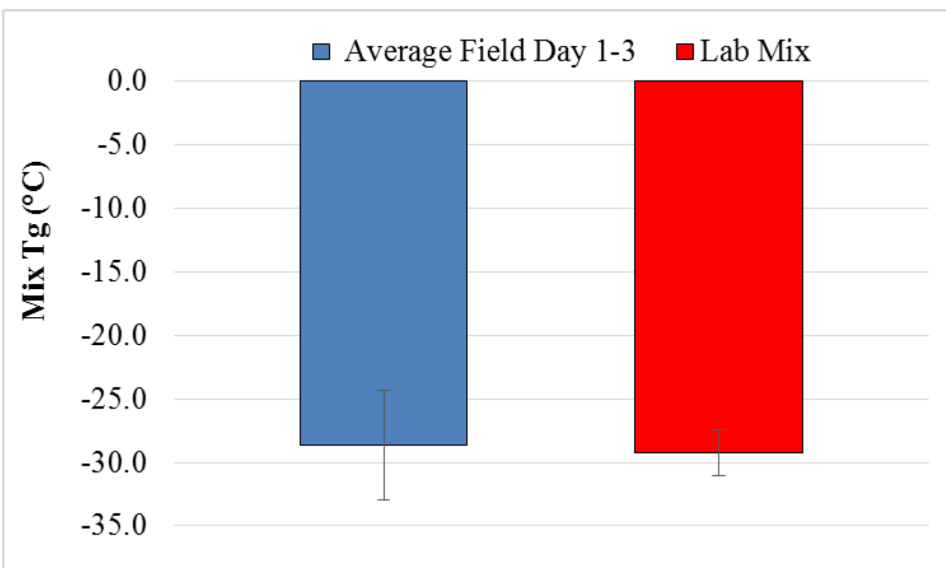
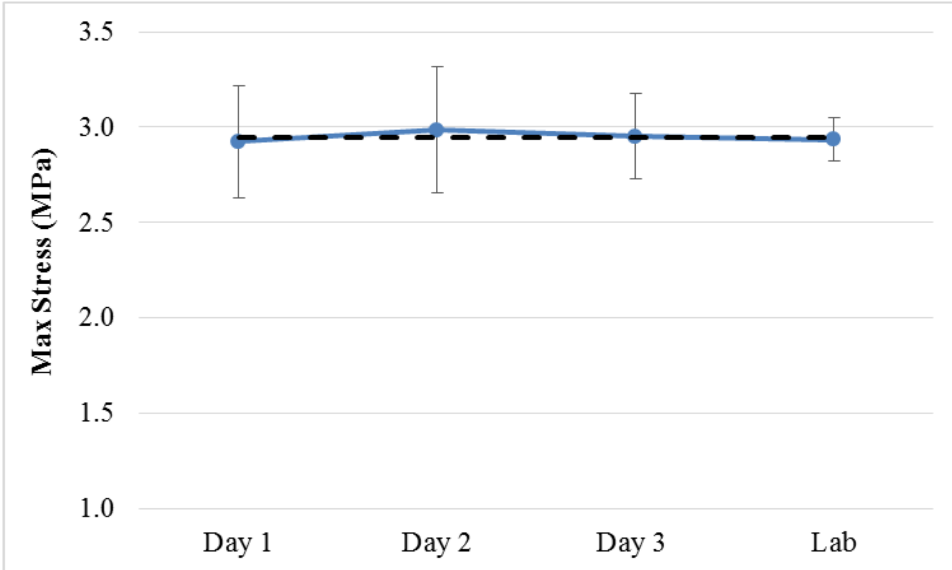


Figure 60. Comparison of Mixture Glass Transition Temperature Results between Field and Laboratory Produced Samples for the STH 70 Project.

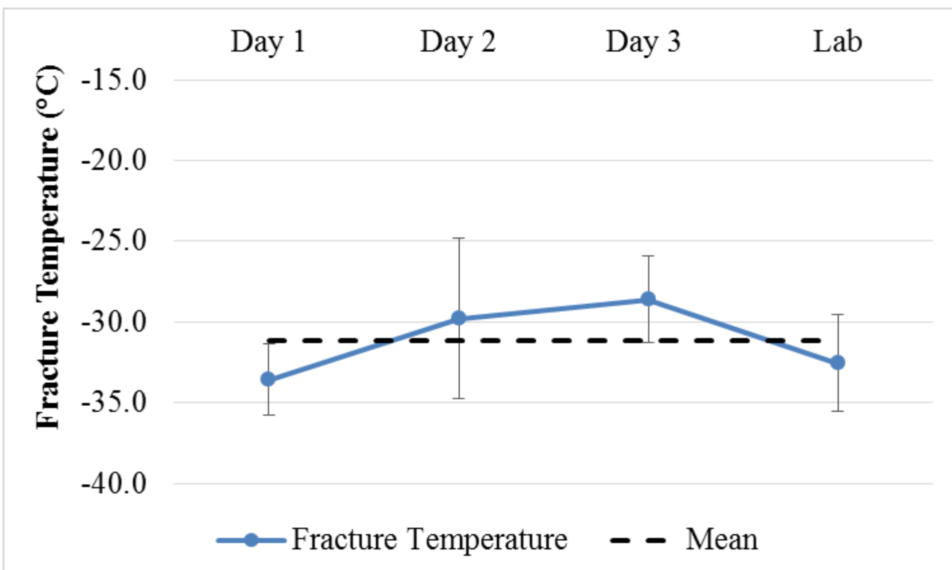
Restrained testing was conducted concurrently with unrestrained testing using beams prepared from the same SGC sample. As described previously, the outputs of restrained temperature are the fracture stress and temperature. The variation in these values by production day and comparison between field and laboratory performance as well as the mean across all samples tested are presented in Figure 61a and Figure 61b for fracture stress and temperature respectively. Error bars in the figures represent two standard deviations from the mean.

Overall the results presented in Figure 61 demonstrate that consistent performance properties were achieved during production and that the short term aging protocols provided in Appendix D were successful in achieving the goal of laboratory and field produced mixes achieving similar performance. The results are also consistent with the quality control data which showed small variations with mixture volumetric properties, gradation, and binder content during production. In regards to fracture stress, values of approximately 3MPa were observed for all samples tested with a variation of ±0.25 MPa for the field produced samples, variability of the laboratory prepared samples was significantly lower. The average fracture temperature for all materials was approximately -30°C with variations of ±3°C. The base binder used in this project was a PG 58-28, the mix design had a binder content of 5.5 percent with an average of 23.0 percent binder replacement, with 9.6 percent from FRAP and 13.4 percent from RAS.

Qualitative observations presented previously regarding the success of the short term aging protocol in producing laboratory and field mixtures with similar performance properties were verified statistically through the use of a paired t-test at a confidence level of 95 percent. The results are presented in Table 46 for all analysis parameters associated with unrestrained and restrained mixture testing. Significant differences are highlighted in bold. The results of the statistical analysis confirm the similarity between the low temperature performance of field and laboratory produced specimens short-term conditioned with the protocol provided in Appendix D. Differences in liquid coefficient of thermal contraction were deemed significant; however the difference was insufficient to produce variations in mixture glass transition temperature or glassy coefficient of thermal expansion. No significant differences were observed for mixture fracture properties. Overall variability was higher for field produced samples by approximately a factor of two.



(a)



(b)

Figure 61. Restrained Testing Results – Thermal Stress (a) and Fracture Temperature (b) for Field and Laboratory Produced STH 70 Mixes.

Table 46. Basic Statistical Analysis on Asphalt Thermal Cracking Analyzer Parameters for the STH 70 Project.

Asphalt Thermal Cracking Analyzer Parameters		Condition	Basic Statistics			t-Value	p-Value
			N	Mean	Std Dev.		
Unrestrained Testing	Mixture Tg	Field	8	-29.1	2.15	0.20	0.845
Unrestrained Testing	Mixture Tg	Lab	2	-29.3	0.9	0.20	0.845
Unrestrained Testing	**Liquid Coefficient of Thermal Contraction**	**Field**	**8**	**6.5E-05**	**4.4E-06**	**6.19**	**<0.005**
Unrestrained Testing	**Liquid Coefficient of Thermal Contraction**	**Lab**	**2**	**5.4E-05**	**1.2E-06**	**6.19**	**<0.005**
Unrestrained Testing	Glassy Coefficient of Thermal Contraction	Field	8	1.9E-05	5.6E-06	0.20	0.845
Unrestrained Testing	Glassy Coefficient of Thermal Contraction	Lab	2	1.9E-05	1.6E-07	0.20	0.845
Restrained Testing	Fracture Temperature	Field	9	-30.6	2.71	1.53	0.157
Restrained Testing	Fracture Temperature	Lab	3	-32.5	1.50	1.53	0.157
Restrained Testing	Fracture Stress	Field	9	2.95	0.127	0.33	0.749
Restrained Testing	Fracture Stress	Lab	3	2.94	0.058	0.33	0.749

Relative to the Capitol Drive Project, the improved consistency and repeatability of low temperature mixture evaluation observed for the STH 70 project presents promising potential for application of this test method to assess low temperature performance properties in the mix design phase and estimate how the mix will perform in the field during early service life through use of the correct mixture aging protocol in sample preparation. Specifically, mixture testing results for the STH 70 project indicate that the mix design is capable of meeting low temperature PG climactic requirements (-28°C) at a binder replacement level of 24.6 percent. Moving forward it is recommended that restrained and unrestrained testing be conducted concurrently to obtain information regarding mixture thermo-volumetric properties and resistance to thermal stress build up. It is well established that low temperature cracking is a durability related failure that manifests later in pavement service life. To evaluate current binder replacement criteria for both RAP and RAS performance evaluation of mixes after long term conditioning is recommended.

5.2.4.8 Moisture Sensitivity

AASHTO T283 was conducted on each of the production samples after reheating to the compaction temperature of 130 °C. The results are summarized and compared to the mixture design in Table 47.

Table 47. Summary of Moisture Sensitivity Testing for the STH 70 Project.

Property	Design	9/4/13	9/5/13	9/6/13
Unconditioned strength, psi	NR	121.1	110.7	114.4
Conditioned strength, psi	NR	87.4	68.1	76.7
Tensile strength ratio (TSR)	71	72.2	61.5	67.0

The production sample on 9/5/13 appears to have significantly lower TSR result compared to the design and the other production samples. Table 48 presents an analysis of variance for the measured tensile strengths. This analysis indicates that both the dry and conditioned tensile strengths are significantly different for at least one of the production days. Using the Scheffé multiple comparison test, is was concluded that the mean unconditioned tensile strength for the 9/4/13 sample was significantly higher than the mean for the other two days. Additionally, the mean conditioned tensile strengths are significantly different for all production days. There does not appear to be a rational relationship between the measured tensile strengths and the intermediate temperature grade of the recovered binder as shown in Figure 62.

Table 48. Summary of One-Way Analysis of Variance of STH 70 Moisture Sensitivity Data.

Factor	Dry Tensile Strength		Conditioned Tensile Strength	
	F	**p-value**	**F**	**p-value**
Sample	11.76	0.008	18.00	0.003

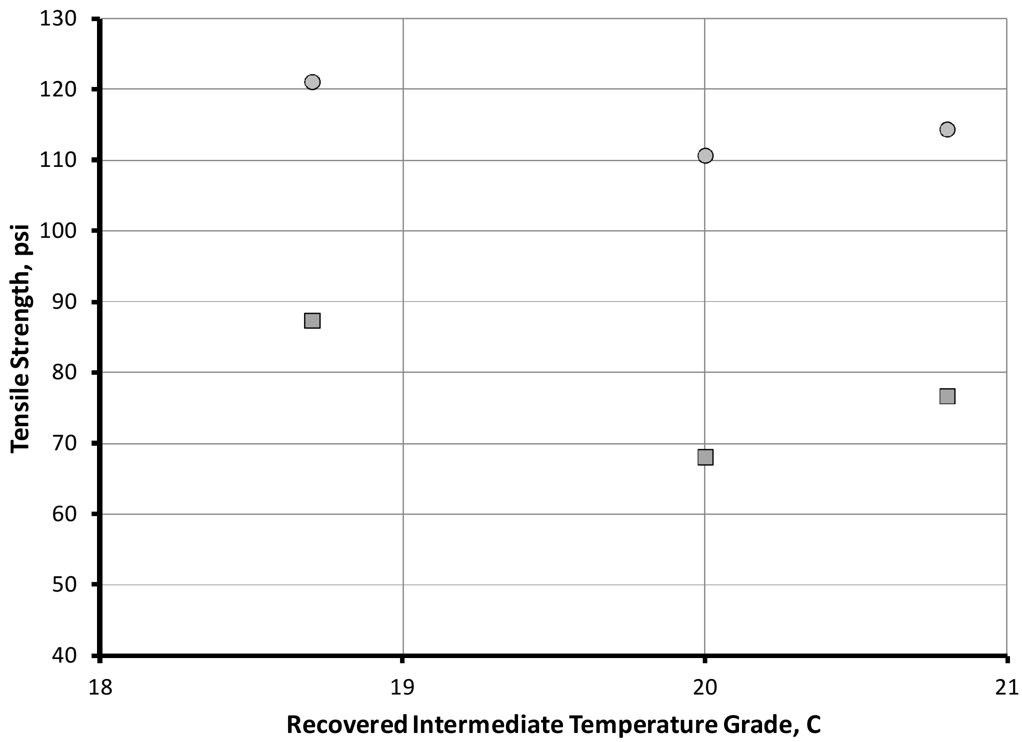


Figure 62. Tensile Strength Versus Recovered Intermediate Temperature Grade for the Production Mixtures From the STH 70 Project.

5.3 Field Validation Findings

The field validation of the WHRP Project 0092-12-02 Draft Specifications was limited to two projects: Capitol Drive, and STH 70. The mixtures for both projects included recycled asphalt binder from RAP and RAS. Both projects were produced at HMA temperatures using different WMA technologies as compaction aids. The Capitol Drive project used a chemical WMA additive while the STH 70 project used water injection foaming. Both projects complied with current WisDOT specification requirements. The major findings of the field validation are presented below:

5.3.1 Rutting and Thermal Cracking Performance Tests

The WHRP Project 0092-12-02 Draft Specification With Performance Tests included flow number and Asphalt Thermal Cracking Analyzer tests during design and acceptance for specifying mixtures with adequate resistance to rutting and low temperature cracking. The criteria included in the Draft Specification for the flow number were based on research completed in WHRP Project 0092-09-01 (*9*). Criteria for the Asphalt Thermal Cracking Analyzer were not included in the Draft Specification because less research was completed with this device.

The design and production mixtures for both field projects exceeded the minimum flow number criteria contained in the draft specifications for the traffic level and speed at each project. The Capital Drive project included a number of intersections and the flow number criteria for intersections are 6 times the flow number required for the same traffic level at normal operating speed. Flow number variability was high for two of the production days for the Capital Drive project with coefficients of variation for triplicate tests exceeding 40 percent. Flow number variability for the STH 70 project was reasonable ranging from 7 to 20 percent for triplicate tests.

The results of the fracture temperature from the Asphalt Thermal Cracking Analyzer for the field mixtures showed good correlation with the low temperature grade of the recovered binder as shown in Figure 63. Based on this relationship and the typical standard deviation of the fracture temperature of 1.5 °C, Table 49 presents initial estimates of criteria for the Asphalt Thermal Cracking Analyzer test as a function of the pavement temperature from LTPPBind 3.1. The primary assumption in the use of these criteria is that the low temperature performance grade accurately estimates the thermal cracking performance of Wisconsin mixtures.

The limited field validation completed in this project provides proof of concept of how performance testing can be used to control rutting resistance and low temperature cracking during mixture design and production. Further validation of the criteria for these tests in needed before this approach can be used in practice. Additionally, specimen fabrication and testing time limit the frequency of performance testing.

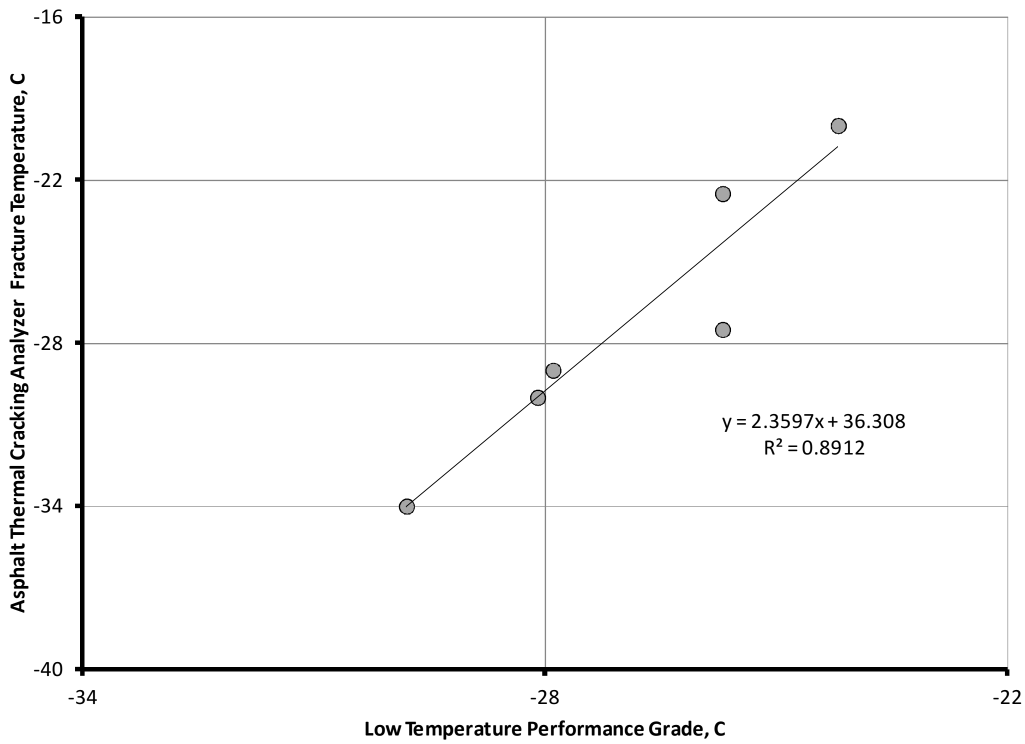


Figure 63. Relationship Between Asphalt Thermal Cracking Analyzer Fracture Temperature and Low Temperature Recovered Binder Grade.

Table 49. Tentative Criteria for Asphalt Thermal Cracking Analyzer From Analysis of Low Temperature Binder Properties.

Low Pavement Temperature from LTPPBind 3.1, °C	Maximum Asphalt Thermal Cracking Analyzer Fracture Temperature, °C
-22	-16
-25	-23
-28	-30
-31	-37
-34	-44

5.3.2 Correction Factors for Reheating

Both of the draft specifications produced in WHRP Project 0092-12-02 include the determination of reheat correction factors. The data collected in the field validation indicate that reheat correction factors may be needed when a transient WMA process such as foaming is used. The chemical WMA process used on the Captiol Drive Project resulted in a correction factor of zero for reheated specimens while the water injection process used on STH 70 resulted in a correction factor of -0.7 percent, indicating that air voids for reheated specimens are 0.7 percent higher than that obtained from specimens compacted without reheating. The difference for this mixture is one half of the allowable tolerance currently included in WisDOT specifications for Department verification testing.

5.3.3 Recycled Materials Properties

The WHRP Project 0092-12-02 Draft Specification Without Performance Tests relies on the careful control of the virgin and recycled asphalt binder in the mixture to provide acceptable rutting and low temperature cracking performance. Testing of the recycled materials from the validation projects showed the potential for significant differences in the binder content of the recycled materials between design and production. The binder content of the production samples of RAS from the Capitol Drive project was 5.7 percent higher than that reported in the mix design. Additionally, the binder content for the production samples of FRAP from the STH 70 project was 1.3 percent lower than that reported in the design. Both of these differences were statistically significant considering the standard deviation of the binder contents from the production samples. The variability of the binder content of RAP from the validation projects was reasonable, having pooled coefficient of variation of 0.30 percent. The variability of the RAS was much higher having a coefficient of variation of 1.6 percent. Changes in the binder content of the recycled materials will result in changes in the binder content of the mix, the recycled binder ratio, and the continuous grade of the blended binder in the mixture.

Aggregate blend changes that change the amount of recycled material included in the mixture will also affect the recycled binder ratio and the grade of the blended binder in the mixture. During the Capitol Drive project, the RAS content was increased 1 percent and the RAP content was decreased 3 percent resulting in an increase in the recycled binder ratio and the amount of recycled binder from the stiffer RAS. The net effect of this production change was a 2.5 °C decrease in the low temperature grade of the blended binder.

The continuous grade properties of the recovered RAP binder for both projects and the recovered RAS binder for the Capitol Drive project were with the materials previously tested in

WHRP Project 0092-10-06 (*3*). The continuous grade of the recovered RAS binder for the STH 70 project was somewhat softer than the materials tested in WRHP Project 0092-10-06.

5.3.4 Moisture Sensitivity

Some variation in the moisture sensitivity of the STH 70 mixture was observed in the production samples. The design tensile strength ratio for this mixture was 71 percent. The tensile strength ratio on production samples of this mixture ranged from 61 to 72, confirming the need to perform moisture sensitivity testing on production samples. Moisture sensitivity results on production samples for the Capitol Drive project, which used a chemical WMA additive, were consistent and showed little deviation from the mix design value of 88 percent.

5.3.5 WMA Mix Design Procedure

Validation of the WMA mix design procedure in the Appendix to AASHTO R35 was not possible using data from the two validation projects. Both projects were produced at HMA temperatures using a WMA process as a compaction aid; therefore, the effect of lower mixture temperatures on compactability and coating could not be evaluated. The water injection foaming process was successfully replicated in the laboratory to prepare specimens for the mix design, performance testing, and for the reheat correction factor evaluation.

Chapter 6. Conclusions and Recommendations

6.1 Conclusions

Several important conclusions were drawn from the laboratory experiments completed in Task 3 of WHRP Project 0092-12-02. The conclusions listed below shaped the draft specifications presented in Appendix B and Appendix C.

1. **RAS Mixing.** It does appear that RAS binders properly mix with new binders even at the highest WMA process temperatures. A minimum production temperature of 300 °F for mixtures containing RAS was included in the draft specifications based on testing from other projects that showed adequate mixing of RAS binders occurs at this temperature.

2. **Short-Term Conditioning for Performance Testing.** The criteria for many performance tests are based in the properties of mixture conditioned in a force draft oven for 4 hours at 135 °C in accordance with the performance test section of AASHTO R30. Recently it has become apparent that this level of conditioning approximates the aging that occurs during construction and a short time in-service. WMA mixtures that are produced and compacted below the AASHTO R30 performance test conditioning temperature of 135 °C should not be conditioned at temperatures exceeding the field compaction temperature. The short-term conditioning experiment concluded that a two step process can be used with WMA mixtures to simulate construction and early in-service aging. Construction aging is simulated by conditioning the mixture for 2 hours at the compaction temperature. Early in-service aging is simulated by conditioning the mixture for 14 hours at 100 °C. When this conditioning is applied to HMA, the rutting resistance is equivalent to that obtained from the standard AASHTO R30 conditioning for performance tests. When applied to WMA, the rutting resistance of the WMA mixtures range from 60 to 90 percent of that for the HMA mixtures, which is reasonable considering the reported field performance of WMA mixtures.

