Balanced Mixture Design Pilot and Test Sections

Randy West

Rachel Cousins

Carolina Rodezno

Fan Yin

Nathan Moore

Matthew Sasser

Grant Julian

National Center for Asphalt Technology at Auburn University

WisDOT ID no. 0092-22-04

October 2023

Research & Library Unit

Wisconsin Highway Research Program

WISCONSIN DOT

PUTTING RESEARCH TO WORK

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. WHRP 0092-22-04	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Balanced Mixture Design Pilot and Field Sections		**5. Report Date** October 2023 **6. Performing Organization Code**
7. Author(s) Randy West, Rachel Cousins, Carolina Rodezno, Fan Yin, Nathan Moore, Matthew Sasser		**8. Performing Organization Report No.**
9. Performing Organization Name and Address National Center for Asphalt Technology at Auburn University 277 Technology Parkway Auburn, AL, 36830		**10. Work Unit No.** **11. Contract or Grant No.** WHRP 0092-22-04
12. Sponsoring Agency Name and Address Wisconsin Department of Transportation Research & Library Unit 4822 Madison Yards Way Room 911 Madison, WI 53705		**13. Type of Report and Period Covered** Draft Final Report Nov. 22, 2021 – Nov.21, 2023 **14. Sponsoring Agency Code**
15. Supplementary Notes		

16. Abstract

The Wisconsin Department of Transportation (WisDOT) continues to make thoughtful steps toward the implementation of Balanced Mix Design (BMD) tests and criteria for asphalt mixture design approval and Quality Assurance. This research project involved two important steps toward that goal, (1) validation of BMD tests and criteria, and (2) assessing the overall variability of the BMD test results in a mix production setting. In the first part of the study, the research team assisted WisDOT in the experimental design and preliminary testing of six test sections for the BMD validation experiment. A few issues were encountered during construction of the test sections. Different granular base materials were placed and compacted in the area where the test sections were constructed. Analysis of Falling Weight Deflectometer (FWD) data from tests conducted throughout the area where the test sections were constructed was inconclusive, leaving uncertainty about the uniformity of the pavement structures which could impact field performance of the test sections and confound the desired lab-to-field correlations. Another issue was from the lab-to-lab comparisons of the Indirect Tensile Asphalt Cracking Test (IDEAL-CT) and Hamburg Wheel Tracking Tests (HWTT) for the mixtures sampled from the test sections. The differences between the results from the contractor, WisDOT and the research team should be further investigated. The second part of the study involved testing mixture samples obtained from WisDOT projects across the state. The test results were used to quantify production variability for the BMD test parameters. All testing was conducted and analyzed by the research team. Key variability statistics were summarized and used to illustrate how contractors should target mix production to achieve the desired quality and full pay based on WisDOT's preliminary BMD specification criteria.

17. Key Words Asphalt mixtures, balanced mix design, Hamburg Wheel Tracking Test, Indirect Tensile Asphalt Cracking Test, production variability, specification criteria	**18. Distribution Statement** No restrictions. This document is available through the National Technical Information Service. 5285 Port Royal Road, Springfield, VA 22161

19. Security Classification (of this report) Unclassified	**20. Security Classification (of this page)** Unclassified	**21. No. of Pages** 83	**22. Price**

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

DISCLAIMER

This research was funded through the Wisconsin Highway Research Program by the Wisconsin Department of Transportation and the Federal Highway Administration under Project 0092-22-04. The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views of the Wisconsin Department of Transportation or the Federal Highway Administration at the time of publication.

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof. This report does not constitute a standard, specification or regulation.

The United States Government does not endorse products or manufacturers. Trade and manufacturers' names appear in this report only because they are considered essential to the objective of the document.