3. **Coating.** A simple, repeatable procedure to evaluate coating could not be developed with the resources available in the project. Image analysis appears to be sensitive to ambient light source and reflectivity of light off the coated aggregate during the image capturing step confounding measurement of the percent uncoated area. Water absorption measurements are overwhelmed by the amount of water that is entrapped in asperities in the coating of the coarse aggregates. Absorption can be used to evaluate the coating of coarse aggregates when coated with binder only, but this approach cannot be used in mixture acceptance.

   Evaluating the quality of coating using the boiling test appears promising. Experiments completed during Task 3 found that although equal coating extent was achieved during mixing, the quality of coating was influenced by viscosity for most conventional and modified binders tested. A moderate relationship between coating quality as measured by the coating index from the boiling test and the tensile strength ration from AASHTO T283 was also observed. However, additional testing including more binder and aggregate sources is needed to confirm this relationship.

   Since a reliable coating test could not be developed and the TOC was concerned with the reproducibility of AASHTO T195, minimum production temperatures for various processes were included in the draft specifications. These production temperatures were based on experience with various WMA processes.

4. **Resistance to Thermal Cracking.** Repeatable measurements of the glass transition temperature and the coefficients of thermal contraction in asphalt mixtures can be made with unrestrained tests in the Asphalt Thermal Cracking Analyzer. However, the thermo-volumetric properties of mixtures alone do not appear to be related to the thermal cracking resistance of mixtures. Based on additional work performed with the Asphalt Thermal Cracking Analyzer, it appears that both the development of thermal strain in an unrestrained sample and thermal stress build up in a restrained sample are needed to obtain a complete evaluation of thermal cracking performance. The draft

specification with performance tests was modified to include parameters from both unrestrained and restrained tests using the Asphalt Thermal Cracking Analyzer.

In Task 5, limited validation of the WHRP Project 0092-12-02 draft specifications was performed using materials from two field projects: (1) WisDOT Project 2025-14-70, Capitol Drive, State Highway 190 from Brookfield Road to State Highway 100, and (2) WisDOT Project 9070-03-60, STH 70 Fifield – Woodruff: North County Line – Morgan Rd. Data from three lots of paving for both projects were collected and analyzed. The mixtures used on these projects included a combination of RAP and RAS. Both mixtures were produced and placed at normal HMA temperatures, but included a WMA process as a compaction aid. The Capitol Drive project used a chemical WMA additive, the STH 70 project used water injection foaming. Conclusions drawn from the field validation testing and analysis are presented below.

1. **Performance Testing.** The WHRP Project 0092-12-02 Draft Specification With Performance Tests included flow number and Asphalt Thermal Cracking Analyzer tests during design and acceptance for specifying mixtures with adequate resistance to rutting and low temperature cracking. The field validation confirmed that these tests can be used to assess mixture performance. The flow number testing confirmed the reasonableness of the criteria that were developed in WHRP Project 0092-09-01 (*9*) and included in the draft specifications. The Asphalt Thermal Cracking Analyzer testing showed good correlation between the fracture temperature and the low temperature continuous grade of binder recovered from the validation project mixtures. Tentative fracture temperature criteria consistent with current low temperature binder grading were developed using data from the validation project mixtures.

   Specimen fabrication and testing time will limit the frequency of acceptance testing using the flow number and Asphalt Thermal Cracking Analyzer tests. The conditioning procedure developed in Task 3 to reasonably address both WMA and HMA mixtures requires overnight conditioning of loose mix prior to specimen fabrication. Specimen fabrication for both tests require sawing and coring test specimens from larger gyratory specimens. The testing time with the Asphalt Thermal Cracking Analyzer test is approximately 3 hours; the flow number test is much shorter requiring about 20 minutes for the highest traffic level mixtures. Overall, fabrication and testing of performance specimens requires approximately 3 days.

2. **Unified WMA and HMA Volumetric Design.** Both of the WHRP Project 0092-12-02 draft specifications include the WMA Appendix for AASHTO R35 to provide a unified mixture volumetric design procedure for WMA and HMA mixtures. For design, the draft specifications also include the establishment of reheat correction factors for reconciling quality control data which is collected on plant samples without reheating and verification data which is collected on retained samples after reheating. Validation of the complete design procedure was not possible using data from the two projects because both mixtures were produced at hot mix temperatures. Portions of the design procedure were validated. First, volumetric properties of laboratory samples prepared from component materials using the specified design procedure compared well with those for field produced mixtures. Of particular interest was the comparison for the water injection foaming process used on the STH 70 project which was successfully reproduced in the laboratory using a Wirtgen WLB-10 laboratory foaming device. Second, the reheat correction factor was significant for the STH 70 water injection foaming mixture, but not for the chemical WMA additive used in the Capitol Drive mixture. The correction factor for the water injection foaming process was 0.7 percent, which is approximately one half of the allowable tolerance for verification results in the current WisDOT specifications and the WHRP Project 0092-12-02 draft specifications.

3. **Recycled Material Properties.** The WHRP Project 0092-12-02 Draft Specification Without Performance Tests relies on the careful control of the virgin and recycled asphalt binder in the mixture to provide acceptable rutting and low temperature cracking performance. This control includes limiting the amount of recycled binder used depending on the source (RAP or RAS) when no adjustment is made to the virgin binder grade, and measuring the binder content of the recycled materials daily during production. The recycled binder content limits included in the draft specification were

those developed in WHRP Project 0092-10-06, which are based on limiting the change in the low temperature grade to less than 3 °C for surface mixtures (*3*).

Both projects used recycled binder contents that were greater than permitted by the WHRP draft specification for surface mixtures. The maximum recycled binder ratio for RAS in the WHRP 0092-12-03 draft specification is 5 percent when no RAP is used. The maximum recycled binder ratio for RAP is 20 percent when no RAS is used. When RAP is used with RAS, the allowable RAP recycled binder ratio decreases 4 percent for each 1 percent RAS binder replacement. These criteria are somewhat more conservative for RAP than those developed in NCHRP Project 9-46, which recommends no change in the grade of the virgin binder as long as the RAP binder ratio is less than 25 percent (*23*). NCHRP Project 9-46 did not address RAS. The Capitol Drive production mixture averaged 20.7 percent RAS binder replacement and 7.8 percent RAP binder replacement while the STH 70 production mixture averaged 13.4 percent RAS binder replacement and 9.6 percent RAP binder replacement. The change in the low temperature grade for binder recovered from the production mixtures averaged 5.7 °C for the Capitol Drive project and 1.4 °C for the STH 70 project. The RAS binder from the STH 70 was significantly softer than the RAS tested in WHRP Project 0092-10-06. The RAP from both projects and the RAS from the Capitol Drive project were within the range of the materials tested in WHRP Project 0092-10-06 (*3*). Although the change in low temperature grade for the two projects cannot be used to validate the recycled binder ratio limits in the draft specification, they indicate that it is possible to have nearly a one grade change in low temperature properties using current WisDOT binder replacement criteria.

The WHRP 0092-12-02 draft specification also requires measuring the binder content of the recycled materials during production and controlling the binder replacement within tolerance limits that were to be determined using data from the validation projects. The characterization of the recycled materials showed that it is important to measure the binder content of the recycled materials during production. In some cases, there were significant differences between the binder contents reported in the mix designs and those measured during production. The variability of the binder content of the RAS during production was higher than that for the RAP. The pooled standard deviation of the RAS binder replacement was 1.3 percent compared to 0.5 percent for the RAP binder replacement. These data suggest production tolerance limits for the average of 4 samples of 1.3 percent for RAS binder replacement and 0.5 percent for RAP binder replacement.

4. **Recovered Binder Properties.** The average continuous performance grade of binder recovered from the mixtures was PG 73.4 (21.7) -25.2 for the Capitol Drive project and PG 69.6 (19.8) -28.6 for the STH 70 project. Based on the nearest LTPPBind weather station, the reliability against thermal cracking was 97.3 percent for the Capitol Drive project, but only 77.9 percent for the STH 70 project. The primary reason for the lower reliability against thermal cracking for the STH 70 project was the selection of PG 58-28 virgin binder. Had no recycled binder been used on this project, the reliability against thermal cracking would have been 88.1 percent based on the properties of the virgin binder. This emphasizes the need to consider the environmental conditions at the project location when selecting virgin binder grades. The recycled binder used in the Capitol Drive project had greater effect on the mixture low temperature properties compared to the recycled binder used in the STH 70 project, but because both projects used PG XX-28 binders and the environment for the Capitol Drive project was less severe, the Capitol Drive project had greater reliability against thermal cracking.

5. **Blending Chart Analysis.** The procedures recommend in WHRP Project 0092-10-06 were used to develop blending charts for the recycled materials for both projects (*3*). There was good agreement between the blending charts and the binder recovered from the production mixtures. On the Capitol Drive project, the blending chart estimated a continuous binder grade of PG 79.0 (21.9) -24.1 compared to an average recovered continuous binder grade of PG 73.4 (21.7) -25.1. The agreement for the STH 70 project was better with the blending chart estimating a continuous binder grade of PG 69.3 (19.7) -28.0 compared to an average recovered continuous binder grade of

PG 69.6 (19.8) -28.6. These comparisons, while limited, confirm the usefulness of blending chart analysis in mixture design.

The blended binder reliability analysis developed in WHRP Project 0092-10-06 appears to provide a reasonable and flexible approach for determining allowable binder replacement. This analysis uses low temperature data from LTPPBind for the nearest weather station and blending charts to determine the required low temperature grade for a given level of reliability. Using this approach, the blended binder in the mixture for the Capitol Drive project, had a reasonable reliability against thermal cracking of 97.3 percent. The STH 70, on the other had a lower reliability of against thermal cracking of 77.9 percent, primarily due to the selection of a PG 58-28 as the virgin binder grade.

6. **Moisture Sensitivity.** Both WHRP Project 0092-12-02 draft specifications include moisture sensitivity testing on production mixtures. The limited field validation confirmed that this testing should be included. The STH 70 mixture has a design tensile strength ratio of 71 percent. During production values as low as 62 percent were measured.

6.2 Recommendations

The primary recommendation concerning the draft specifications developed in WHRP Project 0092-12-03 is that additional validation work is needed before either specification can be considered for implementation. With the available budget, only two field projects could be included in the validation effort, and both project used WMA processes at HMA temperatures as compaction aids. If additional validation work is undertaken, a wider range of projects should be considered. Of particular interest are high recycle content mixtures produced at reduced temperatures using various WMA processes. WisDOT should consider performing the testing that was conducted during the field validation on additional projects from throughout the state and monitoring the performance of the projects. This will provide additional data to further refine the WHRP Project 0092-12-02 draft specifications. It will also provide important data on mixture composition that can lead to improvement in the performance of asphalt mixtures in Wisconsin.

The work completed in WHRP Project 0092-12-02 has shown promise in using performance related tests for the design and acceptance of a asphalt concrete mixtures. For the flow number and Asphalt Thermal Cracking Analyzer tests included in the WHRP Project 0092-12-02 draft specifications, specimen fabrication and testing time severely limit the frequency at which this testing can be conducted. WisDOT should consider investigating other performance related tests which require less time. The specific tests that should be investigated are: (1) the high temperature IDT test for rutting resistance (*8*), and (2) an acoustic emission test to characterize the embrittlement temperature of asphalt concrete mixtures (*24*). Both of these tests can be conducted on the gyratory specimens that are fabricated for normal volumetric quality control. The high temperature IDT test has shown excellent correlation with the flow number test, and the testing can be conducted with the load frames used to conduct either Marshall stability or the indirect tensile test for AASHTO T283. Criteria similar to the flow number have been developed for this test (*8*). In the acoustic emission test, the compacted HMA specimen is placed in a small cooling chamber with acoustic emission sensors. The specimen is gradually cooled while monitoring for acoustic emission events. When the specimen becomes embrittled, microcracking caused by internal thermal stresses begin to produce acoustic emission event. Although additional development of the method is needed, embrittlement temperatures determined in this way in general have compared favorably to other indicators of low temperature performance, such as critical temperatures determined using the bending beam rheometer (*24*).

In addition to the recommendations specific to WHRP Project 0092-12-02 draft specifications, the following recommendations are provided for consideration in future research projects.

1. The coating study introduced the concept that mixture durability is dependent on both the extent and quality of coating. AASHTO T195 included in the WMA mix design procedure measures of only the extent of coating; coating quality is not considered. Recent research at UW-MARC conducted in parallel to this project assessed the quality

of coating using the boiling test specified in ASTM D3625. The study served as a proof of concept that achieving a sufficient extent of coating does not necessarily guarantee quality. In the study, aggregates were coated to the same extent using different mixing temperatures. The results from the boiling test indicated that the quality of the bond was substantially less when the asphalt binder was mixed with the aggregate at lower temperatures. Limited indirect tensile test data was collected and a strong relationship between coating loss after boiling and TSR values was observed. It is recommended that WisDOT consider further development of the boiling test as a means to verify acceptable coating. This test could be used for mixture design and acceptance.

2. It may be possible to improve the current WMA coating evaluation, AASHTO T195, by incorporating the scale for determination of degree of asphalt binder coverage from UNI EN 12697-11 in the procedure. This will allow the consideration of the extent of coating on each particle.

3. Further evaluation of the tentative fracture stress criteria for the Asphalt Thermal Cracking Analyzer test developed from the field validation mixtures is needed. WisDOT should consider testing additional mixtures and monitoring field performance to establish appropriate specification limits for this test.

4. Both mixture thermo-volumetric properties and stress build up during cooling are strongly influenced by mixture components, specifically the glass transition temperatures of the bituminous materials and the aggregate structure developed during compaction. Additional validation efforts for the Asphalt Thermal Cracking Analyzer test should included the measurement of the aggregate structure of the test specimens through use of planar imaging processing and analysis techniques (IPas^2) to establish the effects of experimental factors on aggregate structure parameters and investigate correlations with thermal cracking resistance.

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Appendix A. Initial Recommended Specification Changes

Introduction

This Appendix documents the work completed in Task 1 of WHRP Project 0092-12-02. In this task the following documents were reviewed considering recent research concerning WMA and the use of reclaimed asphalt pavement (RAP) and recycled asphalt shingles (RAS) in HMA and WMA:

1. Section 460 of the 2012 WisDOT Standard Specifications including Additional Special Provision 6,
2. Chapter 8, Section 65 of the WisDOT Construction and Materials Manual.

The focus of the review was the development of a single specification covering HMA, WMA, and SMA produced with or without recycled asphaltic binders. The recommended changes to Section 460 of the WisDOT Standard Specifications are described below using the headings from Section 460.

460.1 Description

Several approaches to modifying the terminology used in Section 460 were considered. Most of these, such as using asphalt concrete in place of HMA, would result in the need to make changes to other referenced documents, including certification programs and titles. One approach that limits the changes to Section 450 and 460 of the Standard Specifications and Chapter 8, Section 65 of the WisDOT Construction and Materials Manual is to define HMA as asphalt concrete produced at elevated temperature. Therefore, it is recommended to replace Paragraph 1 of Section 460.1 with the following:

(1) Hot Mix Asphalt (HMA) is defined as asphalt concrete produced at elevated temperature where the aggregates are dried before mixing with asphaltic binder. This includes traditional HMA mixtures produced between 260 and 340 ºF and mixtures produced as warm mix asphalt (WMA) using WMA additives or processes approved by the department. This section describes HMA mixture design, providing and maintaining a quality management program for HMA mixtures, and constructing HMA pavement.

460.2 Materials

Most of the recommended changes are to this part of Section 460. The recommended changes are discussed below in the order of the subheadings in this part of the specification.

460.2.1 General

Modify paragraph 1 of Section 460.2.1 to include the language in Additional Special Provision 6:

(1) Furnish a homogeneous mixture of coarse aggregate, fine aggregate, mineral filler if required, SMA stabilizer if required, recycled material if used, warm mix asphalt additive or process if used, and asphaltic material.

460.2.2 Aggregates

No changes to the aggregates section are needed.

460.2.3 Asphaltic Binders

To allow the greatest flexibility for producing mixtures with WMA processes and/or different recycled materials, it is recommended that the specification be modified to use mixture tests for rutting resistance and low temperature cracking to control the binder in the mixture. These tests would be conducted during design and as part of quality control. The department would specify values for the flow number test to control rutting resistance and the values for glass transition temperature and coefficient of thermal contraction/expansion from the thermal contraction and glass transition temperature test to control thermal cracking rather than a binder grade. Therefore, Paragraph 1 of Section 460.2.3 should be modified as follows:

(1) The department will designate the required rutting resistance (high design temperature and flow number) and thermal cracking resistance (coefficient of contraction and glass transition temperature) of the HMA. The contractor may use neat binder; modified binder; and RAP, FRAP, and RAS to produce mixtures meeting the specified levels of rutting resistance and thermal cracking resistance. All virgin binders (neat or modified) used in HMA shall conform to the requirements of AASHTO M320. The contractor shall designate the grade of the virgin binder used in HMA mixtures.

This section does not allow the use of rejuvenating agents unless they are added to the virgin binder, and then certified to meet AASHTO M320 requirements for the binder grade designated by the producer.

460.2.4 Warm Mix Additive or Process

To cover WMA and to provide the department control over the WMA additives and processes, a section on WMA additives and processes should be added as was done in Additional Special Provision 6. The wording should be revised to be consistent with the definition of HMA included in Section 460.1 Description:

(1) Use additives or processes from the department's approved product list. Follow supplier or manufacturer recommendations when using WMA additives or processes to produce HMA.

460.2.5 Recycled Asphaltic Materials

Based on the findings from WHRP Project 0092-10-06 where recovered RAP binder properties were found to be relatively consistent throughout Wisconsin and recovered RAS binder properties were also relatively consistent (*1*), the effect of these materials can be controlled during production by controlling how much of the virgin binder each replaces. Since WMA processes may improve low temperature properties, it is recommended that the producer be provided flexibility within general maximum binder replacement levels to produce design mixtures meeting the requirements for rutting resistance and thermal cracking resistance. Once that mixture is designed, then the contribution of each type of recycled material to total binder content of the mixture should be controlled through quality control testing during production. This can be accomplished by eliminating Paragraph 2 containing the allowable binder replacement and modifying Paragraph 1 to read:

(1) Binder replacement, defined as the ratio of weight percent recycled asphaltic binder to weight percent total asphaltic binder, shall not exceed 0.35 for upper layers and 0.50 for lower layers.

The suggested limits of 0.35 and 0.50 are based on the findings from WHRP 0092-10-06 for RAP mixtures which were increased to account for the positive effect of WMA processes on resistance to low temperature cracking. These are maximum limits to ensure homogeneity of the mixture and the design and production mixture will still be required to meet the specified rutting resistance based on the flow number and thermal cracking resistance based on the thermal contraction and glass transition temperature test. If RAS is used it is unlikely that these maximum replacement levels will be reached.

An outstanding issue to be addressed in the laboratory experiments, is whether RAS properly mixes at WMA temperatures. NCHRP Project 9-43 and numerous field demonstration projects have shown that RAP does mix well at WMA temperatures (*2*). One of the experiments proposed for WHRP Project 0092-12-02 is an extension of the NCHRP Project 9-43 RAP mixing study to include RAS. The objective of this experiment is to determine if a low production temperature limit is needed for mixtures incorporating RAS.

460.2.6 Recovered Asphaltic Binders

It is recommended that the title of this section be change to Recycled Asphaltic Binders because recovered binder is only available in laboratory tests. Further, Paragraph 2 addressing binder replacement ratios should be deleted and Paragraph 1 should be modified to address each recycled material and that testing is needed for design and quality control. If the recycled binder contribution changes during production, the producer should modify the virgin binder content to maintain the mixture within the production asphalt contents.

(1) Establish the recycled asphaltic binder content of each recycled material for mixture design and quality control according to AASHTO T164 using the appropriate dust correction procedure. If quality control tests indicate a change in the recycled asphaltic binder content during production, adjust the virgin binder added to maintain the total asphaltic binder content of the mixture within the tolerances given in Section 460.2.8.2.1.5

460.2.7 HMA Mixture Design

Several changes to mixture design are needed to implement the recommended specification changes. This includes changes to Section 460.2.7 of the WisDOT Standard Specifications and changes to WisDOT test method 1559 in the Construction and Materials Manual. The primary change in Section 460.2.7 is a modification of Table 460-2 to include:

- **Coating.** An evaluation of coating at the production temperature. It is generally agreed that for the wide range of WMA processes that are available, some evaluation of coating rather than a viscosity based mixing temperature is needed. In NCHRP Project 9-43, AASHTO T195 was included in the recommended WMA appendix to AASHTO R35 (*2*). This method is highly subjective and likely not repeatable between operators. Therefore, one of the experiments planned for WHRP Project 0092-12-02 is an evaluation of other methods for quantifying coating that can be used for mixture design, quality control, and acceptance.
- **Compactability.** Compactability as specified by the gyration ratio in the WMA appendix to AASHTO R35. This involves compacting specimens at the optimum binder content at two temperatures: the planned field compaction temperature and 30 ºC below the planned compaction temperature. A tentative gyration ratio of 1.25 was included in the WMA appendix to AASHTO R35 (*2*). This tentative criteria should be evaluated in the field projects included in WHRP Project 0092-12-02.
- **Flow Number.** Recommendations for using the flow number test, AASHTO TP79, in mixture design and acceptance were developed in WHRP Project 0092-09-01 (*3*). These recommendations include criteria for acceptable rutting resistance considering the design high pavement temperature, design traffic level and design traffic speed. The level of short-term conditioning has a significant effect on flow number test results. Criteria for 2 hours at the compaction temperature, and 4 hours at 135 ºC, the standard AASHTO R30 conditioning for performance testing, were provided in WHRP Project 0092-09-01. The criteria in the modified Table 460-2 are based on 2 hours of short-term conditioning at the compaction temperature. Since the recommended specifications include flow number testing on both laboratory and plant produced mixtures, further evaluation of short-term conditioning is proposed as a experiment in WHRP Project 0092-12-02. The objective of this experiment is to develop short-term conditioning procedures that can be applied to both laboratory and plant produced mixtures.
- **Thermal Contraction and Glass Transition Temperature Test.** Two measurements from the thermal contraction and glass transition temperature test that was developed in the Asphalt Research Consortium (ARC) project are being considered as measures of the thermal cracking resistance of asphalt concrete mixtures: (1) the coefficient of thermal

contraction/expansion (CTE), and (2) the glass transition temperature. Figure A1 compares thermal cracking in three sections at MNROAD with the coefficient of thermal contraction and the glass transition temperature. WHRP Project 0092-12-02 includes a laboratory experiment to develop appropriate initial criteria for Wisconsin considering current WisDOT binder selection.

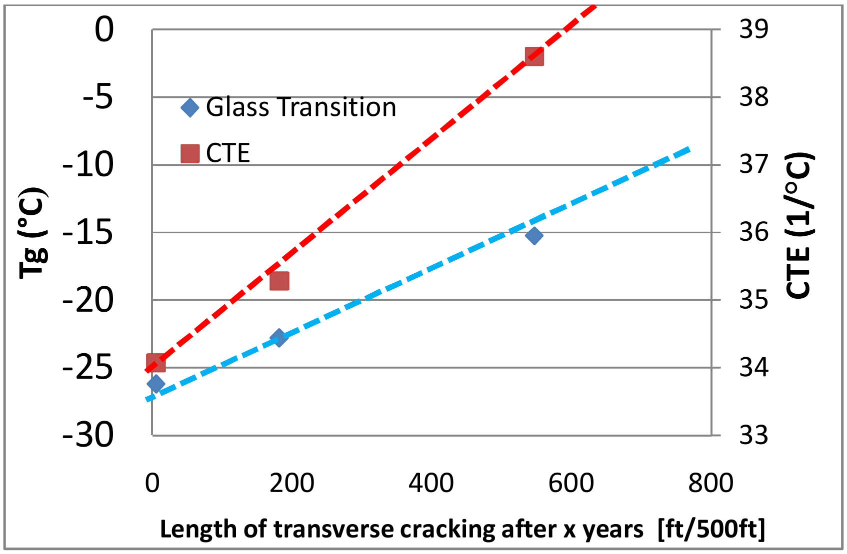


Figure A1. Comparison of Thermal Cracking With Thermal Contraction and Glass Transition Temperature Test Results.

- **Reheat Correction Factor for WMA.** WisDOT verification testing will always be performed on reheated samples. Reheat correction factors for volumetric analysis should be developed during mixture design. This will require a WisDOT test method to be developed.

The recommended changes to Table 460-2 are shown in Table A1. In addition to these changes, WisDOT test method 1559 will require modification to incorporate the additional testing described above.

Table A1. Recommended Modifications to Table 460-2.

Mixture type	E - 0.3	E - 1	E - 3	E - 10	E - 30	E - 30x	SMA
ESALs x 10^6 (20 yr design life)	< 0.3	0.3 - < 1	1 - < 3	3 - < 10	10 - < 30	>= 30	___
LA Wear (AASHTO T 96) 100 revolutions(max % loss) 500 revolutions(max % loss)	 13 50	 13 50	 13 45	 13 45	 13 45	 13 45	 13 40
Soundness (AASHTO T 104) (sodium sulfate, max % loss)	12	12	12	12	12	12	12
Freeze/Thaw (AASHTO T 103) (specified counties, max % loss)	18	18	18	18	18	18	18
Fractured Faces (ASTM 5821) (one face/2 face, % by count)	60 / __	65 / __	75 / 60	85 / 80	98 / 90	100/100	100/90
Flat & Elongated (ASTM D 4791) (max %, by weight)	5 (5:1 ratio)	5 (5:1 ratio)	5 (5:1 ratio)	5 (5:1 ratio)	5 (5:1 ratio)	5 (5:1 ratio)	20 (3:1ratio)
Fine Aggregate Angularity (AASHTO T304, method A, min)	40	40	43	45	45	45	45
Sand Equivalency (AASHTO T 176, min)	40	40	40	45	45	50	50
Gyratory Compaction Gyrations for N_{ini} Gyrations for N_{des} Gyrations for N_{max}	 6 40 60	 7 60 75	 7 75 115	 8 100 160	 8 100 160	 9 125 205	 8 65 160
Air Voids, $\%V_a$ ($\%G_{mm}\ N_{des}$)	4.0 (96.0)	4.0 (96.0)	4.0 (96.0)	4.0 (96.0)	4.0 (96.0)	4.0 (96.0)	4.0 (96.0)
$\%\ G_{mm}\ N_{ini}$	<= 91.5[1]	<= 90.5[1]	<= 89.0[1]	<= 89.0	<= 89.0	<= 89.0	___
Dust to Binder Ratio[2] (% passing 0.075/Pbe)	0.6 - 1.2	0.6 - 1.2	0.6 - 1.2	0.6 - 1.2	0.6 - 1.2	0.6 - 1.2	1.2 - 2.0
Voids filled with Binder (VFB or VFA, %)	70 - 80[4 [5]	65 - 78[4]	65 - 75[4]	65 - 75[3] [4]	65 - 75[3] [4]	65 - 75[3] [4]	70 – 80
Tensile Strength Ratio (TSR) (ASTM 4867) no antistripping additive with antistripping additive	 0.70 0.75	 0.70 0.75	 0.70 0.75	 0.70 0.75	 0.70 0.75	 0.70 0.75	 0.70 0.75
Compactability (Gyration Ratio, Appendix AASHTO R35)	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Flow Number at High Design Temperature (Test Method BBB) [6] Highway Speed Slow Speed Intersection	 ___ ___ ___	 5 15 30	 10 30 60	 20 60 120	 45 135 ___	 105 315 ___	 105 315 ___
Thermal Cracking Properties (AASHTO TPZZ) [7]	North / South	North / South	North / South	North / South	North / South	North / South	North / South
Unrestrained	TBD / TBD	TBD / TBD	TBD / TBD	TBD / TBD	TBD / TBD	TBD / TBD	TBD / TBD
Restrained	TBD / TBD	TBD / TBD	TBD / TBD	TBD / TBD	TBD / TBD	TBD / TBD	TBD / TBD
Reheat Correction Factor for WMA (Test Method CCC) [8]	Report	Report	Report	Report	Report	Report	Report
Draindown at Production Temperature (%)	___	___	___	___	___	___	0.30

Notes:

[1] The percent maximum density at initial compaction is only a guideline.

[2] For a gradation that passes below the boundaries of the caution zone(ref. AASHTO MP3),

the dust to binder ratio limits are 0.6 - 1.6.

[3] For 9.5mm nominal maximum size mixtures, the specified VFB range is 73 - 76%.

[4] For 37.5mm nominal maximum size mixes, the specified VFB lower limit is 67%.

[5] For 25.0mm nominal maximum size mixes, the specified VFB lower limit is 67%

[6] Test Method BBB is WisDOT modification of AASHTO TP79 to specify binder content, filler content, short-term aging, specimen air voids, contact deviator stress, and repeated deviator stress. To be develop in WHRP Project 0092-12-02

[7] AASHTO TPZZ under implementation in Asphalt Research Consortium project

[8] Test Method CCC to be developed in WHRP Project 0092-12-02

TBD = criteria to be determined in WHRP Project 0092-12-02

460.2.8 Quality Management Program

Section 460.2.8 also requires several changes. These are discussed below for Contractor Testing and Department Testing.

460.2.8.2 Contractor Testing

No changes are needed for the Personnel Requirements and Laboratory Requirements in this section. Changes are recommended for the Required Sampling and Testing as discussed below.

<u>460.2.8.2.1.3.1 Contracts with 5000 Tons of Mixture or Greater</u>

Paragraph 1 of this section should be modified to permit off-site flow number, and thermal contraction and glass transition temperature testing. These tests will not be performed at the same frequency as current quality control tests. Modify Paragraph 1 to read:

(1) Furnish and maintain a laboratory at the plant site fully equipped to perform the daily contractor QC testing. Have the laboratory on-site and operational before beginning mixture production. Flow number, and thermal contraction and glass transition temperature testing may be conducted at an off-site laboratory.

Paragraph 2 should be modified to require testing of volumetric quality control samples without reheating:

(2) Obtain random samples and perform tests according to CMM 8.36. Obtain HMA mixture samples from trucks at the plant. Perform quality control tests for air voids without reheating samples.

Paragraph 4 should be modified to identify the required daily quality control testing and to add asphalt content and gradation tests for each source of recycled material and evaluation of coating using the method to be developed in WHRP Project 0092-12-02:

(4) Use the test methods identified below, or other methods the engineer approves, to perform daily QC testing at a frequency greater than or equal to that indicated:

Each recycled asphaltic material

Asphalt content according to AASHTO T164

Gradation according to AASHTO T30

Blended aggregate gradations:

Drum plants:

- Field extraction by department test method number 1560.
- Belt samples, optional for virgin mixtures, obtained from stopped belt or from the belt discharge using an engineer-approved sampling device and performed according to AASHTO T11 and T27.

Batch plants:

- Field extraction by department test method number 1560.

Asphalt content (AC) in percent:

AC by calculation.

AC by nuclear gauge reading, optional.

AC by inventory, optional.

Bulk specific gravity of the compacted mixture according to AASHTO T166.

Maximum specific gravity according to AASHTO T 209.

Air voids (Va) by calculation according to AASHTO T 269.

VMA by calculation according to AASHTO R 35

Coating according to Test Method AAA

Paragraph 5 should be modified to provide a testing frequency for each recycled source. Daily testing of each recycled source is recommended. All other quality control testing will follow current frequencies:

(5) Test each recycled asphaltic material source daily. Test each design mixture at a frequency at or above the following:

TOTAL DAILY PLANT PRODUCTION FOR DEPARTMENT CONTRACTS in tons	SAMPLES PER DAY[1]
50 to 600	1
601 to 1500	2
1501 to 2700	3
2701 to 4200	4
greater than 4200	see footnote[2]

[1] Frequencies are for planned production. If production is other than planned, conform to CMM 8.36.

[2] Add a random sample for each additional 1500 tons or fraction of 1500 tons.

Add a new Paragraph 6 that addresses the frequency of quality control flow number, and thermal contraction and glass transition temperature testing. This testing will be at a reduced frequency compared to normal volumetric quality control testing and treated similarly to current field tensile strength ratio testing. The recommended frequency is one test per 10,000 tons of mixture:

(6) Conduct (1) flow number and (2) thermal contraction and glass transition temperature testing on each design mixture at the rate of 1 test per 10,000 tons. Obtain samples within the first 2,000 tons of each increment. If test results are below the specification limit, stop production and notify the engineer. The engineer and contractor will jointly determine a corrective action.

Renumber the current Paragraph 6 as Paragraph 7 and make moisture sensitivity testing mandatory for all mixtures. The major concern with mixtures using WMA additives and processes is whether the resistance to moisture damage is less for these mixtures. There are currently two national research studies in progress addressing this issue: NCHRP Project 9-49 and NCHRP 9-49A (*4*). Until these projects are completed it is recommended that WisDOT require production moisture sensitivity testing for all mixtures.

(7) Conduct field tensile strength ratio tests according to ASTM D 4867 on all mixtures. Test each full 50,000 ton production increment, or fraction of an increment, after the first 5,000 tons of production. Perform required increment testing in the first week of production of that

increment. If field tensile strength ratio values are either below the spec limit or less than the mixture design JMF percentage value by 20 or more, stop production and notify the engineer. The engineer and contractor will jointly determine a corrective action.

460.2.8.2.1.3.2 Contracts with Less than 5000 Tons of Mixture

This section of the specification only includes one paragraph. It should be modified to require flow number, thermal contraction and glass transition temperature, and tensile strength ratio testing on one sample:

(1) Conform to 460.2.8.2.1.3.1 modified as follows:
- The contractor may conduct QC tests in an off-site laboratory.
- One field tensile strength ratio testing is required.
- One flow number test is required
- One thermal contraction and glass transition temperature test is required.

460.2.8.2.1.3.3 Contracts with Less than 500 Tons of Mixture

No changes to this section are needed.

460.2.8.2.1.3.4 Temporary Pavements

No changes to this section are needed.

460.2.8.2.1.4.1 Documentation

No changes to this section are needed.

460.2.8.2.1.4.2 Control Charts

Changes are needed in the Control Charts section to add control charts for binder replacement and coating as outlined below:

(1) Maintain standardized control charts at the laboratory. Record contractor test results on the charts the same day as testing. Post CA test results on the charts as data becomes available. Record data on the standardized control charts as follows:
- Blended aggregate gradation tests in percent passing. Of the following, plot those sieves the design specifications require: 37.5-mm, 25.0-mm,

19.0-mm, 12.5-mm, 9.5-mm, 2.36-mm, and 75-µm.

- Asphalt material content in percent.
- Binder replacement from each recycled asphaltic material source based on daily recycled asphalt material content and current asphalt material content.
- Air voids in percent.
- VMA in percent.
- Coating in appropriate units

For mixtures incorporating recycled materials it is important to monitor the amount of virgin binder replaced with recycled binder as this will affect the results of the flow number and the thermal contraction and glass transition temperature tests.

460.2.8.2.1.5 Control Limits

Limits for binder replacement and coating need to be added to this section. The binder replacement limits should apply to RAS and RAP sources separately due to their significantly different properties. Modify Paragraph 1 as follows:

(1) Conform to the following control limits for the JMF and warning limits based on a running average of the last 4 data points:

ITEM Percent passing given sieve:	JMF LIMITS	WARNING LIMITS
37.5-mm	+/- 6.0	+/- 4.5
25.0-mm	+/- 6.0	+/- 4.5
19.0-mm	+/- 5.5	+/- 4.0
12.5-mm	+/- 5.5	+/- 4.0
9.5-mm	+/- 5.5	+/- 4.0
2.36-mm	+/- 5.0	+/- 4.0
75-µm	+/- 2.0	+/- 1.5
Asphaltic content in percent	+/- 0.4	+/- 0.3
Air voids in percent	+/- 1.3	+/- 1.0
VMA in percent	- 1.5	- 1.2
RAP binder replacement	+/- aa	+/- bb
RAS binder replacement	+/- aa	+/- bb
Coating	xx min	yy min

Appropriate limits for binder replacement will be determined in WHRP Project 0092-12-02 considering the effects of RAP and RAS on binder grade using data from WHRP Project 0092-

10-06 (*1*). It is recommended that the JMF limit for coating be the minimum allowable and that the warning limit be somewhat higher.

460.2.8.2.1.6 Job Mix Formula Adjustment

No changes to this section are needed.

460.2.8.2.1.7 Corrective Action

Paragraph 6 addressing payment should be modified to include pay factors for binder replacement and coating as follows:

(6) The department will reduce payment for nonconforming QMP HMA mixtures, starting from the stop point to the point when the running average is back inside the warning limits, as follows:

ITEM	PAYMENT FOR MIXTURE[1] [2]	
	PRODUCED WITHIN WARNING BANDS	PRODUCED OUTSIDE JMF LIMITS
Gradation	90%	75%
Asphalt Content	85%	75%
Air Voids	70%	50%
VMA	90%	75%
Binder Replacement[3]	aa%	bb%
Coating	100%	50%

[1] For projects or plants where the total production of each mixture design requires less than 4 tests refer to CMM 8.36.

[2] Payment is in percent of the contract unit price for both the HMA Pavement and Asphaltic Material bid items. The department will reduce pay based on the nonconforming property with lowest percent pay. The asphaltic material quantity is based on the JMF asphalt content. The department will administer pay reduction under the Nonconforming QMP Asphaltic Material and the Nonconforming QMP HMA Mixture administrative items.

[3] Pay adjustment for binder replacement waived if the flow number testing and the thermal contraction and glass transition temperature testing provide acceptable properties.

Recommended pay factors for binder replacement will be developed in WHRP Project 0092-12-02 considering the effects of RAP and RAS on binder grade using data from WHRP Project 0092-10-06. If the flow number testing and the thermal contraction and glass transition testing indicate compliance with the specifications, then pay adjustments based on binder replacement will not be applied. Because, the JMF Limit for coating will be set at the specification minimum, it is recommended that payment be 100 percent for coating to the JMF limit. It is recommended that coating outside the JMF limit be treated the same as air voids. Paragraph 8 of this section should also be modified to treat coating in the same manner as air voids.

(8) If the air voids or coating running average of 4 exceeds the JMF limits, the material is nonconforming. Remove and replace unacceptable material at no additional expense to the department. The engineer will determine the quantity of material to replace based on the testing data using the methods in CMM 8.36 and an inspection of the completed pavement. If the engineer allows the mixture to remain in place, the department will pay for the mixture and asphaltic material at 50 percent of the contract price.

Changes to the Optional Contractor Assurance section are needed to add the additional tests required by the specification. These changes are described below:

460.2.8.2.2.4 Testing

Modify Paragraph 2 to include additional testing required by the specifications. Also since reheated samples will be used in this testing, modify the air void calculation to include the use of the reheat factors.

(2) Perform selected testing as follows:

- Bulk specific gravity (Gmb) of the compacted mixture according to AASHTO T 166 based on the average of 2 specimens.
- Maximum specific gravity (Gmm) according to AASHTO T 209.
- Air voids (Va). Calculate according to AASHTO T 269. If reheated samples are used, apply reheat adjustment from approved mixture design.
- Asphalt content
- Binder replacement based on daily recycled asphalt material content
- VMA by calculation according to AASHTO R 35.
- Coating according to Test Method AAA
- Flow number according to Test Method BBB
- Coefficient of thermal contraction from thermal contraction and glass transition test (AASHTO TPZZ)
- Glass transition from thermal contraction and glass transition test (AASHTO TPZZ)

460.2.8.2.2.6 Allowable Differences

Paragraph 1 needs to be modified to provide allowable limits between quality control and optional contractor assurance test results.

(1) Differences between the QC and CA split sample test results are acceptable in limiting liability, as provided in CMM 8.36, if within the following limits:

ITEM	ALLOWABLE DIFFERENCES
Percent passing 12.5 mm sieve	6.0
Percent passing 9.5 mm sieve	6.0
Percent passing 4.75 mm sieve	5.0
Percent passing 2.36 mm sieve	4.0
Percent passing 600-µm sieve	3.5
Percent passing 75-µm sieve	2.0
Bulk specific gravity of the compacted mixture	0.030
Maximum specific gravity	0.020
Asphalt content	TBD
Binder Replacement	TBD
Coating	TBD
Flow number	TBD
Thermal coefficient of contraction	TBD
Glass transition temperature	TBD

Recommended allowable differences will be determined in WHRP Project 0092-12-02 based on the laboratory reproducibility of the tests (i.e., variability of results obtained from different laboratories) because quality control and optional contractor assurance tests are conducted in separate laboratories on split samples.

460.2.8.3 Department Testing

The changes that are needed to the Quality Verification Program are similar to those described for the Optional Contractor Assurance: (1) add additional tests required by the specification, and (2) appropriate limits for those tests.

460.2.8.3.1.4 Department Verification Testing Requirements

It is recommended that verification include evaluation of: (1) air voids, (2) VMA, (3) coating, (4) flow number, (5) coefficient of thermal contraction, and (6) glass transition temperature. Modify Paragraph 3 to read:

(3) Perform selected testing as follows:
- Bulk specific gravity (Gmb) of the compacted mixture according to AASHTO T 166 based on the average of 2 specimens.
- Maximum specific gravity (Gmm) according to AASHTO T 209.
- Air voids (Va). Calculate according to AASHTO T 269, then apply reheat adjustment from approved mixture design.
- VMA by calculation according to AASHTO R 35.
- Coating according to Test Method AAA
- Flow number according to Test Method BBB
- Coefficient of thermal contraction from the thermal contraction and glass transition test (AASHTO TPZZ)
- Glass transition from the thermal contraction and glass transition test (AASHTO TPZZ)

460.2.8.3.1.6 Acceptable Verification Parameters

Verification results should be based on the design parameters given in Table 460-2. The current 2 day turn-around time is recommended for volumetric properties and coating. A 5 day turn-around is recommended for flow number and glass transition testing.

(1) The engineer will provide the following test results to the contractor within 2 mixture-production days after obtaining the sample. The quality of the product is acceptably verified if it meets the following limits:
- Va is within a range of 2.7 to 5.3 percent.
- VMA is within minus 1.5 of the minimum requirement for the mix design nominal maximum aggregate size.
- Coating exceeds the limit in Table 460-2

The engineer will provide the following test results to the contractor within 5 mixture-production days after obtaining the sample. The quality of the product is acceptably verified if it meets the following limits:
- Flow number exceeds the minimum value in Table 460-2 for the design traffic level and speed.

- Thermal coefficient of contraction is less than the maximum value in Table 460-2 for the geographic location and traffic level.
- Glass transition temperature is less than the maximum value in Table 460-2 for the geographic location.

460.3 Construction

No changes are needed to this section.

460.4 Measurement

No changes are needed to this section.

460.5 HMA Pavement

460.5.2.1 General

Modify Paragraphs 2 and 3 as provided in Additional Special Provision 6.

(2) Payment for HMA Pavement Type E-0.3, E-1, E-3, E-10, E-30, and E-30x is full compensation for providing HMA mixture designs; for preparing foundation; for furnishing, preparing, hauling, mixing, placing, and compacting mixture; for QMP testing and aggregate source testing; for warm mix asphalt additives or processes; and for all materials except asphaltic materials.

(3) Payment for HMA Pavement Type SMA, is full compensation for providing HMA mixture designs; for preparing foundation; for furnishing, preparing, hauling, mixing, placing, and compacting the mixture; for QMP testing and aggregate source testing; for all materials including asphaltic materials and warm mix asphalt additives and processes; and for stabilizer, hydrated lime, and liquid antistripping agent if required.

References

1. Bonaquist, R., "Effect of Recovered Binders from Recycled Shingles and Increased RAP Percentages on Resultant Binder PG," Report Number WHRP 11-13, Wisconsin Department of Transportation, Madison, WI, December, 2011.

2. Bonaquist, R. "Mix Design Practices for Warm-Mix Asphalt," **NCHRP Report 691**, National Cooperative Highway Research Program, Washington, D.C., 2011.

3. Bonaquist, R., "Evaluation of Flow Number (F_n) as a Discriminating HMA Mixture Property," Draft Report for WHRP Project 0092-09-01, January, 2012.

4. Transportation Research Board, "Performance of WMA Technologies: Stage I--Moisture Susceptibility," NCHRP Project 9-49, http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=2710, and "Performance of WMA Technologies: Stage II--Long-Term Field Performance," NCHRP Project 9-49A, http://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=3013, last accessed 2/21/2012.

Appendix B. WHRP Project 0092-12-02 Draft Specification With Performance Tests

Modifications from WisDOT Standard Specification shown in ***bold italics***.

SECTION 460 HOT MIX ASPHALT PAVEMENT

460.1 Description

(1) ***Hot Mix Asphalt (HMA) is defined as asphalt concrete produced at elevated temperature where the aggregates are dried before mixing with asphaltic binder. This includes traditional HMA mixtures produced between 260 and 340 °F and mixtures produced as warm mix asphalt (WMA) using WMA additives or processes approved by the department.*** This section describes HMA mixture design, providing and maintaining a quality management program for HMA mixtures, and constructing HMA pavement.

460.2 Materials

460.2.1 General

(1) Furnish a homogeneous mixture of coarse aggregate, fine aggregate, mineral filler if required, SMA stabilizer if required, recycled material if used, ***warm mix asphalt additive or process if used***, and asphaltic material.

460.2.2 Aggregates

460.2.2.1 General.

(1) Provide coarse aggregates from a department-approved source as specified under 106.3.4.2. Obtain the engineer's approval of the aggregates before producing HMA mixtures.

(2) Furnish an aggregate blend consisting of hard durable particles containing no more than a combined total of one percent, by weight, of lumps of clay, loam, shale, soft particles, organic matter, adherent coatings, and other deleterious material. Ensure that the aggregate blend conforms to the percent fractured faces and flat & elongated requirements of table 460-2. If the aggregate blend contains materials from different deposits or sources, ensure that material from each deposit or source has a LA wear percent loss meeting the requirements of table 460-2.

460.2.2.2 Freeze-Thaw Soundness

(1) If the aggregate blend contains materials from different deposits or sources, ensure that material from each deposit or source has a freeze-thaw loss percentage meeting the requirements of table 460-2 and 106.3.4.2.2.

460.2.2.3 Aggregate Gradation Master Range

(1) Ensure that the aggregate blend, including recycled material and mineral filler, conforms to the gradation requirements in table 460-1. The values listed are design limits; production values may exceed those limits.

TABLE 460-1 AGGREGATE GRADATION MASTER RANGE AND VMA REQUIREMENTS

SIEVE	PERCENTS PASSING DESIGNATED SIEVES						
	NOMINAL SIZE						
	37.5 mm	25.0 mm	19.0 mm	12.5 mm	9.5 mm	SMA 12.5 mm	SMA 9.5 mm
50.0-mm	100						
37.5-mm	90 - 100	100					
25.0-mm	90 max	90 - 100	100				
19.0-mm		90 max	90 – 100	100		100	
12.5-mm			90 max	90 – 100	100	90 – 97	100
9.5-mm				90 max	90 – 100	58 – 72	90 - 100
4.75-mm					90 max	25 - 35	35 – 45
2.36-mm	15 - 41	19 - 45	23 – 49	28 – 58	20 – 65	15 – 25	18 – 28
75-µm	0 - 6.0	1.0 – 7.0	2.0 – 8.0	2.0 – 10.0	2.0 – 10.0	8.0 – 12.0	10.0 – 14.0
% MINIMUM VMA	11.0	12.0	13.0	14.0	15.0	16.0	17.0

(2) Unless the contract designates otherwise, ensure that the nominal size of the aggregate used in the mixture conforms to 460.3.2 and the following:

PAVEMENT LAYER	NOMINAL SIZE
Lower layer pavement	19.0 mm
Upper layer pavement	12.5 mm
Stone matrix layer pavement	12.5 mm

460.2.3 Asphaltic Binders

(1) ***The department will designate the required rutting resistance (design high temperature and flow number) and thermal cracking resistance (coefficient of contraction and glass transition temperature) of the HMA. The contractor may use neat binder, modified binder and RAP, FRAP, and RAS to produce mixtures meeting the specified levels of rutting resistance and thermal cracking resistance. All virgin binders (neat or modified) used in HMA shall conform to the requirements of AASHTO M320. The contractor shall designate the grade of virgin binder used in HMA mixtures.***

460.2.4 Additives

460.2.4.1 Hydrated Lime Antistripping Agent

(1) If used in HMA mixtures, furnish hydrated lime conforming to ASTM C 977 and containing no more than 8 percent unhydrated oxides. Percent added is by weight of the total dry aggregate.

460.2.4.2 Liquid Antistripping Agent

(1) If used in HMA mixtures, add liquid antistripping agent to the asphaltic binder before introducing the binder into the mixture. Provide documentation indicating that addition of liquid antistripping agent will not alter the characteristics of the original asphaltic binder performance grade (PG).

460.2.4.3 Stone Matrix Asphalt Stabilizer

(1) Add an organic fiber, an inorganic fiber, a polymer-plastic, a polymer-elastomer, or approved alternate stabilizer to all SMA mixtures. If proposing an alternate, submit the proposed additive

system, asphaltic binder, and stabilizer additive, along with samples of the other mixture materials to the department at least 14 days before the project let date. The department will approve or reject that proposed alternate additive system no later than 48 hours before the project let date.

(2) Use a single additive system for all SMA pavement in the contract.

460.2.4.4 Warm Mix Additive or Process

(1) Use additives or processes from the department's approved product list. Follow supplier or manufacturer recommendations when using WMA additives or processes to produce HMA.

460.2.5 Recycled Asphaltic Materials

(1) The contractor may use recycled asphaltic materials from FRAP, RAP, and RAS in HMA mixtures. Stockpile recycled materials separately from virgin materials and list each as individual JMF components.

(2) ***Binder replacement, defined as the ratio of the weight percent recycled asphaltic binder to weight percent total asphaltic binder, shall not exceed 0.35 for upper layers and 0.50 for lower layers.***

460.2.6 Recycled Asphaltic Binders

(1) ***Establish the recycled asphaltic binder content of each recycled material for mixture design and quality control according to AASHTO T164 using the appropriate dust correction procedure. If quality control tests indicate a change in the recycled asphalt binder content during production, adjust the virgin binder added to maintain the total binder content of the mixture within the tolerances given in Section 460.2.8.2.1.5.***

460.2.7 HMA Mixture Design

(1) For each HMA mixture type used under the contract, develop and submit an asphaltic mixture design according to the department's test method number 1559 as described in CMM 8.65.5 and conforming to the requirements of table 460-1 and table 460-2. The values listed are design limits; production values may exceed those limits. The department will review mixture designs and report the results of that review to the designer according to the department's test method number 1559.

TABLE 460-2 MIXTURE REQUIREMENTS

Mixture type	E - 0.3	E - 1	E - 3	E - 10	E - 30	E - 30x	SMA
ESALs x 10^6 (20 yr design life)	< 0.3	0.3 - < 1	1 - < 3	3 - < 10	10 - < 30	>= 30	___
LA Wear (AASHTO T 96) 100 revolutions(max % loss) 500 revolutions(max % loss)	 13 50	 13 50	 13 45	 13 45	 13 45	 13 45	 13 40
Soundness (AASHTO T 104) (sodium sulfate, max % loss)	12	12	12	12	12	12	12
Freeze/Thaw (AASHTO T 103) (specified counties, max % loss)	18	18	18	18	18	18	18
Fractured Faces (ASTM 5821) (one face/2 face, % by count)	60 / __	65 / __	75 / 60	85 / 80	98 / 90	100/100	100/90
Flat & Elongated (ASTM D 4791) (max %, by weight)	5 (5:1 ratio)	5 (5:1 ratio)	5 (5:1 ratio)	5 (5:1 ratio)	5 (5:1 ratio)	5 (5:1 ratio)	20 (3:1ratio)
Fine Aggregate Angularity (AASHTO T304, method A, min)	40	40	43	45	45	45	45
Sand Equivalency (AASHTO T 176, min)	40	40	40	45	45	50	50
Gyratory Compaction Gyrations for N_{ini} Gyrations for N_{des} Gyrations for N_{max}	 6 40 60	 7 60 75	 7 75 115	 8 100 160	 8 100 160	 9 125 205	 8 65 160
Air Voids, $\%V_a$ ($\%G_{mm} N_{des}$)	4.0 (96.0)	4.0 (96.0)	4.0 (96.0)	4.0 (96.0)	4.0 (96.0)	4.0 (96.0)	4.0 (96.0)
$\% G_{mm} N_{ini}$	<= 91.5[1]	<= 90.5[1]	<= 89.0[1]	<= 89.0	<= 89.0	<= 89.0	___
Dust to Binder Ratio[2] (% passing 0.075/Pbe)	0.6 - 1.2	0.6 - 1.2	0.6 - 1.2	0.6 - 1.2	0.6 - 1.2	0.6 - 1.2	1.2 - 2.0
Voids filled with Binder (VFB or VFA, %)	70 - 80[4] [5]	65 - 78[4]	65 - 75[4]	65 - 75[3] [4]	65 - 75[3] [4]	65 - 75[3] [4]	70 – 80
Tensile Strength Ratio (TSR) (ASTM 4867) no antistripping additive with antistripping additive	 0.70 0.75	 0.70 0.75	 0.70 0.75	 0.70 0.75	 0.70 0.75	 0.70 0.75	 0.70 0.75
Compactability (Gyration Ratio, Appendix AASHTO R35)	***1.25***	***1.25***	***1.25***	***1.25***	***1.25***	***1.25***	***1.25***
Flow Number at High Design Temperature (Test Method BBB) [6] ***Highway Speed*** ***Slow Speed*** ***Intersection***	 ___ ___ ___	 ***5*** ***10*** ***30***	 ***15*** ***30*** ***90***	 ***45*** ***90*** ***270***	 ***135*** ***270*** ___	 ***420*** ***840*** ___	 ***420*** ***840*** ___
Asphalt Thermal Cracking Analyzer (AASHTO TPZZ) [7]	***North / South***	***North / South***	***North / South***	***North / South***	***North / South***	***North / South***	***North / South***
T_g ***Fracture Temperature***	***TBD / TBD*** ***TBD / TBD***	***TBD / TBD*** ***TBD / TBD***	***TBD / TBD*** ***TBD / TBD***	***TBD / TBD*** ***TBD / TBD***	***TBD / TBD*** ***TBD / TBD***	***TBD / TBD*** ***TBD / TBD***	***TBD / TBD*** ***TBD / TBD***
Reheat Correction Factor for WMA (Test Method CCC) [8]	***Report***	***Report***	***Report***	***Report***	***Report***	***Report***	***Report***
Draindown at Production Temperature (%)	___	___	___	___	___	___	0.30

[1] The percent maximum density at initial compaction is only a guideline.

[2] For a gradation that passes below the boundaries of the caution zone(ref. AASHTO MP3), the dust to binder ratio limits are 0.6 - 1.6.

[3] For 9.5mm nominal maximum size mixtures, the specified VFB range is 73 - 76%.

[4] For 37.5mm nominal maximum size mixes, the specified VFB lower limit is 67%.

[5] For 25.0mm nominal maximum size mixes, the specified VFB lower limit is 67%
[6] Test Method BBB is WisDOT modification of AASHTO TP79 to specify binder content, filler content, short-term aging, specimen air voids, contact deviator stress, and repeated deviator stress. To be develop in WHRP Project 0092-12-02
[7] AASHTO TPZZ under development in Asphalt Research Consortium project
[8] Test Method CCC to be developed in WHRP Project 0092-12-02

(2) Perform the mixture design using the planned production and field compaction temperature. Minimum production temperatures are given in table 460-3.

TABLE 460-3 MINIMUM MIXTURE PRODUCTION TEMPERATURES

Mixture Type	*MINIMUM PRODUCTION TEMPERATURE, °F*				
	No WMA Additive or Process	*Chemical WMA Additive*	*Wax WMA Additive*	*Synthetic Zeolite WMA Additive*	*Water Injection*
Virgin	*260*	*230*	*230*	*230*	*250*
RAP or FRAP	*260*	*230*	*230*	*230*	*250*
RAS	*300*	*300*	*300*	*300*	*300*

460.2.8 Quality Management Program
460.2.8.1 General
(1) Provide and maintain a QC program defined as all activities, including mix design, process control inspection, sampling and testing, and process adjustments related to producing and placing HMA pavement conforming to the specifications. The contractor may also provide an optional CA program.

(2) The department will provide product quality verification as follows:
1. By conducting verification testing of independent samples.
2. By periodically observing contractor sampling and testing.
3. By monitoring required control charts exhibiting test results and control parameters.
4. By the engineer directing the contractor to take additional samples at any time during production.

(3) Refer to CMM 8.36 for detailed guidance on sampling, testing, and documentation under the QMP.

460.2.8.2 Contractor Testing
460.2.8.2.1 Required Quality Control Program
460.2.8.2.1.1 Personnel Requirements
(1) Provide HTCP certified sampling and testing personnel. Provide at least one full-time HMA technician certified at a level appropriate for sampling and production control testing at each plant site furnishing material to the project. Before mixture production begins, provide an

organizational chart in the contractor's laboratory. Include the names, telephone numbers, and current certifications of all personnel with QC or CA responsibilities. Keep the chart updated.

(2) Ensure that sampling and testing personnel are minimally qualified as follows[1]:
- HMA technician certified at a level appropriate for sampling and production control testing.
- HMA ACT[2] .

> [1] After informing the engineer, a non-certified person under the direct observation of a certified HMA technician may sample for a period not to exceed 3 calendar days.
> [2] A certified HMA technician must coordinate and take responsibility for the work an ACT performs. No more than one ACT can work under a single certified technician.

(3) Have a certified HMA technician ensure that all sampling and testing is performed correctly, analyze test results, and post resulting data.

(4) Have an HMA technician certified at a level appropriate for process control and troubleshooting or mix design available to make necessary process adjustments.

460.2.8.2.1.2 Laboratory Requirements

(1) Conduct QC testing in a facility conforming to the department's laboratory qualification program.

(2) Ensure that the laboratory has at least 320 square feet of workspace and has a telephone for exclusive use by QMP personnel. Ensure that all testing equipment conforms to the equipment specifications applicable to the required testing methods.

460.2.8.2.1.3 Required Sampling and Testing

460.2.8.2.1.3.1 Contracts with 5000 Tons of Mixture or Greater

(1) Furnish and maintain a laboratory at the plant site fully equipped to perform the daily contractor QC testing. Have the laboratory on-site and operational before beginning mixture production. ***Flow number and Asphalt Thermal Cracking Analyzer testing may be conducted at an off-site laboratory***.

(2) Obtain random samples and perform tests according to CMM 8.36. Obtain HMA mixture samples from trucks at the plant. Perform quality control tests for air voids without reheating samples.

(3) Retain the split portion of the contractor HMA mixture and blended aggregate samples for 14 calendar days at the laboratory site in a dry, protected area. The engineer may decrease this 14-day retention period. At project completion the contractor may dispose of remaining samples if the engineer approves.

(4) ***When recycled asphaltic material is used, perform the following tests at the rate of at least one per day for each recycled asphaltic material:***

> ***Asphalt content according to AASHTO T164***
> ***Gradation according to AASHTO T30***

(5) Use the test methods identified below, or other methods the engineer approves, to perform daily QC testing at a frequency greater than or equal to that indicated:

Blended aggregate gradations:

Drum plants:

- Field extraction by department test method number 1560.
- Belt samples, optional for virgin mixtures, obtained from stopped belt or from the belt discharge using an engineer-approved sampling device and performed according to AASHTO T11 and T27.

Batch plants:

- Field extraction by department test method number 1560.

Asphalt content (AC) in percent:

AC by calculation.

AC by nuclear gauge reading, optional.

AC by inventory, optional.

Bulk specific gravity of the compacted mixture according to AASHTO T166.

Maximum specific gravity according to AASHTO T 209.

Air voids (Va) by calculation according to AASHTO T 269.

VMA by calculation according to AASHTO R 35

Test each design mixture at a frequency at or above the following:

TOTAL DAILY PLANT PRODUCTION FOR DEPARTMENT CONTRACTS in tons	SAMPLES PER DAY[1]
50 to 600	1
601 to 1500	2
1501 to 2700	3
2701 to 4200	4
greater than 4200	see footnote[2]

[1] Frequencies are for planned production. If production is other than planned, conform to CMM 8.36.

[2] Add a random sample for each additional 1500 tons or fraction of 1500 tons.

(6) Conduct field tensile strength ratio tests according to ASTM D 4867 ***on all mixtures***. Test each full 50,000 ton production increment, or fraction of an increment, after the first 5,000 tons of production. Perform required increment testing in the first week of production of that increment. If field tensile strength ratio values are either below the spec limit or less than the mixture design JMF percentage value by 20 or more, notify the engineer. The engineer and contractor will jointly determine a corrective action.

(7) ***Conduct flow number and Asphalt Thermal Cracking Analyzer testing on each design mixture at the rate of 1 test per 10,000 tons. Obtain samples within the first 2,000 tons of each***

increment. If test results are below the specification limit, stop production and notify the engineer. The engineer and contractor will jointly determine a corrective action.

460.2.8.2.1.3.2 Contracts with Less Than 5000 Tons of Mixture

(1) Conform to 460.2.8.2.1.3.1 modified as follows:

-The contractor may conduct QC tests in an off-site laboratory.

-One field tensile strength ratio testing is required.

-One flow number test is required.

-One Asphalt Thermal Cracking Analyzer test is required.

460.2.8.2.1.3.3 Contracts with Less Than 500 Tons of Mixture

(1) The engineer may waive QC testing on contracts with less than 500 tons of mixture. If testing is waived, acceptance will be by visual inspection unless defined otherwise by contract change order.

(2) If HMA density testing is waived under 460.3.3.3, QC testing is also waived.

460.2.8.2.1.3.4 Temporary Pavements

(1) The engineer may waive all testing for temporary pavements, defined for this purpose as pavements that will be placed and removed before contract completion.

460.2.8.2.1.4 Documentation

460.2.8.2.1.4.1 Records

(1) Document all observations, inspection records, mixture adjustments, and test results daily. Note observations and inspection records in a permanent field record as they occur. Record all process adjustments and JMF changes. Submit copies of the running average calculation sheets for blended aggregate, mixture properties, and asphalt content along with mixture adjustment records to the engineer each day. Submit testing records and control charts to the engineer in a neat and orderly manner within 10 days after paving is completed.

(2) Continue charts, records, and testing frequencies, for a mixture produced at one plant site, from contract to contract.

460.2.8.2.1.4.2 Control Charts

(1) Maintain standardized control charts at the laboratory. Record contractor test results on the charts the same day as testing. Post CA test results on the charts as data becomes available. Record data on the standardized control charts as follows:

- Blended aggregate gradation tests in percent passing. Of the following, plot those sieves the design specifications require: 37.5-mm, 25.0-mm, 19.0-mm, 12.5-mm, 9.5-mm, 2.36-mm, and 75-µm.
- Asphalt material content in percent.
- ***Binder replacement from each recycled asphaltic material based on daily recycled asphalt material content and current asphalt material content.***
- Air voids in percent.
- VMA in percent.

(2) Plot both the individual test point and the running average of the last 4 data points on each chart. Show QC data in black with the running average in red and CA data in blue. Draw the warning limits with a dashed green line and the JMF limits with a dashed red line. The contractor may use computer generated black-and-white printouts with a legend that clearly identifies the specified color coded components.

460.2.8.2.1.5 Control Limits

(1) Conform to the following control limits for the JMF and warning limits based on a running average of the last 4 data points:

ITEM	JMF LIMITS	WARNING LIMITS
Percent Passing given sieve		
37.5 mm	+/- 6.0	+/- 4.5
25.0 mm	+/- 6.0	+/- 4.5
19.0 mm	+/- 5.5	+/- 4.0
12.5 mm	+/- 5.5	+/- 4.0
9.5 mm	+/- 5.5	+/- 4.0
2.36 mm	+/- 5.0	+/- 4.0
75 µm	+/- 2.0	+/- 1.5
Asphalt content in percent	+/- 0.4	+/- 0.3
Air voids in percent	+/- 1.3	+/- 1.0
VMA in percent	- 1.5	- 1.2
RAP binder replacement	***+/- TBD***	***+/- TBD***
RAS binder replacement	***+/- TBD***	***+/- TBD***

(2) Warning bands are defined as the area between the JMF limits and the warning limits.

460.2.8.2.1.6 Job Mix Formula Adjustment

(1) The contractor may request adjustment of the JMF according to the department's test method number 1559. Have an HTCP HMA technician certified at a level appropriate for process control and troubleshooting or mix design submit a written JMF adjustment request. Ensure that the resulting JMF is within specified master gradation bands. The department will have an HMA technician certified at level III review the proposed adjustment and, if acceptable, issue a revised JMF. The department will not allow adjustments exceeding specified JMF tolerance limits. Have an HMA technician certified at level II make related process adjustments.

(2) If mixture redesign is necessary, submit a new JMF, subject to the same specification requirements as the original JMF.

(3) Do not reduce the JMF asphalt content unless the production VMA meets or exceeds the minimum VMA design requirement for the mixture produced as defined in table 460-1.

460.2.8.2.1.7 Corrective Action

(1) When running average values trend toward the warning limits, consider taking corrective action. Document all corrective actions undertaken. Include all test results in the contract files and in running average calculations.

(2) Notify the engineer if running average values exceed the warning limits. If two consecutive running average values exceed the warning limits, stop production and make adjustments. Do not restart production until after notifying the engineer of the adjustments made. Do not calculate a new running average until the fourth test after the required production stop.

(3) If the process adjustment improves the property in question so that the running average after 4 additional tests is within the warning limits, the contractor may continue production with no reduction in payment.

(4) If the adjustment does not improve the properties and the running average after 4 additional tests stays inside the warning bands, the mixture is nonconforming and subject to pay adjustment.

(5) If the contractor fails to stop production and make adjustments when required, all mixture produced from the stop point to the point when the running average is back inside the warning limits is nonconforming and subject to pay adjustment.

(6) The department will reduce payment for nonconforming QMP HMA mixtures, starting from the stop point to the point when the running average is back inside the warning limits, as follows:

	PAYMENT FOR MIXTURE[1] [2]	
ITEM	PRODUCED WITHIN WARNING BANDS	PRODUCED OUTSIDE JMF LIMITS
Gradation	90 %	75 %
Asphalt Content	85 %	75 %
Air Voids	70 %	50 %
VMA	90 %	75 %
Binder Replacement[3]	***TBD***	***TBD***

[1] For projects or plants where the total production of each mixture design requires less than 4 tests refer to CMM 8.36.
[2] Payment is in percent of the contract unit price for both the HMA Pavement and Asphaltic Material bid items. The department will reduce pay based on the nonconforming property with lowest percent pay. The asphaltic material quantity is based on the JMF asphalt content. The department will administer pay reduction under the Nonconforming QMP Asphaltic Material and the Nonconforming QMP HMA Mixture administrative items.
[3] Pay adjustment for binder replacement waived if flow number and glass transition temperature testing provide acceptable properties.

(7) If the running average values exceed the JMF limits, stop production and make adjustments. Do not restart production until after notifying the engineer of the adjustments made. Continue calculating the running average after the production stop.

(8) If the air voids running average of 4 exceeds the JMF limits, the material is nonconforming. Remove and replace unacceptable material at no additional expense to the department. The

engineer will determine the quantity of material to replace based on the testing data using the methods in CMM 8.36 and an inspection of the completed pavement. If the engineer allows the mixture to remain in place, the department will pay for the mixture and asphaltic material at 50 percent of the contract price.

(9) If the running average of 4 exceeds the JMF limits for other properties, the department will pay 75 percent of the contract price for mixture and asphaltic material if the engineer allows the mixture to remain in place. The engineer will determine the quantity of material subject to pay reduction based on the testing data and an inspection of the completed pavement.

460.2.8.2.2 Optional Contractor Assurance

460.2.8.2.2.1 General

(1) CA testing is optional and is conducted to further validate production testing. The contractor may offer CA data to provide an additional piece of information for the following:

1. Process control decisions.
2. Troubleshooting possible sampling, splitting, or equipment problems.
3. Limiting liability, as defined in CMM 8.36, for nonconforming product as a result of department verification testing. These provisions do not supersede department's rights under 107.16.

460.2.8.2.2.2 Personnel Requirements

(1) Ensure that an HMA technician certified under HTCP at a level appropriate for mixture production control testing performs all CA testing and data analysis. Personnel performing CA testing cannot perform QC testing for the same materials.

460.2.8.2.2.3 Laboratory Requirements

(1) Conduct CA testing in a facility conforming to the department's laboratory qualification program. Furnish and maintain a laboratory fully equipped for performing selected CA tests. If the a single laboratory is providing CA and QC data for the same materials, ensure that a separate set of equipment is used to prepare CA samples and run CA tests.

460.2.8.2.2.4 Testing

(1) For the CA program, use the test methods enumerated here in 460.2.8.2.2.4, other engineer-approved methods, or other methods the industry and department HMA technical team recognizes. The contractor may select tests at its option. If using tests in limiting liability, as provided in CMM 8.36, data must exist for the property in question.

(2) Perform selected testing as follows:

- Bulk specific gravity (Gmb) of the compacted mixture according to AASHTO T 166 based on the average of 2 specimens.
- Maximum specific gravity (Gmm) according to AASHTO T 209.
- Air voids (Va). Calculate according to AASHTO T 269. ***If reheated samples are used, apply reheat adjustment from approved mixture design.***
- ***Asphalt content***
- ***Binder replacement based on daily recycled asphalt material content***
- VMA by calculation according to AASHTO R 35.

- Flow number according to Test Method BBB
- Fracture temperature from Asphalt Thermal Cracking Analyzer test (AASHTO TPZZ)
- Glass transition from Asphalt Thermal Cracking Analyzer test (AASHTO TPZZ)

(3) There is no specified frequency for CA testing.

(4) The department will compare CA samples to QC samples. Obtain CA samples by retaining a QC split portion conforming to the "rule of retained" requirements, as provided in CMM 8.36. Alternatively the contractor may have CA personnel take an additional sample during production.

460.2.8.2.2.5 Documentation

(1) Report CA test results to the engineer and the contractor's field staff within 2 business days after receiving the samples.

460.2.8.2.2.6 Allowable Differences

(1) Differences between the QC and CA split sample test results are acceptable in limiting liability, as provided in CMM 8.36, if within the following limits:

ITEM	ALLOWABLE DIFFERENCES
Percent passing 12.5 mm sieve	6.0
Percent passing 9.5 mm sieve	6.0
Percent passing 4.75 mm sieve	5.0
Percent passing 2.36 mm sieve	4.0
Percent passing 600 µm sieve	3.5
Percent passing 75 µm sieve	2.0
Bulk specific gravity	0.030
Maximum specific gravity	0.030
Asphalt content	***TBD***
Binder replacement	***TBD***
Flow number	***TBD***
Fracture temperature	***TBD***
Glass transition temperature	***TBD***

460.2.8.3 Department Testing

460.2.8.3.1 Quality Verification Program

460.2.8.3.1.1 General

(1) The engineer will conduct QV tests to determine the quality of the final product and measure characteristics that predict relative performance.

460.2.8.3.1.2 Personnel Requirements

(1) The department will provide at least one HMA technician, certified under HTCP at a level appropriate for sampling and mixture production control testing, to observe QV sampling of project mixtures.

(2) An HMA technician certified at a level appropriate for sampling and mixture production control testing, or an HMA ACT working under the HMA certified technician, will split samples and do the testing. An HMA technician certified at a level appropriate for sampling and mixture production control testing must coordinate and take responsibility for the work an ACT performs. No more than one ACT can work under a single certified technician.

(3) An HMA technician certified at a level appropriate for sampling and mixture production control testing will ensure that all sampling and testing is performed correctly, analyze test results, and post resulting data.

(4) The department will make an organizational chart available at the testing laboratory and to the contractor before mixture production begins. The department's chart will include names, telephone numbers, and current certifications of all QV testing personnel. The department will update the chart with appropriate changes, as they become effective.

460.2.8.3.1.3 Laboratory Requirements

(1) The department will furnish and maintain a facility for QV testing conforming to the department's laboratory qualification program requirements and fully equipped to perform QV testing. In all cases, the department will conduct testing in a separate laboratory from the contractor's laboratory.

460.2.8.3.1.4 Department Verification Testing Requirements

(1) HTCP certified department personnel will obtain random samples by directly supervising HTCP certified contractor personnel sampling from trucks at the plant. The department will sample according to CMM 8.36. Sample size must be adequate to run the appropriate required tests in addition to one set of duplicate tests that may be required for dispute resolution. The engineer will split the sample for testing and retain the remaining portion for additional testing if needed.

(2) The department will verify product quality using the test methods enumerated here in 460.2.8.3.1.4(2), other engineer-approved methods, or other methods the industry and department HMA technical team recognizes. The department will identify test methods before construction starts and use only those methods during production of that material unless the engineer and contractor mutually agree otherwise.

(3) The department will perform all testing conforming to the following standards:

- Bulk specific gravity (Gmb) of the compacted mixture according to AASHTO T 166 based on the average of 2 specimens.
- Maximum specific gravity (Gmm) according to AASHTO T 209.
- Air voids (Va). Calculate according to AASHTO T 269. ***If reheated samples are used, apply reheat adjustment from approved mixture design.***
- VMA by calculation according to AASHTO R 35.
- ***Flow number according to Test Method BBB***
- ***Fracture temperature from Asphalt Thermal Cracking Analyzer test (AASHTO TPZZ)***
- ***Glass transition from Asphalt Thermal Cracking Analyzer test (AASHTO TPZZ)***

(4) The department will randomly test each design mixture at the following minimum frequency:

FOR TONNAGES TOTALING:	
Less than 501 tons	no tests required
From 501 to 30,000 tons	one test
More than 30,000 tons	Add one test for each additional 30,000-ton increment

460.2.8.3.1.5 Documentation

(1) The engineer will document all observations during QV sampling, and review QC mixture adjustments and QC/CA test results daily. The engineer will note results of observations and inspection records in a permanent field record as they occur.

460.2.8.3.1.6 Acceptable Verification Parameters

(1) The engineer will provide the following test results to the contractor within 2 mixture-production days after obtaining the sample. The quality of the product is acceptably verified if it meets the following limits:

- Air voids within a range of 2.7 to 5.3 percent.
- VMA is within minus 1.5 of the minimum requirement for the mix design nominal maximum aggregate size.

The engineer will provide the following test results to the contractor within 5 mixture-production days after obtaining the sample. The quality of the product is acceptably verified if it meets the following limits:

- ***Flow number exceeds the minimum value in Table 460-2 for the design traffic level and speed.***
- ***Fracture temperature is less than the maximum value in Table 460-2 for the geographic location and traffic level.***
- ***Glass transition temperature is less than the maximum value in Table 460-2 for the geographic location and traffic level.***

(2) If QV test results are outside the specified limits, the engineer will investigate immediately through dispute resolution procedures. The engineer may stop production while the investigation is in progress if the potential for a pavement failure is present.

(3) If production continues for that mixture design, the engineer will provide additional retained sample testing at the frequency provided for in CMM 8.36. This supplemental testing will continue until the material meets allowable differences or as the engineer and contractor mutually agree.

460.2.8.3.1.7 Dispute Resolution

(1) When QV test results do not meet the specified limits, the bureau's AASHTO accredited laboratory and certified personnel will referee test the retained portion of the QV sample and the retained portion of the nearest available previous QC sample.

(2) The department will notify the contractor of the referee test results within 3 business days after receipt of the samples.

(3) The department will determine mixture conformance and acceptability by analyzing referee test results, reviewing mixture project data, and inspecting the completed pavement all according to CMM 8.36.

460.2.8.3.1.8 Corrective Action

(1) Remove and replace unacceptable material at no additional expense to the department.

(2) The department will reduce pay for the tonnage of nonconforming mixture, as determined during QV dispute resolution, if the engineer allows that mixture to remain in place. If production of that mixture design continued during the investigation, the department will also adjust pay for that mixture forward to the next conforming QV or QC/CA point. The department will pay for the affected mixture at 50 percent of the contract price. The department will adjust pay for both the mixture and the asphaltic material.

460.2.8.3.2 Independent Assurance Testing

(1) The department will evaluate both the contractor and department testing personnel and equipment as specified in 106.3.4.3.4.

460.3 Construction

460.3.1 General

(1) Construct HMA pavement conforming to the general provisions of 450.3.

460.3.2 Thickness

(1) Provide the plan thickness for lower and upper layers limited as follows:

NOMINAL SIZE	MINIMUM LAYER THICKNESS in inches	MAXIMUM LOWER LAYER THICKNESS in inches	MAXIMUM UPPER LAYER THICKNESS in inches	MAXIMUM SINGLE LAYER[3] THICKNESS in inches
37.5 mm	3.5	5	4.5	6
25.0 mm	3.25	5	4	6
19.0 mm	2.25	4	3	5
12.5 mm[1]	1.75	3[2]	2.5	4
9.5 mm[1]	1.5	3[2]	2	3

[1] SMA mixtures use nominal size 12.5 mm or 9.5 mm.

[2] SMA mixtures with nominal sizes of 12.5 mm and 9.5 mm have no maximum lower layer thickness specified.

[3] For use on cross-overs and shoulders.

460.3.3 HMA Pavement Density Maximum Density Method

460.3.3.1 Minimum Required Density

(1) Compact all layers of HMA mixture to the density table 460-4 shows for the applicable mixture, location, and layer.

TABLE 460-4 MINIMUM REQUIRED DENSITY[1]

LOCATION	LAYER	PERCENT OF TARGET MAXIMUM DENSITY		
		MIXTURE TYPE		
		E-0.3, E-1, and E-3	E-10, E-30, and E-30x	SMA[5]
TRAFFIC LANES[2]	LOWER	91.5[3]	92.0[4]	----
	UPPER	91.5	92.0	----
SIDE ROADS, CROSSOVERS, TURN LANES, & RAMPS	LOWER	91.5[3]	92.0[4]	----
	UPPER	91.5	92.0	----
SHOULDERS & APPURTENANCES	LOWER	89.5	89.5	----
	UPPER	90.5	90.5	----

[1] The table values are for average lot density. If any individual density test result falls more than 3.0 percent below the minimum required target maximum density, the engineer may investigate the acceptability of that material.
[2] Includes parking lanes as determined by the engineer.
[3] Minimum reduced by 2.0 percent for a lower layer constructed directly on crushed aggregate or recycled base courses.
[4] Minimum reduced by 1.0 percent for lower a layer constructed directly on crushed aggregate or recycled base courses.
[5] The minimum required densities for SMA mixtures are specified in the contract special provisions.

460.3.3.2 Pavement Density Determination

(1) The engineer will determine the target maximum density using department procedures described in CMM 8.15. The engineer will measure pavement density for either nuclear density or the density of sawed or cored samples. The engineer and contractor will decide which method to use before paving. A change to the method requires agreement between the engineer, contractor, and the department's quality management section. The engineer will determine density as soon as it is practical after compaction and before placement of subsequent layers or before opening to traffic. Cut pavement samples as the engineer directs and restore the surface with new, well compacted mixture.

(2) Do not re-roll compacted mixtures with deficient density test results. Do not operate continuously below the specified minimum density. Stop production, identify the source of the problem, and make corrections to produce work meeting the specification requirements.

(3) A lot is defined in CMM 8.15 and placed within a single layer for each location and target maximum density category indicated in table 460-4.

(4) For nuclear density, the department will test 5 random samples on each lot. For the density of sawed or cored samples, the department will test 3 random samples, each with an area of at least 28 square inches, from each lot. The lot density is the average of all samples taken for that lot. The number of nuclear density tests required for legs of side roads at intersections, crossovers, turn lanes, and ramps with less than 750 tons per layer are specified in CMM 8.15.

(5) A certified nuclear density technician, or an nuclear density ACT working under a certified nuclear density technician, will locate samples and do the testing. A certified nuclear density technician certified must coordinate and take responsibility for the work an ACT performs. No more than one ACT can work under a single certified technician. The responsible certified technician will ensure that sample location and testing is performed correctly, analyze test results, and provide density results to the contractor weekly.

460.3.3.3 Waiving Density Testing

(1) The engineer may waive density testing for one or more of the following reasons:

1. It is not practical to determine density by the lot system.
2. The contract contains less than 750 tons of a given mixture type placed within the same layer and target maximum density category.

(2) If the department waives density testing notify the contractor before paving. The department will accept the mixture by the ordinary compaction procedure as specified in 450.3.2.6.2.

(3) If HMA QC testing is waived under 460.2.8.2.1.3.3, density testing is also waived.

460.4 Measurement

(1) The department will measure the HMA Pavement bid items acceptably completed by the ton as specified in 450.4.

460.5 Payment

460.5.1 General

(1) The department will pay for measured quantities at the contract unit price under the following bid items:

ITEM NUMBER	DESCRIPTION	UNIT
460.1100	HMA Pavement Type E-0.3	TON
460.1101	HMA Pavement Type E-1	TON
460.1103	HMA Pavement Type E-3	TON
460.1110	HMA Pavement Type E-10	TON
460.1130	HMA Pavement Type E-20	TON
460.1132	HMA Pavement Type E-30X	TON
460.1700	HMA Pavement Type SMA	TON
460.2000	Incentive Density HMA Pavement	DOL

460.5.2 HMA Pavement

460.5.2.1 General

(1) The department will pay for the HMA Pavement bid items at the contract unit price subject to one or more of the following adjustments:

1. Disincentive for density of HMA pavement as specified in 460.5.2.2.
2. Incentive for density of HMA pavement as specified in or 460.5.2.3.
3. Reduced payment for nonconforming smoothness as specified in 450.3.2.9.
4. Reduced payment for nonconforming QMP HMA mixtures as specified in 460.2.8.2.1.7.

(2) Payment for HMA Pavement Type E-0.3, E-1, E-3, E-10, E-30, and E-30x is full compensation for providing HMA mixture designs; for preparing foundation; for furnishing, preparing, hauling, mixing, placing, and compacting mixture; for QMP testing and aggregate source testing; for warm mix asphalt additives or processes; and for all materials except asphaltic materials.

(3) Payment for HMA Pavement Type SMA, is full compensation for providing HMA mixture designs; for preparing foundation; for furnishing, preparing, hauling, mixing, placing, and compacting the mixture; for QMP testing and aggregate source testing; and for all materials including asphaltic materials and warm mix asphalt additives and processes; and for stabilizer, hydrated lime, and liquid antistripping agent if required.

(4) If provided for in the plan quantities, the department will pay for a leveling layer, placed to correct irregularities in an existing paved surface before overlaying, under the pertinent paving bid item. Absent a plan quantity, the department will pay for a leveling layer as extra work.

(5) Except for SMA mixes, the department will pay for asphaltic materials separately under the Asphaltic Materials bid items as specified in 455.5. Except for SMA mixes, hydrated lime or liquid antistripping agent, when required, is included in the contract price for the asphaltic material.

(6) If the department waives density testing under 460.3.3.3, the department will not adjust pay under either 460.5.2.2 or 460.5.2.3.

(7) Restore the surface after cutting density samples as specified in 460.3.3.2(1) at no additional cost to the department.

460.5.2.2 Disincentive for HMA Pavement Density

(1) The department will administer density disincentives under the Disincentive Density HMA Pavement and the Disincentive Density Asphaltic Material administrative items. If the lot density is less than the specified minimum in table 460-4, the department will reduce pay based on the contract unit price for both the HMA Pavement and Asphaltic Material bid items for that lot as follows:

DISINCENTIVE PAY REDUCTION FOR HMA PAVEMENT DENSITY

PERCENT OF LOT DENSITY BELOW SPECIFIED MINIMUM	PAYMENT FACTOR (percent of contract price)
From 0.5 to 1.0 inclusive	98
From 1.1 to 1.5 inclusive	95
From 1.6 to 2.0 inclusive	91
From 2.1 to 2.5 inclusive	85
From 2.6 to 3.0 inclusive	70
More than 3.0[1]	----

[1] Remove and replace the lot with a mixture at the specified density. When acceptably replaced, the department will pay for the replaced work at the contract unit price. Alternatively the engineer may allow the nonconforming material to remain in place with a 50 percent payment factor.

(2) If the engineer directs placing HMA mixtures between October 15 and May 1 for department convenience as specified in 450.3.2.1(5), the department will not assess a density disincentive on pavement the department orders the contractor to place when the temperature, as defined in 450.3.2.1(2), is less than 36 F.

460.5.2.3 Incentive for HMA Pavement Density

(1) If the lot density is greater than the minimum specified in table 460-3 and all individual air voids test results for that mixture placed during the same day are within +1.0 percent or - 0.5 percent of the design target in table 460-2, the department will adjust pay for that lot as follows:

INCENTIVE PAY ADJUSTMENT FOR HMA PAVEMENT DENSITY

PERCENT OF LOT DENSITY ABOVE SPECIFIED MINIMUM	PAYMENT FACTOR PER TON[1]
From -0.4 to 1.0 inclusive	$0
From 1.1 to 1.8 inclusive	$0.40
More than 1.8	$0.80

[1] The department will prorate the pay adjustment for a partial lot.

(2) The department will adjust pay under the Incentive Density HMA Pavement bid item. Adjustment under this item is not limited, either up or down, to the bid amount the schedule of items shows.

(3) The department will restrict incentive payment for shoulders paved integrally with the traffic lane, if the traffic lane does not meet incentive requirements, the department will not pay incentive on the integrally paved shoulder.

Appendix C. WHRP Project 0092-12-02 Draft Specification Without Performance Tests

Modifications from WisDOT Standard Specification shown in ***bold italics***.

SECTION 460 HOT MIX ASPHALT PAVEMENT

460.1 Description

(1) ***Hot Mix Asphalt (HMA) is defined as asphalt concrete produced at elevated temperature where the aggregates are dried before mixing with asphaltic binder. This includes traditional HMA mixtures produced between 260 and 340 °F and mixtures produced as warm mix asphalt (WMA) using WMA additives or processes approved by the department.*** This section describes HMA mixture design, providing and maintaining a quality management program for HMA mixtures, and constructing HMA pavement.

460.2 Materials

460.2.1 General

(1) Furnish a homogeneous mixture of coarse aggregate, fine aggregate, mineral filler if required, SMA stabilizer if required, recycled material if used, warm mix asphalt additive or process if used, and asphaltic material.

460.2.2 Aggregates

460.2.2.1 General.

(1) Provide coarse aggregates from a department-approved source as specified under 106.3.4.2. Obtain the engineer's approval of the aggregates before producing HMA mixtures.

(2) Furnish an aggregate blend consisting of hard durable particles containing no more than a combined total of one percent, by weight, of lumps of clay, loam, shale, soft particles, organic matter, adherent coatings, and other deleterious material. Ensure that the aggregate blend conforms to the percent fractured faces and flat & elongated requirements of table 460-2. If the aggregate blend contains materials from different deposits or sources, ensure that material from each deposit or source has a LA wear percent loss meeting the requirements of table 460-2.

460.2.2.2 Freeze-Thaw Soundness

(1) If the aggregate blend contains materials from different deposits or sources, ensure that material from each deposit or source has a freeze-thaw loss percentage meeting the requirements of table 460-2 and 106.3.4.2.2.

460.2.2.3 Aggregate Gradation Master Range

(1) Ensure that the aggregate blend, including recycled material and mineral filler, conforms to the gradation requirements in table 460-1. The values listed are design limits; production values may exceed those limits.

TABLE 460-1 AGGREGATE GRADATION MASTER RANGE AND VMA REQUIREMENTS

SIEVE	PERCENTS PASSING DESIGNATED SIEVES						
	NOMINAL SIZE						
	37.5 mm	25.0 mm	19.0 mm	12.5 mm	9.5 mm	SMA 12.5 mm	SMA 9.5 mm
50.0-mm	100						
37.5-mm	90 – 100	100					
25.0-mm	90 max	90 - 100	100				
19.0-mm		90 max	90 – 100	100		100	
12.5-mm			90 max	90 – 100	100	90 – 97	100
9.5-mm				90 max	90 – 100	58 – 72	90 - 100
4.75-mm					90 max	25 – 35	35 – 45
2.36-mm	15 – 41	19 - 45	23 – 49	28 – 58	20 – 65	15 – 25	18 – 28
75-µm	0 - 6.0	1.0 – 7.0	2.0 – 8.0	2.0 – 10.0	2.0 – 10.0	8.0 – 12.0	10.0 – 14.0
% MINIMUM VMA	11.0	12.0	13.0	14.0	15.0	16.0	17.0

(2) Unless the contract designates otherwise, ensure that the nominal size of the aggregate used in the mixture conforms to 460.3.2 and the following:

PAVEMENT LAYER	NOMINAL SIZE
Lower layer pavement	19.0 mm
Upper layer pavement	12.5 mm
Stone matrix layer pavement	12.5 mm

460.2.3 Asphaltic Binders

(1) The department will designate the grade of asphaltic binder in the contract. The contractor may use ***neat binder***, modified binder, a blend of neat and recycled binder, or a blend of modified and recycled binder. Ensure that the resultant asphaltic binder conforms to the contract specifications.

460.2.4 Additives

460.2.4.1 Hydrated Lime Antistripping Agent

(1) If used in HMA mixtures, furnish hydrated lime conforming to ASTM C 977 and containing no more than 8 percent unhydrated oxides. Percent added is by weight of the total dry aggregate.

460.2.4.2 Liquid Antistripping Agent

(1) If used in HMA mixtures, add liquid antistripping agent to the asphaltic binder before introducing the binder into the mixture. Provide documentation indicating that addition of liquid antistripping agent will not alter the characteristics of the original asphaltic binder performance grade (PG).

460.2.4.3 Stone Matrix Asphalt Stabilizer

(1) Add an organic fiber, an inorganic fiber, a polymer-plastic, a polymer-elastomer, or approved alternate stabilizer to all SMA mixtures. If proposing an alternate, submit the proposed additive system, asphaltic binder, and stabilizer additive, along with samples of the other mixture materials to the department at least 14 days before the project let date. The department will

approve or reject that proposed alternate additive system no later than 48 hours before the project let date.

(2) Use a single additive system for all SMA pavement in the contract.

460.2.4.4 Warm Mix Additive or Process

(1) Use additives or processes from the department's approved product list. Follow supplier or manufacturer recommendations when using WMA additives or processes to produce HMA.

460.2.5 Recycled Asphaltic Materials

(1) The contractor may use recycled asphaltic materials from FRAP, RAP, and RAS in HMA mixtures. Stockpile recycled materials separately from virgin materials and list each as individual JMF components.

(2) Control recycled asphaltic materials in HMA by evaluating the binder replacement, defined as the ratio of the weight percent recycled asphaltic binder to weight percent total asphaltic binder. ***When the binder replacement conforms to table 460-2, no change to the specified binder grade is necessary.***

TABLE 460-2 ALLOWABLE RECYCLED BINDER REPLACEMENT

Recycled Binder Type	***Maximum Binder Replacement***	
	Surface Layers	***Lower Layers***
RAP[1]	***0.20***	***0.45***
RAS	***0.05***	***0.20***
Combination of RAP and RAS	***Reduce RAP binder replacement 0.04 for each 0.01 RAS binder replacement.***	***Reduce RAP binder replacement 0.0225 for each 0.01 RAS binder replacement.***

[1] ***Includes RAP, FRAP, and combinations of RAP and FRAP***

(3) ***When binder replacement exceeds the values given in table 460-2, provide blending charts for mix design and recovered binder grading during production indicating that the resultant binder grade meets the grade the contract originally specified.***

460.2.6 Recycled Asphaltic Binders

(1) Establish the recycled asphaltic binder content of each recycled material for mixture design and quality control according to AASHTO T164 using the appropriate dust correction procedure. ***If quality control tests indicate a change in the recycled asphalt binder content during production, adjust the virgin binder added to maintain the total binder content of the mixture within the tolerances given in Section 460.2.8.2.1.5***

460.2.7 HMA Mixture Design

(1) For each HMA mixture type used under the contract, develop and submit an asphaltic mixture design according to the department's test method number 1559 as described in CMM 8.65.5 and conforming to the requirements of table 460-1 and table 460-3. The values listed are design limits; production values may exceed those limits. The department will review mixture

designs and report the results of that review to the designer according to the department's test method number 1559.

TABLE 460-3 MIXTURE REQUIREMENTS

Mixture type	E - 0.3	E - 1	E - 3	E - 10	E - 30	E - 30x	SMA
ESALs x 10^6 (20 yr design life)	< 0.3	0.3 - < 1	1 - < 3	3 - < 10	10 - < 30	>= 30	___
LA Wear (AASHTO T 96) 100 revolutions(max % loss) 500 revolutions(max % loss)	 13 50	 13 50	 13 45	 13 45	 13 45	 13 45	 13 40
Soundness (AASHTO T 104) (sodium sulfate, max % loss)	12	12	12	12	12	12	12
Freeze/Thaw (AASHTO T 103) (specified counties, max % loss)	18	18	18	18	18	18	18
Fractured Faces (ASTM 5821) (one face/2 face, % by count)	60 / __	65 / __	75 / 60	85 / 80	98 / 90	100/100	100/90
Flat & Elongated (ASTM D 4791) (max %, by weight)	5 (5:1 ratio)	5 (5:1 ratio)	5 (5:1 ratio)	5 (5:1 ratio)	5 (5:1 ratio)	5 (5:1 ratio)	20 (3:1ratio)
Fine Aggregate Angularity (AASHTO T304, method A, min)	40	40	43	45	45	45	45
Sand Equivalency (AASHTO T 176, min)	40	40	40	45	45	50	50
Gyratory Compaction Gyrations for N_{ini} Gyrations for N_{des} Gyrations for N_{max}	 6 40 60	 7 60 75	 7 75 115	 8 100 160	 8 100 160	 9 125 205	 8 65 160
Air Voids, $\%V_a$ ($\%G_{mm} N_{des}$)	4.0 (96.0)	4.0 (96.0)	4.0 (96.0)	4.0 (96.0)	4.0 (96.0)	4.0 (96.0)	4.0 (96.0)
$\% G_{mm} N_{ini}$	<= 91.5[1]	<= 90.5[1]	<= 89.0[1]	<= 89.0	<= 89.0	<= 89.0	___
Dust to Binder Ratio[2] (% passing 0.075/Pbe)	0.6 - 1.2	0.6 - 1.2	0.6 - 1.2	0.6 - 1.2	0.6 - 1.2	0.6 - 1.2	1.2 - 2.0
Voids filled with Binder (VFB or VFA, %)	70 - 80[4] [5]	65 - 78[4]	65 - 75[4]	65 - 75[3] [4]	65 - 75[3] [4]	65 - 75[3] [4]	70 – 80
Tensile Strength Ratio (TSR) (ASTM 4867) no antistripping additive with antistripping additive	 0.70 0.75	 0.70 0.75	 0.70 0.75	 0.70 0.75	 0.70 0.75	 0.70 0.75	 0.70 0.75
Compactability (Gyration Ratio, Appendix AASHTO R35)	***1.25***	***1.25***	***1.25***	***1.25***	***1.25***	***1.25***	***1.25***
Flow Number at High Design Temperature (Test Method BBB)[6] Highway Speed Slow Speed Intersection	 ___ ___ ___	 ***5 10 30***	 ***15 30 90***	 ***45 90 270***	 ***135 270*** ___	 ***420 840*** ___	 ***420 840*** ___
Reheat Correction Factor for WMA (Test Method CCC)[7]	***Report***	***Report***	***Report***	***Report***	***Report***	***Report***	***Report***
Draindown at Production Temperature (%)	___	___	___	___	___	___	0.30

[1] The percent maximum density at initial compaction is only a guideline.
[2] For a gradation that passes below the boundaries of the caution zone(ref. AASHTO MP3), the dust to binder ratio limits are 0.6 - 1.6.
[3] For 9.5mm nominal maximum size mixtures, the specified VFB range is 73 - 76%.
[4] For 37.5mm nominal maximum size mixes, the specified VFB lower limit is 67%.
[5] For 25.0mm nominal maximum size mixes, the specified VFB lower limit is 67%

[6] Test Method BBB is WisDOT modification of AASHTO TP79 to specify binder content, filler content, short-term aging, specimen air voids, contact deviator stress, and repeated deviator stress. To be develop in WHRP Project 0092-12-02
[7] Test Method CCC to be developed in WHRP Project 0092-12-02

(2) Perform the mixture design using the planned production and field compaction temperature. Minimum production temperatures are given in table 460-4.

TABLE 460-4 MINIMUM MIXTURE PRODUCTION TEMPERATURES

Mixture Type	***MINIMUM PRODUCTION TEMPERATURE, °F***				
	No WMA Additive or Process	***Chemical WMA Additive***	***Wax WMA Additive***	***Synthetic Zeolite WMA Additive***	***Water Injection***
Virgin	***260***	***230***	***230***	***230***	***250***
RAP or FRAP	***260***	***230***	***230***	***230***	***250***
RAS	***300***	***300***	***300***	***300***	***300***

460.2.8 Quality Management Program
460.2.8.1 General
(1) Provide and maintain a QC program defined as all activities, including mix design, process control inspection, sampling and testing, and process adjustments related to producing and placing HMA pavement conforming to the specifications. The contractor may also provide an optional CA program.

(2) The department will provide product quality verification as follows:

1. By conducting verification testing of independent samples.
2. By periodically observing contractor sampling and testing.
3. By monitoring required control charts exhibiting test results and control parameters.
4. By the engineer directing the contractor to take additional samples at any time during production.

(3) Refer to CMM 8.36 for detailed guidance on sampling, testing, and documentation under the QMP.

460.2.8.2 Contractor Testing
460.2.8.2.1 Required Quality Control Program
460.2.8.2.1.1 Personnel Requirements
(1) Provide HTCP certified sampling and testing personnel. Provide at least one full-time HMA technician certified at a level appropriate for sampling and production control testing at each plant site furnishing material to the project. Before mixture production begins, provide an organizational chart in the contractor's laboratory. Include the names, telephone numbers, and current certifications of all personnel with QC or CA responsibilities. Keep the chart updated.

(2) Ensure that sampling and testing personnel are minimally qualified as follows[1]:

- HMA technician certified at a level appropriate for sampling and production control testing.
- HMA ACT[2] .

[1] After informing the engineer, a non-certified person under the direct observation of a certified HMA technician may sample for a period not to exceed 3 calendar days.
[2] A certified HMA technician must coordinate and take responsibility for the work an ACT performs. No more than one ACT can work under a single certified technician.

(3) Have a certified HMA technician ensure that all sampling and testing is performed correctly, analyze test results, and post resulting data.

(4) Have an HMA technician certified at a level appropriate for process control and troubleshooting or mix design available to make necessary process adjustments.

460.2.8.2.1.2 Laboratory Requirements

(1) Conduct QC testing in a facility conforming to the department's laboratory qualification program.

(2) Ensure that the laboratory has at least 320 square feet of workspace and has a telephone for exclusive use by QMP personnel. Ensure that all testing equipment conforms to the equipment specifications applicable to the required testing methods.

460.2.8.2.1.3 Required Sampling and Testing

460.2.8.2.1.3.1 Contracts with 5000 Tons of Mixture or Greater

(1) Furnish and maintain a laboratory at the plant site fully equipped to perform the daily contractor QC testing. Have the laboratory on-site and operational before beginning mixture production. Recovered binder grading, if required, may be conducted at an off-site laboratory.

(2) Obtain random samples and perform tests according to CMM 8.36. Obtain HMA mixture samples from trucks at the plant. Perform quality control tests for air voids without reheating samples.

(3) Retain the split portion of the contractor HMA mixture and blended aggregate samples for 14 calendar days at the laboratory site in a dry, protected area. The engineer may decrease this 14-day retention period. At project completion the contractor may dispose of remaining samples if the engineer approves.

(4) When recycled asphaltic material is used, perform the following tests at the rate of at least one per day for each recycled asphaltic material:

Asphalt content according to AASHTO T164
Gradation according to AASHTO T30

(5) Use the test methods identified below, or other methods the engineer approves, to perform daily QC testing at a frequency greater than or equal to that indicated:

Blended aggregate gradations:

Drum plants:

- Field extraction by department test method number 1560.
- Belt samples, optional for virgin mixtures, obtained from stopped belt or from the belt discharge using an engineer-approved sampling device and performed according to AASHTO T11 and T27.

Batch plants:

- Field extraction by department test method number 1560.

Asphalt content (AC) in percent:

AC by calculation.

AC by nuclear gauge reading, optional.

AC by inventory, optional.

Bulk specific gravity of the compacted mixture according to AASHTO T166.

Maximum specific gravity according to AASHTO T 209.

Air voids (Va) by calculation according to AASHTO T 269.

VMA by calculation according to AASHTO R 35

Test each design mixture at a frequency at or above the following:

TOTAL DAILY PLANT PRODUCTION FOR DEPARTMENT CONTRACTS in tons	SAMPLES PER DAY[1]
50 to 600	1
601 to 1500	2
1501 to 2700	3
2701 to 4200	4
greater than 4200	see footnote[2]

[1] Frequencies are for planned production. If production is other than planned, conform to CMM 8.36.

[2] Add a random sample for each additional 1500 tons or fraction of 1500 tons.

(6) ***Conduct field tensile strength ratio tests according to ASTM D 4867 on all mixtures.*** Test each full 50,000 ton production increment, or fraction of an increment, after the first 5,000 tons of production. Perform required increment testing in the first week of production of that increment. If field tensile strength ratio values are either below the spec limit or less than the mixture design JMF percentage value by 20 or more, notify the engineer. The engineer and contractor will jointly determine a corrective action.

(7) If the binder replacement in the mixture exceeds the limits in table 460-2, extract, recover, and performance grade the binder in the mixture at the rate of 1 test per 10,000 tons. Obtain samples within the first 2,000 tons of each increment. If test results are outside the specified

binder grade for the project, stop production and notify the engineer. The engineer and contractor will jointly determine a corrective action.

460.2.8.2.1.3.2 Contracts with Less Than 5000 Tons of Mixture

(1) Conform to 460.2.8.2.1.3.1 modified as follows:

-The contractor may conduct QC tests in an off-site laboratory.

-One field tensile strength ratio testing is required.

-One recovered binder grade is required.

460.2.8.2.1.3.3 Contracts with Less Than 500 Tons of Mixture

(1) The engineer may waive QC testing on contracts with less than 500 tons of mixture. If testing is waived, acceptance will be by visual inspection unless defined otherwise by contract change order.

(2) If HMA density testing is waived under 460.3.3.3, QC testing is also waived.

460.2.8.2.1.3.4 Temporary Pavements

(1) The engineer may waive all testing for temporary pavements, defined for this purpose as pavements that will be placed and removed before contract completion.

460.2.8.2.1.4 Documentation

460.2.8.2.1.4.1 Records

(1) Document all observations, inspection records, mixture adjustments, and test results daily. Note observations and inspection records in a permanent field record as they occur. Record all process adjustments and JMF changes. Submit copies of the running average calculation sheets for blended aggregate, mixture properties, and asphalt content along with mixture adjustment records to the engineer each day. Submit testing records and control charts to the engineer in a neat and orderly manner within 10 days after paving is completed.

(2) Continue charts, records, and testing frequencies, for a mixture produced at one plant site, from contract to contract.

460.2.8.2.1.4.2 Control Charts

(1) Maintain standardized control charts at the laboratory. Record contractor test results on the charts the same day as testing. Post CA test results on the charts as data becomes available. Record data on the standardized control charts as follows:

- Blended aggregate gradation tests in percent passing. Of the following, plot those sieves the design specifications require: 37.5-mm, 25.0-mm, 19.0-mm, 12.5-mm, 9.5-mm, 2.36-mm, and 75-µm.
- Asphalt material content in percent.
- ***Binder replacement from each recycled asphaltic material based on daily recycled asphalt material content and current asphalt material content.***
- Air voids in percent.
- VMA in percent.

(2) Plot both the individual test point and the running average of the last 4 data points on each chart. Show QC data in black with the running average in red and CA data in blue. Draw the warning limits with a dashed green line and the JMF limits with a dashed red line. The contractor may use computer generated black-and-white printouts with a legend that clearly identifies the specified color coded components.

460.2.8.2.1.5 Control Limits

(1) Conform to the following control limits for the JMF and warning limits based on a running average of the last 4 data points:

ITEM	JMF LIMITS	WARNING LIMITS
Percent Passing given sieve		
37.5 mm	+/- 6.0	+/- 4.5
25.0 mm	+/- 6.0	+/- 4.5
19.0 mm	+/- 5.5	+/- 4.0
12.5 mm	+/- 5.5	+/- 4.0
9.5 mm	+/- 5.5	+/- 4.0
2.36 mm	+/- 5.0	+/- 4.0
75 µm	+/- 2.0	+/- 1.5
Asphalt content in percent	+/- 0.4	+/- 0.3
Air voids in percent	+/- 1.3	+/- 1.0
VMA in percent	- 1.5	- 1.2
RAP binder replacement	***+/- TBD***	***+/- TBD***
RAS binder replacement	***+/- TBD***	***+/- TBD***

(2) Warning bands are defined as the area between the JMF limits and the warning limits.

460.2.8.2.1.6 Job Mix Formula Adjustment

(1) The contractor may request adjustment of the JMF according to the department's test method number 1559. Have an HTCP HMA technician certified at a level appropriate for process control and troubleshooting or mix design submit a written JMF adjustment request. Ensure that the resulting JMF is within specified master gradation bands. The department will have an HMA technician certified at level III review the proposed adjustment and, if acceptable, issue a revised JMF. The department will not allow adjustments exceeding specified JMF tolerance limits. Have an HMA technician certified at level II make related process adjustments.

(2) If mixture redesign is necessary, submit a new JMF, subject to the same specification requirements as the original JMF.

(3) Do not reduce the JMF asphalt content unless the production VMA meets or exceeds the minimum VMA design requirement for the mixture produced as defined in table 460-1.

460.2.8.2.1.7 Corrective Action

(1) When running average values trend toward the warning limits, consider taking corrective action. Document all corrective actions undertaken. Include all test results in the contract files and in running average calculations.

(2) Notify the engineer if running average values exceed the warning limits. If two consecutive running average values exceed the warning limits, stop production and make adjustments. Do not restart production until after notifying the engineer of the adjustments made. Do not calculate a new running average until the fourth test after the required production stop.

(3) If the process adjustment improves the property in question so that the running average after 4 additional tests is within the warning limits, the contractor may continue production with no reduction in payment.

(4) If the adjustment does not improve the properties and the running average after 4 additional tests stays inside the warning bands, the mixture is nonconforming and subject to pay adjustment.

(5) If the contractor fails to stop production and make adjustments when required, all mixture produced from the stop point to the point when the running average is back inside the warning limits is nonconforming and subject to pay adjustment.

(6) The department will reduce payment for nonconforming QMP HMA mixtures, starting from the stop point to the point when the running average is back inside the warning limits, as follows:

	PAYMENT FOR MIXTURE[1] [2]	
ITEM	PRODUCED WITHIN WARNING BANDS	PRODUCED OUTSIDE JMF LIMITS
Gradation	90 %	75 %
Asphalt Content	85 %	75 %
Air Voids	70 %	50 %
VMA	90 %	75 %
Binder Replacement[3]	***TBD***	***TBD***

[1] For projects or plants where the total production of each mixture design requires less than 4 tests refer to CMM 8.36.
[2] Payment is in percent of the contract unit price for both the HMA Pavement and Asphaltic Material bid items. The department will reduce pay based on the nonconforming property with lowest percent pay. The asphaltic material quantity is based on the JMF asphalt content. The department will administer pay reduction under the Nonconforming QMP Asphaltic Material and the Nonconforming QMP HMA Mixture administrative items.
[3] Pay adjustment for binder replacement waived if recovered binder grading indicates the binder meets the binder grade specified in the contract.

(7) If the running average values exceed the JMF limits, stop production and make adjustments. Do not restart production until after notifying the engineer of the adjustments made. Continue calculating the running average after the production stop.

(8) If the air voids running average of 4 exceeds the JMF limits, the material is nonconforming. Remove and replace unacceptable material at no additional expense to the department. The

engineer will determine the quantity of material to replace based on the testing data using the methods in CMM 8.36 and an inspection of the completed pavement. If the engineer allows the mixture to remain in place, the department will pay for the mixture and asphaltic material at 50 percent of the contract price.

(9) If the running average of 4 exceeds the JMF limits for other properties, the department will pay 75 percent of the contract price for mixture and asphaltic material if the engineer allows the mixture to remain in place. The engineer will determine the quantity of material subject to pay reduction based on the testing data and an inspection of the completed pavement.

460.2.8.2.2 Optional Contractor Assurance

460.2.8.2.2.1 General

(1) CA testing is optional and is conducted to further validate production testing. The contractor may offer CA data to provide an additional piece of information for the following:

1. Process control decisions.
2. Troubleshooting possible sampling, splitting, or equipment problems.
3. Limiting liability, as defined in CMM 8.36, for nonconforming product as a result of department verification testing. These provisions do not supersede department's rights under 107.16.

460.2.8.2.2.2 Personnel Requirements

(1) Ensure that an HMA technician certified under HTCP at a level appropriate for mixture production control testing performs all CA testing and data analysis. Personnel performing CA testing cannot perform QC testing for the same materials.

460.2.8.2.2.3 Laboratory Requirements

(1) Conduct CA testing in a facility conforming to the department's laboratory qualification program. Furnish and maintain a laboratory fully equipped for performing selected CA tests. If the a single laboratory is providing CA and QC data for the same materials, ensure that a separate set of equipment is used to prepare CA samples and run CA tests.

460.2.8.2.2.4 Testing

(1) For the CA program, use the test methods enumerated here in 460.2.8.2.2.4, other engineer-approved methods, or other methods the industry and department HMA technical team recognizes. The contractor may select tests at its option. If using tests in limiting liability, as provided in CMM 8.36, data must exist for the property in question.

(2) Perform selected testing as follows:

- Bulk specific gravity (Gmb) of the compacted mixture according to AASHTO T 166 based on the average of 2 specimens.
- Maximum specific gravity (Gmm) according to AASHTO T 209.
- Air voids (Va). Calculate according to AASHTO T 269. ***If reheated samples are used, apply reheat adjustment from approved mixture design.***
- ***Asphalt content***
- ***Binder replacement based on daily recycled asphalt material content***
- VMA by calculation according to AASHTO R 35.

- Recovered binder grading if binder replacement exceeds limits in table 460-2.

(3) There is no specified frequency for CA testing.

(4) The department will compare CA samples to QC samples. Obtain CA samples by retaining a QC split portion conforming to the "rule of retained" requirements, as provided in CMM 8.36. Alternatively the contractor may have CA personnel take an additional sample during production.

460.2.8.2.2.5 Documentation

(1) Report CA test results to the engineer and the contractor's field staff within 2 business days after receiving the samples.

460.2.8.2.2.6 Allowable Differences

(1) Differences between the QC and CA split sample test results are acceptable in limiting liability, as provided in CMM 8.36, if within the following limits:

ITEM	ALLOWABLE DIFFERENCES
Percent passing 12.5 mm sieve	6.0
Percent passing 9.5 mm sieve	6.0
Percent passing 4.75 mm sieve	5.0
Percent passing 2.36 mm sieve	4.0
Percent passing 600 µm sieve	3.5
Percent passing 75 µm sieve	2.0
Bulk specific gravity	0.030
Maximum specific gravity	0.030
Asphalt content	***TBD***
Binder replacement	***TBD***
Recovered binder high temperature grade, if required	***TBD***
Recovered binder intermediate temperature grade, if required	***TBD***
Recovered binder low temperature grade, if required	***TBD***

460.2.8.3 Department Testing

460.2.8.3.1 Quality Verification Program

460.2.8.3.1.1 General

(1) The engineer will conduct QV tests to determine the quality of the final product and measure characteristics that predict relative performance.

460.2.8.3.1.2 Personnel Requirements

(1) The department will provide at least one HMA technician, certified under HTCP at a level appropriate for sampling and mixture production control testing, to observe QV sampling of project mixtures.

(2) An HMA technician certified at a level appropriate for sampling and mixture production control testing, or an HMA ACT working under the HMA certified technician, will split samples and do the testing. An HMA technician certified at a level appropriate for sampling and mixture production control testing must coordinate and take responsibility for the work an ACT performs. No more than one ACT can work under a single certified technician.

(3) An HMA technician certified at a level appropriate for sampling and mixture production control testing will ensure that all sampling and testing is performed correctly, analyze test results, and post resulting data.

(4) The department will make an organizational chart available at the testing laboratory and to the contractor before mixture production begins. The department's chart will include names, telephone numbers, and current certifications of all QV testing personnel. The department will update the chart with appropriate changes, as they become effective.

460.2.8.3.1.3 Laboratory Requirements

(1) The department will furnish and maintain a facility for QV testing conforming to the department's laboratory qualification program requirements and fully equipped to perform QV testing. In all cases, the department will conduct testing in a separate laboratory from the contractor's laboratory.

460.2.8.3.1.4 Department Verification Testing Requirements

(1) HTCP certified department personnel will obtain random samples by directly supervising HTCP certified contractor personnel sampling from trucks at the plant. The department will sample according to CMM 8.36. Sample size must be adequate to run the appropriate required tests in addition to one set of duplicate tests that may be required for dispute resolution. The engineer will split the sample for testing and retain the remaining portion for additional testing if needed.

(2) The department will verify product quality using the test methods enumerated here in 460.2.8.3.1.4(2), other engineer-approved methods, or other methods the industry and department HMA technical team recognizes. The department will identify test methods before construction starts and use only those methods during production of that material unless the engineer and contractor mutually agree otherwise.

(3) The department will perform all testing conforming to the following standards:

- Bulk specific gravity (Gmb) of the compacted mixture according to AASHTO T 166 based on the average of 2 specimens.
- Maximum specific gravity (Gmm) according to AASHTO T 209.
- Air voids (Va). Calculate according to AASHTO T 269. ***If reheated samples are used, apply reheat adjustment from approved mixture design.***
- VMA by calculation according to AASHTO R 35.
- ***Recovered binder grading if binder replacement exceeds the limits given in table 460-2***

(4) The department will randomly test each design mixture at the following minimum frequency:

FOR TONNAGES TOTALING:	
Less than 501 tons	no tests required
From 501 to 30,000 tons	one test
More than 30,000 tons	Add one test for each additional 30,000-ton increment

460.2.8.3.1.5 Documentation

(1) The engineer will document all observations during QV sampling, and review QC mixture adjustments and QC/CA test results daily. The engineer will note results of observations and inspection records in a permanent field record as they occur.

460.2.8.3.1.6 Acceptable Verification Parameters

(1) The engineer will provide the following test results to the contractor within 2 mixture-production days after obtaining the sample. The quality of the product is acceptably verified if it meets the following limits:

- Air voids within a range of 2.7 to 5.3 percent.
- VMA is within minus 1.5 of the minimum requirement for the mix design nominal maximum aggregate size.

If the binder replacement exceeds the limits given in table 460-2, the engineer will provide the following test results to the contractor within 5 mixture-production days after obtaining the sample. The quality of the product is acceptably verified if it meets the following limits:

- Recovered binder grade meets the grade specified in the contract.

(2) If QV test results are outside the specified limits, the engineer will investigate immediately through dispute resolution procedures. The engineer may stop production while the investigation is in progress if the potential for a pavement failure is present.

(3) If production continues for that mixture design, the engineer will provide additional retained sample testing at the frequency provided for in CMM 8.36. This supplemental testing will continue until the material meets allowable differences or as the engineer and contractor mutually agree.

460.2.8.3.1.7 Dispute Resolution

(1) When QV test results do not meet the specified limits, the bureau's AASHTO accredited laboratory and certified personnel will referee test the retained portion of the QV sample and the retained portion of the nearest available previous QC sample.

(2) The department will notify the contractor of the referee test results within 3 business days after receipt of the samples.

(3) The department will determine mixture conformance and acceptability by analyzing referee test results, reviewing mixture project data, and inspecting the completed pavement all according to CMM 8.36.

460.2.8.3.1.8 Corrective Action

(1) Remove and replace unacceptable material at no additional expense to the department.

(2) The department will reduce pay for the tonnage of nonconforming mixture, as determined during QV dispute resolution, if the engineer allows that mixture to remain in place. If production of that mixture design continued during the investigation, the department will also adjust pay for that mixture forward to the next conforming QV or QC/CA point. The department will pay for the affected mixture at 50 percent of the contract price. The department will adjust pay for both the mixture and the asphaltic material.

460.2.8.3.2 Independent Assurance Testing

(1) The department will evaluate both the contractor and department testing personnel and equipment as specified in 106.3.4.3.4.

460.3 Construction

460.3.1 General

(1) Construct HMA pavement conforming to the general provisions of 450.3.

460.3.2 Thickness

(1) Provide the plan thickness for lower and upper layers limited as follows:

NOMINAL SIZE	MINIMUM LAYER THICKNESS in inches	MAXIMUM LOWER LAYER THICKNESS in inches	MAXIMUM UPPER LAYER THICKNESS in inches	MAXIMUM SINGLE LAYER[3] THICKNESS in inches
37.5 mm	3.5	5	4.5	6
25.0 mm	3.25	5	4	6
19.0 mm	2.25	4	3	5
12.5 mm[1]	1.75	3[2]	2.5	4
9.5 mm[1]	1.5	3[2]	2	3

[1] SMA mixtures use nominal size 12.5 mm or 9.5 mm.

[2] SMA mixtures with nominal sizes of 12.5 mm and 9.5 mm have no maximum lower layer thickness specified.

[3] For use on cross-overs and shoulders.

460.3.3 HMA Pavement Density Maximum Density Method

460.3.3.1 Minimum Required Density

(1) Compact all layers of HMA mixture to the density table 460-5 shows for the applicable mixture, location, and layer.

TABLE 460-5 MINIMUM REQUIRED DENSITY[1]

LOCATION	LAYER	PERCENT OF TARGET MAXIMUM DENSITY		
		MIXTURE TYPE		
		E-0.3, E-1, and E-3	E-10, E-30, and E-30x	SMA[5]
TRAFFIC LANES[2]	LOWER	91.5[3]	92.0[4]	----
	UPPER	91.5	92.0	----
SIDE ROADS, CROSSOVERS, TURN LANES, & RAMPS	LOWER	91.5[3]	92.0[4]	----
	UPPER	91.5	92.0	----
SHOULDERS & APPURTENANCES	LOWER	89.5	89.5	----
	UPPER	90.5	90.5	----

[1] The table values are for average lot density. If any individual density test result falls more than 3.0 percent below the minimum required target maximum density, the engineer may investigate the acceptability of that material.
[2] Includes parking lanes as determined by the engineer.
[3] Minimum reduced by 2.0 percent for a lower layer constructed directly on crushed aggregate or recycled base courses.
[4] Minimum reduced by 1.0 percent for lower a layer constructed directly on crushed aggregate or recycled base courses.
[5] The minimum required densities for SMA mixtures are specified in the contract special provisions.

460.3.3.2 Pavement Density Determination

(1) The engineer will determine the target maximum density using department procedures described in CMM 8.15. The engineer will measure pavement density for either nuclear density or the density of sawed or cored samples. The engineer and contractor will decide which method to use before paving. A change to the method requires agreement between the engineer, contractor, and the department's quality management section. The engineer will determine density as soon as it is practical after compaction and before placement of subsequent layers or before opening to traffic. Cut pavement samples as the engineer directs and restore the surface with new, well compacted mixture.

(2) Do not re-roll compacted mixtures with deficient density test results. Do not operate continuously below the specified minimum density. Stop production, identify the source of the problem, and make corrections to produce work meeting the specification requirements.

(3) A lot is defined in CMM 8.15 and placed within a single layer for each location and target maximum density category indicated in table 460-5.

(4) For nuclear density, the department will test 5 random samples on each lot. For the density of sawed or cored samples, the department will test 3 random samples, each with an area of at least

28 square inches, from each lot. The lot density is the average of all samples taken for that lot. The number of nuclear density tests required for legs of side roads at intersections, crossovers, turn lanes, and ramps with less than 750 tons per layer are specified in CMM 8.15.

(5) A certified nuclear density technician, or an nuclear density ACT working under a certified nuclear density technician, will locate samples and do the testing. A certified nuclear density technician certified must coordinate and take responsibility for the work an ACT performs. No more than one ACT can work under a single certified technician. The responsible certified technician will ensure that sample location and testing is performed correctly, analyze test results, and provide density results to the contractor weekly.

460.3.3.3 Waiving Density Testing

(1) The engineer may waive density testing for one or more of the following reasons:

1. It is not practical to determine density by the lot system.
2. The contract contains less than 750 tons of a given mixture type placed within the same layer and target maximum density category.

(2) If the department waives density testing notify the contractor before paving. The department will accept the mixture by the ordinary compaction procedure as specified in 450.3.2.6.2.

(3) If HMA QC testing is waived under 460.2.8.2.1.3.3, density testing is also waived.

460.4 Measurement

(1) The department will measure the HMA Pavement bid items acceptably completed by the ton as specified in 450.4.

460.5 Payment

460.5.1 General

(1) The department will pay for measured quantities at the contract unit price under the following bid items:

ITEM NUMBER	DESCRIPTION	UNIT
460.1100	HMA Pavement Type E-0.3	TON
460.1101	HMA Pavement Type E-1	TON
460.1103	HMA Pavement Type E-3	TON
460.1110	HMA Pavement Type E-10	TON
460.1130	HMA Pavement Type E-20	TON
460.1132	HMA Pavement Type E-30X	TON
460.1700	HMA Pavement Type SMA	TON
460.2000	Incentive Density HMA Pavement	DOL

460.5.2 HMA Pavement

460.5.2.1 General

(1) The department will pay for the HMA Pavement bid items at the contract unit price subject to one or more of the following adjustments:

1. Disincentive for density of HMA pavement as specified in 460.5.2.2.
2. Incentive for density of HMA pavement as specified in or 460.5.2.3.
3. Reduced payment for nonconforming smoothness as specified in 450.3.2.9.
4. Reduced payment for nonconforming QMP HMA mixtures as specified in 460.2.8.2.1.7.

(2) Payment for HMA Pavement Type E-0.3, E-1, E-3, E-10, E-30, and E-30x is full compensation for providing HMA mixture designs; for preparing foundation; for furnishing, preparing, hauling, mixing, placing, and compacting mixture; for QMP testing and aggregate source testing; for warm mix asphalt additives or processes; and for all materials except asphaltic materials.

(3) Payment for HMA Pavement Type SMA, is full compensation for providing HMA mixture designs; for preparing foundation; for furnishing, preparing, hauling, mixing, placing, and compacting the mixture; for QMP testing and aggregate source testing; and for all materials including asphaltic materials and warm mix asphalt additives and processes; and for stabilizer, hydrated lime, and liquid antistripping agent if required.

(4) If provided for in the plan quantities, the department will pay for a leveling layer, placed to correct irregularities in an existing paved surface before overlaying, under the pertinent paving bid item. Absent a plan quantity, the department will pay for a leveling layer as extra work.

(5) Except for SMA mixes, the department will pay for asphaltic materials separately under the Asphaltic Materials bid items as specified in 455.5. Except for SMA mixes, hydrated lime or liquid antistripping agent, when required, is included in the contract price for the asphaltic material.

(6) If the department waives density testing under 460.3.3.3, the department will not adjust pay under either 460.5.2.2 or 460.5.2.3.

(7) Restore the surface after cutting density samples as specified in 460.3.3.2(1) at no additional cost to the department.

460.5.2.2 Disincentive for HMA Pavement Density

(1) The department will administer density disincentives under the Disincentive Density HMA Pavement and the Disincentive Density Asphaltic Material administrative items. If the lot density is less than the specified minimum in table 460-4, the department will reduce pay based on the contract unit price for both the HMA Pavement and Asphaltic Material bid items for that lot as follows:

DISINCENTIVE PAY REDUCTION FOR HMA PAVEMENT DENSITY

PERCENT OF LOT DENSITY BELOW SPECIFIED MINIMUM	PAYMENT FACTOR (percent of contract price)
From 0.5 to 1.0 inclusive	98
From 1.1 to 1.5 inclusive	95
From 1.6 to 2.0 inclusive	91
From 2.1 to 2.5 inclusive	85
From 2.6 to 3.0 inclusive	70
More than 3.0[1]	----

[1] Remove and replace the lot with a mixture at the specified density. When acceptably replaced, the department will pay for the replaced work at the contract unit price. Alternatively the engineer may allow the nonconforming material to remain in place with a 50 percent payment factor.

(2) If the engineer directs placing HMA mixtures between October 15 and May 1 for department convenience as specified in 450.3.2.1(5), the department will not assess a density disincentive on pavement the department orders the contractor to place when the temperature, as defined in 450.3.2.1(2), is less than 36 F.

460.5.2.3 Incentive for HMA Pavement Density

(1) If the lot density is greater than the minimum specified in table 460-3 and all individual air voids test results for that mixture placed during the same day are within +1.0 percent or - 0.5 percent of the design target in table 460-2, the department will adjust pay for that lot as follows:

INCENTIVE PAY ADJUSTMENT FOR HMA PAVEMENT DENSITY

PERCENT OF LOT DENSITY ABOVE SPECIFIED MINIMUM	PAYMENT FACTOR PER TON[1]
From -0.4 to 1.0 inclusive	$0
From 1.1 to 1.8 inclusive	$0.40
More than 1.8	$0.80

[1] The department will prorate the pay adjustment for a partial lot.

(2) The department will adjust pay under the Incentive Density HMA Pavement bid item. Adjustment under this item is not limited, either up or down, to the bid amount the schedule of items shows.

(3) The department will restrict incentive payment for shoulders paved integrally with the traffic lane, if the traffic lane does not meet incentive requirements, the department will not pay incentive on the integrally paved shoulder.

Appendix D Non Standard Tests

Procedure for Short-Term Conditioning of Laboratory and Plant Mixtures for Performance Testing

Summary of Method

This test method describes procedures for conditioning loose mix samples of hot mix asphalt and warm mix asphalt for the preparation of performance test specimens. Procedures are provided for laboratory prepared mixtures and plant mixtures. Laboratory mixtures are first conditioned 2 hours at the compaction temperature to simulate the aging that occurs during production, then for 16 additional hours at 100 °C to simulate a short period of in-service aging. Plant mixtures are conditioned for 18 hours at 100 °C. For hot mix asphalt, this conditioning is approximately equivalent to that obtained from the short-term conditioning for mechanical property testing contained in AASHTO R30.

Equipment

- *Ovens*- Forced draft ovens, thermostatically controlled, capable of maintaining any desired temperature from 95 to 176 °C within ± 3°C.

- *Miscellaneous*- Appropriate sized metal pans for conditioning loose mix, a metal spatula of stirring the loose mix, a timer, and gloves for handling hot materials.

Short-Term Conditioning of Laboratory Prepared Mixtures

1. Prepare HMA mixtures following 8.1 through 8.4 of AASHTO T312. Prepare WMA mixtures following the applicable sections of the Appendix to AASHTO R35.

2. Immediately transfer the mixture from the mixing bowl to a pan and spread to a even thickness ranging between 25 and 50 mm.

3. Place the mixture in a forced-draft oven that was preheated to the planned compaction temperature ± 3°C.

4. Condition the mixture at the planned compaction temperature for 2 hours ±5 minutes. Stir the mixture after 1 hour ±5 minutes to maintain uniform conditioning.

5. Transfer the mixture to a forced-draft oven that was preheated to 100 ± 3°C.

6. Condition the mixture at 100 ± 3°C for 16 hours ±5 minutes.

7. Immediately transfer the conditioned mixture to preheated gyratory molds and compact to the target density in gyratory compactor meeting the requirements of AASHTO T312.

Short-Term Conditioning of Plant Mixtures

1. Place the entire plant mix sample in a pan in a forced-draft oven preheated to 100 °C ± 3 °C. When the mixture softens sufficiently, split the required mass of mixture for specimen fabrication and spread to a even thickness ranging between 25 and 50 mm.

2. Continue conditioning the mixture at 100 °C for a total of 18 hours ±5 minutes from the time the plant mix sample was first placed in the oven.

3. Immediately transfer the conditioned mixture to preheated gyratory molds and compact to the target density in gyratory compactor meeting the requirements of AASHTO T312.

Determination of Coefficients of Thermal Contraction and Glass Transition of Asphalt Mixtures

Summary of Method

This test method can be used to determine the Coefficients of Thermal Contraction (CTC) and Glass Transition (T_g) of asphalt mixtures using the Asphalt Thermal Cracking Analyzer (ATCA). This device measures the linear deflection on an unrestrained asphalt mixture beam as the chamber is cooled at a controlled cooling rate. The chamber is initially heated to above room temperature to remove previous thermal history effects. Once temperature equilibrium is reached in the beam the chamber is cooled at a constant cooling rate while the linear deflection is measured continuously using a pair of Linear Variable Differential Transformers (LVDT) separated from the beam by invar bars glued to the two ends of the sample.

This test method uses beams of asphalt mixture produced from a gyratory compacted sample or cylindrical field core, or using a slab compactor. The thermo-volumetric properties obtained using this method are:

- *Glass Transition Temperature (Tg)* – At the glass transition temperature the material undergoes a transition from "liquid" behavior to "glassy behavior." The glass transition temperature is defined as the temperature at the intersection of the extension of the linear contraction/expansion trends on the volume/length vs. temperature curve. Figure 1 shows this concept.

- *Liquid Coefficient of Contraction (CTC_l)*– The Liquid Coefficient of Contraction is the slope of the volumetric or linear change of dimensions with temperature, when sample is at temperatures sufficiently higher than the T_g to result in a linear rate of volumetric or linear dimensional change with temperature.

- *Glassy Coefficient of Contraction (CTC_g)* – The Glassy Coefficient of Contraction is the slope of the volumetric or linear change of dimensions with temperature, when sample is at temperatures sufficiently lower than the T_g to result in a linear rate of volumetric or linear dimensional change with temperature.

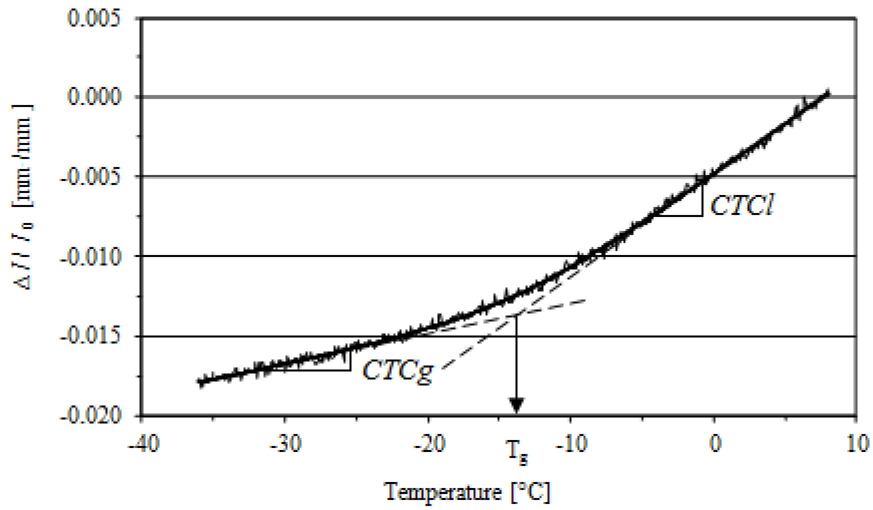


Figure 1. Determination of glass transition temperature

Equipment

- *Environmental Chamber–* A closed loop environmental chamber system, capable of cooling and heating specimen at a constant rate of at least 6°C/hr, and preferably 60°C/hr, and maintaining temperatures as low as -80°C is required for this test.
- The chamber dimensions should be at least 350 mm ×150 mm ×150 mm to allow for the horizontal placement of 300 mm beam specimen along with a dummy sample in the chamber. The chamber should have flat and level surface for sample placement.
- Two circular openings, 20±5 mm in diameter, aligned with specimen ends and placed mid-height of the specimen when placed in chamber are required to allow for extension of invar rods out of chamber and subsequent placement of LVDTs on invar rod ends.
- *Invar rods* – Two invar rods 6±1 mm in diameter and long enough to extend out of environmental chamber at each side. One end of the rods shall be threaded to a length of 5±1 mm, along with a pair of end-pieces 30±5 mm in diameter with a threaded opening corresponding to the threaded end of the rods.
- *Roller rods* – Six cylindrical rods, 5±1 mm in diameter and 70±5 mm long. These rods are evenly spaced under the beam as it lies horizontally in the chamber, to insure minimal frictional resistance to free contraction and expansion of the specimen.
- *Linear Variable Differential Transformers (LVDT)–*Two LVDTs with a working span of 5 mm and a minimum resolution of 0.001 mm.
- *Temperature Probes–*Two thermo-couple probes with minimum resolution of 0.1°C.

Specimen Preparation

*Test Sample–*A beam of compacted asphalt mixture with dimensions of 50±5 mm by 50±5 mm by 300±10 mm is used. The asphalt beam can be cut from a slab produced using a slab compactor, cut from a field sample taken from an existing pavement. The beam can alternatively be produced from a gyratory compacted sample or cylindrical core using the following method:

Using a masonry saw, four prismatic beams of 5 by 5-cm in cross section and 15 cm long are cut from 17 cm gyratory samples. Two of these beams are sawed in half to produce four 7.5 cm blocks. By gluing a 7.5 cm block to each end of the two 15 cm blocks, two 30 cm beams are produced (Figure 2).

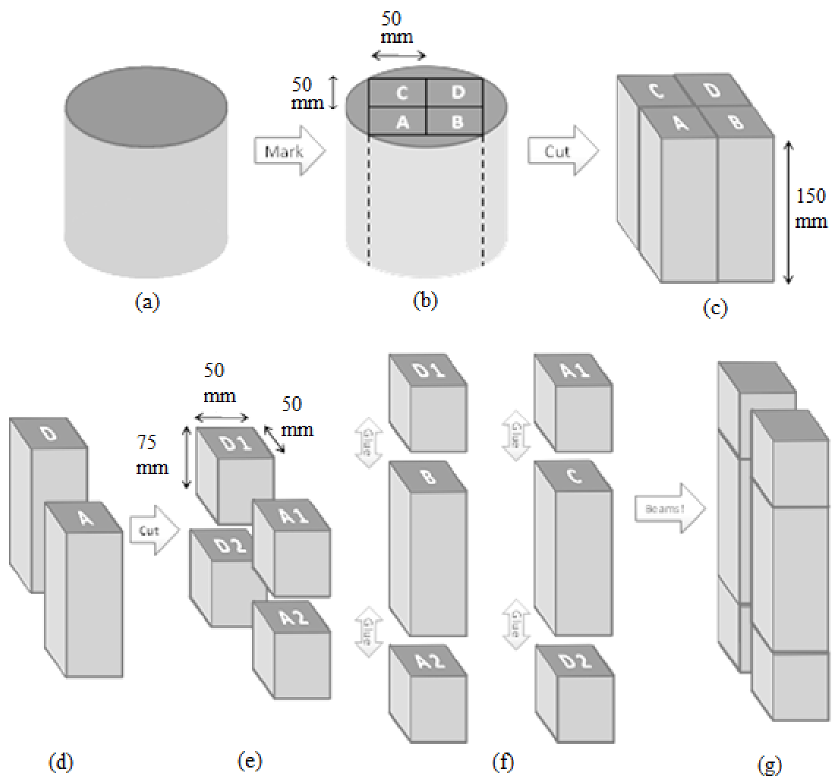


Figure 2 Step by step procedure for producing compacted asphalt mixture beams from cylindrical samples.

Fast Curing Epoxy (3M DP-100 Scotch-Weld) or equivalent fast curing epoxy is used for gluing asphalt mixture beam and the invar rod end-pieces to specimen ends.

After beam is glued and cured, determine the cross sectional area of the beam by measuring width and thickness at the middle of the specimen length and at points at each side of the middle point, to the nearest 0.01 mm. Average the three readings and record to the nearest 0.1 mm.

Procedure

- *Attaching Invar Rods to Sample* – Mark the cross section centroid on each end of the beam by using an ink marker to draw diametric lines across the surface. Apply a 2±0.5 gram of fast during epoxy resin to the back surface of each invar rod end-piece and place firmly on the cross point of the diametric lines at each end of the beam. The end-piece may be kept in place using masking tape until epoxy cures. Invar rods are screwed into each end-piece of the beam. It may be necessary to place beam in chamber and screw in invar rods through the openings of the chamber.

- *Placement of Specimen* – Place the six roller rods at equally spaced intervals across the placement location of the specimen in chamber. Place beam sample on roller rods and align ends with openings of the chamber. Screw invar rods into end-pieces through opening. Center beam on roller such that the beam is equally spaced from the side walls of the chamber and invar rod is extended equally from both sides of chamber.

  Note 1 – The use of invar rods extending out of chamber is to minimize temperature effects on the LVDTs during testing.

- *Placement of LVDTs* – Place each LVDT on invar rod extruding out of chamber opening in such a manner that the LVDTs be initially compressed to a length of 1±0.2 mm on each side. Insure that assembly holding LVDTs sufficiently tight and secure to eliminate any sliding or shifting of the LCDT during test.
- *Placement of Thermocouples* –One of the probes is placed near sample surface, thus measuring chamber air temperature. Readings from this probe is used in the feedback loop to set and maintain cooling rate in chamber. The other probe is placed mid-depth in a dummy asphalt mixture specimen of the same cross section, and minimum length of 100 mm. This probe records asphalt core temperature used for calculation of thermo-volumetric properties.

Procedure

- Begin heating chamber at rate of 60±1°C/hr to 30±0.1°C and keep temperature constant for 30 minutes to insure core temperature has reached chamber temperature. Core temperature is monitored through reading of probe in dummy sample.

  Note 2 – This step is performed to remove any previous temperature history effects and to bring sample core and chamber to the same temperature before start of cooling step.

- Start cooling the chamber at a constant rate 60±1°C/hr to a minimum temperature of -60°C. The chamber temperature should be kept constant at the minimum temperature for 30 minutes before heating begins at a rate of 60±1°C/hr up to the initial temperature of 30°C.

- Automatically record the environmental chamber temperature and dummy core temperature, elapsed time, and LVDT displacement readings as the test progresses during both the cooling and heating phase. Output signals should be conditioned to produce output values at a recommended frequency 1 point per every 5 seconds, and no less than 1 point per every 50 seconds.

- Continue the test until chamber temperature heats back up to 30°C.

Calculation and Interpretation of Results

- Remove data points above 15°C and below -45°C from dataset.

  Note 3 – Due to the lag between sample core temperature and chamber temperature, the rate of change of core temperature gradually becomes constant when a cooling or heating sequence begins, thus core temperature initially varies at a non-constant rate. The same happens when chamber temperature reaches the minimum set point and becomes constant ahead of the specimen core temperature. The elimination of the first and last 15°C of the cooling or heating sequence is to insure that analysis is performed in the range at which core temperature varies at a constant rate.

- Calculate thermal strain during cooling and heating as follows:

  $$\epsilon_i = \frac{[(\delta_0^1 - \delta_i^1) + (\delta_0^2 - \delta_i^2)]}{L}$$

  where:

  ϵ_i is thermal strain at interval i,

  δ_i^1 and δ_i^2 are deformation readings at the ith interval for LVDT 1 and 2, respectively

  δ_0^1 and δ_0^2 are the initial deformation readings for LVDT 1 and 2, respectively

  L is the beam length.

- Plot curve of thermal strain against core temperature.

- Use least square to fit the following equation to curve previously plotted. All parameters except T are fitted through minimization.

  $$\epsilon_{fit} = C + CTC_g(T - T_g) + \ln\left\{\left[1 + e^{\frac{T-T_g}{R}}\right]^{R(CTC_l - CTC_g)}\right\}$$

  where:

  ϵ_{fit} is fitted relationship to experimentally measured thermal strain,

  C is an intercept with no physical meaning,
  CTC_l and CTC_g are the liquid and glassy coefficients of thermal contraction,
  R is a parameter representing the curvature between the two linear asymptotes,
  T is temperature at ith interval, and
  T_g is glass transition temperature.

- Minimization results in estimated values for CTC_l, CTC_g, and T_g.

Re-Heat Correction Factors

Summary of Method
This test method describes procedures for determining reheat correction factors for comparing volumetric properties of WMA obtained on reheated samples with those obtained on samples compacted without reheating.

Equipment

- *Gyratory Compaction Equipment*- A Superpave gyratory compactor and associated equipment to prepare specimens to determine density in accordance with AASHTO T312.

- *Specific Gravity Equipment*- Equipment to measure the bulk specific gravity of compacted asphalt concrete specimens in accordance with AASHTO T166, and the maximum specific gravity of loose asphalt concrete mixtures in accordance with AASHTO T209.

Procedure

1. Prepare sufficient WMA mixture for eight gyratory specimens and one maximum specific gravity specimen following the applicable sections of the Appendix to AASHTO R35.

2. Short-term condition all material for 2 hours at the compaction temperature.

3. Immediately compact four gyratory specimens to the design gyration level without cooling or reheating the mixtures.

4. Measure the maximum specific gravity in accordance with AASHTO T209.

5. Allow the mixture for four of the gyratory specimens to cool to room temperature. Then reheat for two hours at the compaction temperature for the grade of binder used in the mixture and compact four reheated gyratory specimens.

6. Measure the bulk specific gravity of all eight gyratory specimens in accordance with AASHTO T166.

7. Calculate the air void content of each of the gyratory specimens in accordance with AASHTO T269.

8. Calculate the average air void content for the specimens that were compacted without reheating.

9. Calculate the average air void content for the specimens that were compacted after reheating.

10. Calculate the reheat correction factor as the average air void content of the specimens prepared without reheating minus the average air void content of the specimens prepared after reheating.

Procedure for Extraction and Recovery of Recycled Asphalt Shingle Binders for Blending Chart Analysis

General

Extract and recover recycled asphalt shingle (RAS) binders using a combination of Method A (centrifuge extraction) of AASHTO T164 for extraction, and AASHTO 170 as modified below for recovery. The solvent should be reagent grade trichloroethylene.

Extraction

1. Determine the binder content of the RAS in accordance with Method A of AASHTO 160.

2. Using the binder content from Step 1, determine the mass of RAS to be extracted to yield between 75 and 90 g of binder after recovery.

3. Extract the RAS binder in accordance with Method A of AASHTO T164. One recovery yielding between 75 and 90 g of binder will provide between 250 and 300 g of blended RAS/virgin binder for subsequent performance grading.

Recovery

1. Before beginning the recovery, preheat approximately 175 g of virgin binder of known performance grade in a covered container to 150 °C. Record the mass of binder to the nearest 0.1 g. Determine the mass of recovered RAS binder to be blended with this virgin binder to provide a 30/70 RAS to virgin binder blend. Using Equation A1.

$$m_{RAS} = \frac{.30}{.70} \times m_{virgin} = 0.4286 \times m_{virgin} \qquad \text{(A1)}$$

   Where:

   m_{RAS} = mass of recovered RAS binder
   m_{virgin} = mass of recovered RAS binder

2. Recover RAS binder in accordance with AASHTO T170 as modified below.

3. Sample size in Section 8 of AASHTO T170
   a. When recovering RAS binders the recovered sample mass should be between 75 and 90 g. The lower mass is needed to provide additional space in the Abson recovery flask to avoid boil over.

4. Primary distillation in Section 9.3 of AASHTO T170. For RAS binders modify Section 9.3 of AASHTO T170 to read.

a. Concentrate the solution to approximately 200 ml using a rotovapor apparatus. Transfer the residue from the primary distillation flask to the Abson flask when rapid boiling begins to occur in the primary distillation flask. Place the uncovered Abson flask in a ventilated 135 °C oven until the solution begins to boil. Remove the Abson flask from the oven, assemble the apparatus shown in Figure 1, and begin heating. Introduce carbon dioxide at a low rate (approximately 100 ml/min) to provide agitation. Increase the temperature of the residue and maintain the carbon dioxide flow rate of 100 ml/min until the temperature of the residue reaches 157 to 160 °C. At that point increase the carbon dioxide gas flow to approximately 900 ml/min. Continue to increase the temperature of the residue while maintaining the carbon dioxide gas flow at 900 ml/min until the temperature of the residue reaches 190 to 196 °C. Maintain the temperature of the residue and carbon dioxide flow for 5 minutes after solvent dripping ceases, but not less than 20 minutes after reaching 190 °C.

5. Immediately blend the recovered RAS binder with a virgin binder of known performance grade as follows.
    a. Discontinue the carbon dioxide gas flow and heat.
    b. Remove the previously weighed virgin binder from the 150 °C oven and place on a hot plate under a mechanical stirrer.
    c. Disassemble the Abson apparatus and immediately add the mass of recovered RAS binder determined from Equation A1 to the virgin binder and stir for 2 minutes.
    d. Pour a 1 oz tin of blended binder for high temperature unaged performance grade characterization in accordance with AASHTO T315.
    e. Pour remaining blended binder into an 8 oz tin for subsequent conditioning in accordance with AASHTO T240.

Appendix E. Capitol Drive Mix Design

CRM

W234 N796 Busse Rd Pewaukee, WI 53072

Asphalt Mix Submittal Report

Submittal Information		Mix Information	
Submittal Name	507112	Mix ID	_(03-4)
Producer	CRM	Mix Name	507112 E-3 12.5mm
Plant	Design Labs	Design Criteria	
Contact		Design Method	Superpave
Email		Mix Class	C-I
Phone		Mix Category	E-3
Fax		Intended Use	
Customer		Traffic Designation	E-3
Contact		Aggregate Nominal Size	1/2" (12.5mm)
Email		Mixing Temperature	149 °C
Phone		Compaction Temperature	135 °C
Fax		Gyrations@Ndes	75
Project ID	2025-14-70	Gyrations@Nmax	115
Project Name		Gyrations@Nini	7
Contract ID		WisDOT Aggregate Test Number	225-117-2009
Project Location		WisDOT Verfication Number	
Contractor			

Under production eliminate Deg., K&N Natural Sand to 27.0%. A change in binder grade is recognized without the need for additional mix desing laboratory testing as defined in the current WisDOT 1559. Evotherm added as compaction aid.

Prepared For	
Prepared By	Michelle M. Colling
Date Prepared	10/9/2012
Submitted By	Michelle M. Colling - HMA MD
Date Submitted	10/9/2012

Mix Properties

	TMM %
AC Total	5.3
AC Virgin	4.2
AC Recycled	1.1

Recycle AC Contents	%
FRAP	4.20
RAS	20.24

Aggregate	Type	Name	Source	%	Specific Gravity	Grade
Aggregate	Coarse Aggregate	5/8" Chips - K&N	S9 T8N R19E, Waukesha County	16.0		
	Coarse Aggregate	3/8" Chips - K&N	S9 T8N R19E, Waukesha County	20.0		
	Fine Aggregate	MFG'D Sand - Lannon	S23 T8N R18E&S24 T8N R18E Waukesha Co.	22.0		
	Fine Aggregate	NAT Sand - K&N	S9 T8N R19E, Waukesha County	26.7		
	Fine Aggregate	Mineral Filler	S9 T8N R19E, Waukesha County	0.3		
RAP	Fine RAP	RAS Design Lab 2012	40001	3.0		
	Coarse RAP	FRAP	40001	12.0		
Binder	Performance Grade	CRM Milwaukee		4.24	1.032	PG 58-28

CRM

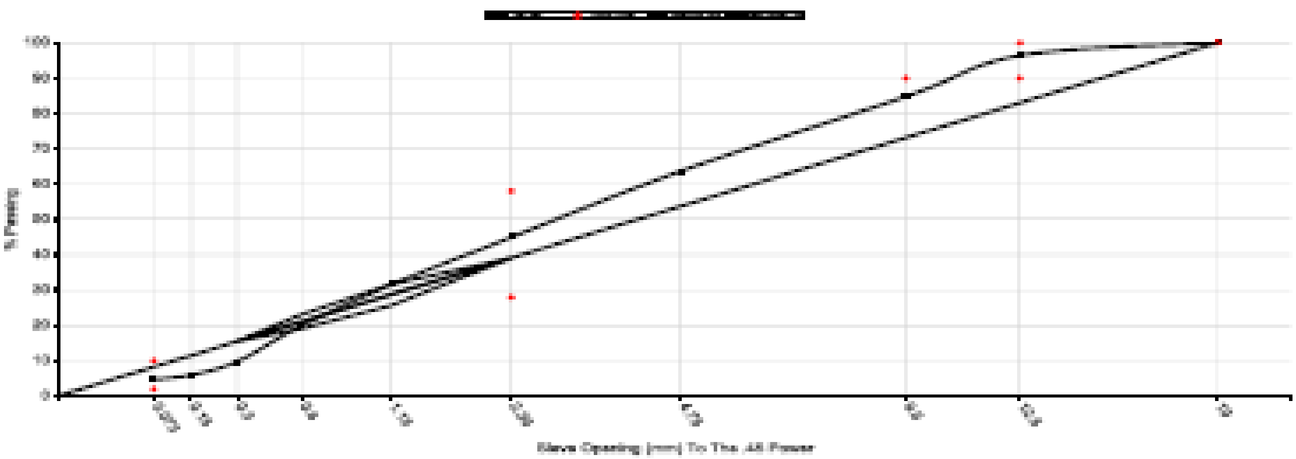
W234 N798 Busse Rd Pewaukee, WI 53072

Mix Properties

Mix _(03-4)-507112 E-3 12.5mm

Specification

Mix Properties				Gradation		
Property	Unit	Design	Specification	Sieve	% Passing	Specification
AC Content (Pb)	%	5.3		3/4" (19mm)	100.0	
Gmb@Ndes		2.420		1/2" (12.5mm)	96.4	
VMA@Ndes	%	14.6		3/8" (9.5mm)	84.8	
Gmm@Nmax		96.9		#4 (4.75mm)	63.7	
Gmm@Nini		88.3		#8 (2.36mm)	44.9	
Va@Ndes	%	4.0		#16 (1.18mm)	31.5	
VFA@Ndes	%	72.9		#30 (0.6mm)	19.9	
Gmm@Ndes	%	96.0		#50 (0.3mm)	9.7	
SPGR (Max,Gmm)		2.516		#100 (0.15mm)	5.9	
Spgr (Effective,Gse)		2.743		#200 (75um)	4.6	
DPE		1.0		Pan	0.0	
TSR (Soak)		88				
TSR Gyrations		21				



CRM

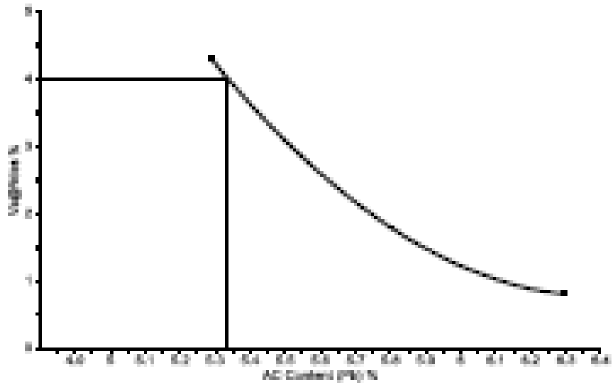
W234 N798 Busse Rd Pewaukee, WI 53072

Mix Blend

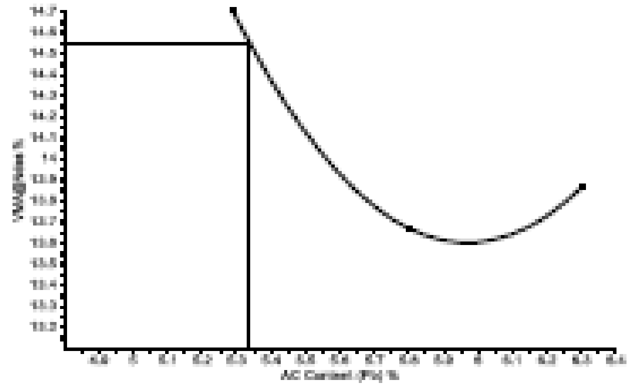
Mix Sieve/Test	Unit	Spec	Result	Dust	5/8" Chips - K&N	3/8" Chips - K&N	MFG'D Sand - Lannon	NAT Sand - K&N	Mineral Filler	RAS Design Lab 2012	FRAP
Type					Coarse Aggregate	Coarse Aggregate	Fine Aggregate	Fine Aggregate	Fine Aggregate	Fine RAP	Coarse RAP
Include					Yes	Yes	Yes	Yes	Yes	Yes	Yes
TMA			100		16	20	22	26.7	0.3	3	12
3/4" (19)	%	100-100	100.0		100.0	100.0	100.0	100.0	100.0	100.0	100.0
1/2" (12.5)	%	90-100	96.4		77.6	100.0	100.0	100.0	100.0	100.0	100.0
3/8" (9.5)	%	<90	84.8		13.7	94.6	100.0	100.0	100.0	99.1	97.4
#4 (4.75)	%		63.7		2.8	24.4	98.8	90.4	100.0	93.8	77.9
#8 (2.36)	%	28-58	44.9		2.3	5.9	62.6	72.9	100.0	89.5	59.7
#16 (1.18)	%		31.5		2.1	4.7	35.4	54.5	100.0	72.1	45.1
#30 (0.6)	%		19.9		2.0	4.4	18.9	32.6	100.0	51.4	33.6
#50 (0.3)	%		9.7		1.9	4.2	9.0	8.8	100.0	43.7	22.2
#100 (0.15)	%		5.9		1.8	4.0	4.4	2.2	100.0	35.9	15.7
#200 (0.075)	%	2-10	4.64		1.60	3.70	2.70	1.30	100.0	30.5	12.40
PAN (0)	%		0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fractured Faces (>1)		>75	96.2		83.3	99.5	100.0	100.0			92.3
Fractured Faces (>2)		>60	95.1		77.5	97.0	100.0	100.0			95.8
Elongated (5:1)		<5	0				1.0	0.0			0.1
FAA, Us		>43	42.9				45.3	40.9		43.7	
FM	%		4.415		6.73	5.58	3.71	3.39		2.350	3.48
SE		>40	96				97	96			
Total Moisture	%		1.2		2.07	1.20	1.20	0.90		0.0	1.20
Absorption	%		1.1		1.1	1.2	1.2	0.9		2.6	1.2
SPGR (Dry,Gsb)			2.681		2.730	2.720	2.707	2.669		2.213	2.676
SPGR (SSD)			2.711		2.759	2.753	2.739	2.691		2.268	2.707
SPGR (Apparent,Gsa)			2.764		2.811	2.814	2.796	2.731		2.344	2.763

Volumetric Charts

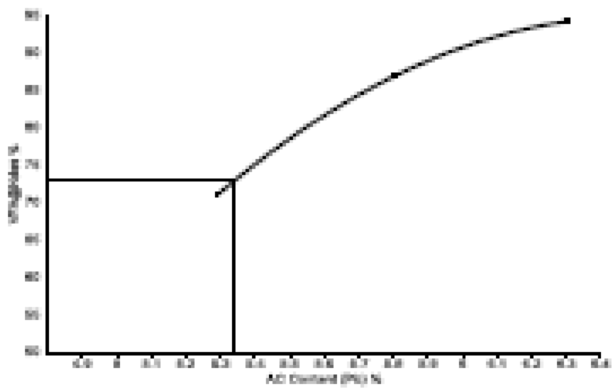
Mix



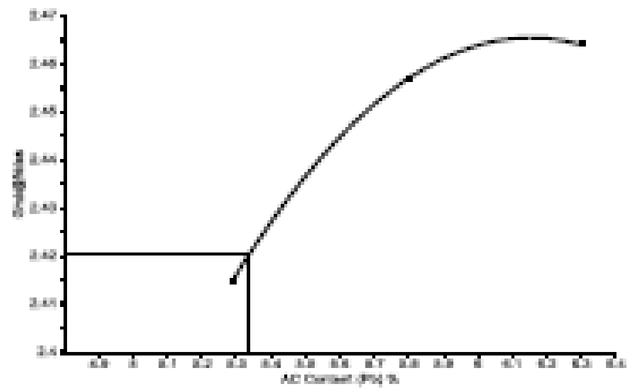
AC Content (Pb)=5.3, Va@Ndes=4.0



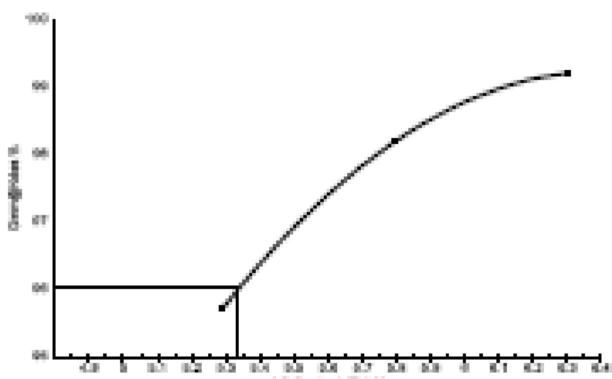
AC Content (Pb)=5.3, VMA@Ndes=14.55



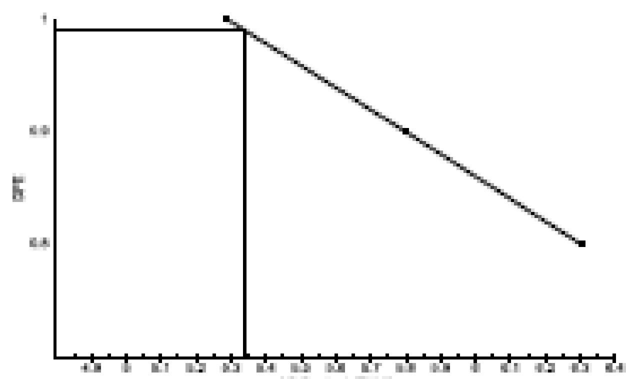
AC Content (Pb)=5.3, VFA@Ndes=72.69



AC Content (Pb)=5.3, Gmb@Ndes=2.420



AC Content (Pb)=5.3, Gmm@Ndes=96.0



AC Content (Pb)=5.3, DPE=1.0

CRM

W234 N798 Busse Rd Pewaukee, WI 53072

Batch Test Summary

Mix

Test	Sample 1	Sample 2	Sample 3
AC Content (Pb) %	5.3	5.8	6.3
Va@Ndes %	4.3	1.8	0.8
VMA@Ndes %	14.70	13.67	13.86
VFA@Ndes %	70.99	86.83	94.23
SPGR (Compacted,Gmb)	2.415	2.457	2.464
Unit Wt (Compacted) kg/m3	2408	2450	2458
SPGR (Max,Gmm)	2.517	2.507	
Unit Wt (Max) kg/m3	2510	2500	
Gmb@Ndes	2.415	2.457	2.464
Gmm@Ndes %	95.7	98.2	99.2
DP	0.9	0.8	0.7
DPE	1.0	0.9	0.8

asphaltQC 10/9/2012

Appendix F. STH 70 Mix Design

Driveways To Highways

8075 County Hwy D
Eagle River, WI 54501

WARM MIX ASPHALT DESIGN REPORT

Pitlik & Wick, Inc. - WisDOT Qualified Laboratory

SUBMITTED: Express Level

MIX DESIGN NO.: PW#205-W

DATE: 8/15/2013

TYPE: 12.5mm E-3

PROJECT NO.: 9070-03-60

PROJECT LOCATION: STH 70 Fifield - Woodruff: North County Line-Morgan Road

REGIONAL HMA REPRESENTIVIES: WisDOT District 7, Dean Gritzmacher, John Brophy

WISDOT ID:

Dawn M. Pitlik, Asphalt Mix Design Technician, Level IIIS.

WARM MIX ASPHALT DESIGN REPORT

GENERAL INFORMATION

Mix Design No.:	PW#205-W	**Specification:**	WisDOT Superpave
Date:	08/15/13	**Type:**	12.5mm E 3
Project No.:	9070-03-60	**Source:**	Blue Lake Pit (Richardson)
Project Location:	STH 70		SW, SE, Section 27, T:39N, R:6, E
	Fifield-Woodruff		Oneida County

MATERIALS SUBMITTED FOR DESIGN

Type & Size	% of Blend
5/8" Rock	22
1/4" Man. Sand	21
5/16" Natural Sand	38
5/8" Frap	16
RAS	3

Blend Fracture, %: 80%/75% 75%/60% Min. **SE, %: 76** 40% Min.
Blend Thin & Elongated%,: 1.1% 5% (5:1) Max. **FAA, %: 43** 43% Min.
Soundness, %: 0.2
Wear, %: 3.9(100) 18.8(500)
Soundness & Wear Test No: 0-225-0074-2013
<1% deleterious Material

AGGREGATE GRADATIONS AND BLEND (PERCENT PASSING)

		5/8" Rock	1/4" Man. Sand	5/16" Natural Sand	5/8" FRAP	RAS		
BLEND:		22	21	38	16	3	100	**Superpave**
Sieve							**BLEND**	**12.5mm**
1", 25.0mm		100.0	100.0	100.0	100.0	100.0	**100.0**	100
3/4", 19.0mm		100.0	100.0	100.0	100.0	100.0	**100.0**	100
1/2", 12.5mm		78.1	100.0	100.0	95.9	100.0	**94.5**	90-100
3/8", 9.5mm		35.5	99.9	99.5	86.3	100.0	**83.4**	90 max
#4, 4.75mm		3.2	79.0	87.6	68.1	100.0	**64.5**	
#8, 2.36mm		2.5	50.3	76.6	55.2	86.5	**51.6**	28-58
#16, 1.18mm		2.4	34.7	65.9	46.3	67.8	**42.3**	
#30, 600um		2.3	25.2	50.7	37.5	42.7	**32.3**	
#50, 300um		2.1	18.3	21.6	23.7	29.1	**17.2**	
#100, 150um		1.8	12.4	5.6	12.5	18.7	**7.7**	
#200, 75um		1.2	8.1	2.7	7.7	10.9	**4.6**	2-10
G_{sb}		2.720	2.681	2.646	2.637	2.565	**2.666**	
G_{se}	**2.718**					**% Absorp.**	**1.0**	
FAA			***13.1***	***19.6***	***8.6***	***1.7***	**43.0**	
			48.8	40.3	41.8	43.1		

BITUMINOUS MATERIALS

Source:	Calumet	**RAP % A.C.:**	**4.5**	**RAS % A.C.:**	**21.1**
Type:	58-28				
Spec. Gravity:	1.028				

HOT MIX ASPHALT DESIGN CRITERIA AND RESULTS

								Heights	
Mix Temp.:	300 F		**Compact Temp.:**	265+/- 15 °F	$N_{ini}/N_{des}/N_{max}$:	7/75/115		Nini	Nmax
TSR, %:	**71**	N_{TSR}:	**20**	N_{ini}:	**90.5**	N_{max}:	**96.7**	121.8,121.8	114.0,114.1

% P_b	G_{mb}	G_{mm}	% V_a	% VFA	% VMA (G_{sb})	PBR%	Pb Added
5.0	2.387	2.514	5.1	66	14.9	27.1	3.65
5.5	2.404	2.490	3.5	77	14.8	24.6	4.15
6.0	2.425	2.474	2.0	86	14.5	22.6	4.65

JOB MIX FORMULA

% P_b	G_{mb}	G_{mm}	% V_a	% VFA	% VMA (G_{sb})	PBR%	Pb Added	Pbe	P200/Pb
5.4	**2.396**	**2.493**	**3.9**	**74**	**15.0**	**25.06**	**4.05**	**4.7**	**1.0**

Dawn M. Pitek, HTCP Certified Hot Mix Asphalt Mix Design Technician   WisDOT ID:

Note: This mix will be asphalt foamed. This process does not change any volumetrics of the mix.

WHRP
Wisconsin Highway Research Program
University of Wisconsin – Madison
1415 Engineering Drive
Madison, WI 53706
http://wisdotresearch.wi.gov/whrp