EXECUTIVE SUMMARY

The Wisconsin DOT continues to make thoughtful steps toward the implementation of Balanced Mix Design (BMD) tests and criteria for asphalt mixture design approval and Quality Assurance. This research project involved two important steps toward that goal, (1) validation of BMD tests and criteria, and (2) assessing the overall variability of the BMD test results in a mix production setting. In the first part of the study, the research team assisted WisDOT in the experimental design and preliminary testing of six test sections for the BMD validation experiment. A few issues were encountered during construction of the test sections. Different granular base materials were placed and compacted in the area where the test sections were constructed. Analysis of Falling Weight Deflectometer (FWD) data from test sections were inconclusive, leaving uncertainty about the uniformity of the pavement structures which could impact field performance of the test sections and confound the desired lab-to-field correlations. Another issue was from the lab-to-lab comparisons of IDEAL-CT and Hamburg Wheel Tracking Tests (HWTT) for the mixtures sampled from the test sections. The differences between the results from the contractor, WisDOT and the research team should be further investigated. The second part of the study involved testing mixture samples obtained from WisDOT projects across the state. The test results were used to quantify production variability for the BMD test parameters. All testing was conducted and analyzed by the research team. Key variability statistics were summarized and used to illustrate how contractors should target mix production to achieve the desired quality and full pay based on WisDOT's preliminary BMD specification criteria and the results from the shadow project testing, as shown in the table below.

WisDOT Preliminary BMD Criteria and Recommended Production Targets

Mix Type	HWTT CRD_{20k} (s=1.6 mm)		HWTT LC_{SN} (s = 1436)		IDEAL-CT CT_{Index} (s = 10.9)	
	Criteria	Target	Criteria	Target	Criteria	Target
LT	≤ 12.0 mm	≤ 9.9 mm	≥ 3,000	≥ 4,441	≥ 30	≥ 44
MT	≤ 7.5 mm	≤ 5.4 mm				
HT	≤ 5.0 mm	≤ 2.9 mm				
SMA	≤ 4.0 mm	n.a.				

n.a. (not available) SMA mixtures were not included in any of the shadow projects; therefore the standard deviations for this mix type are unknown.

ACKNOWLEDGEMENT

The authors acknowledge the support from the Project Oversight Committee (POC) in refining the experimental plan, identifying the materials and mix designs to be used in this study, coordinating the collection and delivery of all the materials, evaluating project progress, and reviewing and providing recommendations to improve this report. Members of the POC were Tirupan Mandal (chair), Ali Arabzadeh, Matthew Bertucci, Daniel Kopacz, Stacy Glidden, Deborah Schwerman, Erik Lyngdal, Erv Dukatz, and Dante Fratta.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

State highway agencies (SHAs) and the asphalt pavement industry have recognized the limitations of the Superpave mix design and the need for implementing balanced mix design (BMD) for improved asphalt mix design approval and quality assurance. Some of the main limitations of the Superpave mix design approach are the accuracy and variability of aggregate bulk specific gravity testing, and the inability to assess the quality of asphalt binders, and the effect of polymers, fibers and variety of other additives, including Warm Mix Asphalt (WMA) additives added to the mix (Yin & West, 2021). BMD typically includes two or more performance tests, such as a rutting test and a cracking test, to assess how well the mixture resists common forms of distress in asphalt pavements. BMD utilizes testing of the composite mixture rather than limiting requirements on certain components (e.g., recycled binder ratios, binder grades), which will enable mix designers to be innovative with new technologies to design high-quality asphalt mixtures and provides agencies with a more reliable way of accepting asphalt paving mixtures.

For example, with BMD, an SHA would require the mix design and/or plant produced mixture to pass a test criterion for moisture damage resistance rather than requiring all mixtures contain a specific dosage of an antistripping additive. A similar scenario would apply to ensuring mixtures have adequate rutting resistance, thermal cracking resistance, reflection cracking resistance, etc. Rather than requiring aggregate components have a minimum angularity and the virgin binder have a minimum stiffness at the expected high pavement temperature, a BMD specification uses tests of the composite mixture to assess its resistance to rutting. In this "system approach" to mix design approval, the properties of individual mixture components and their percentages are less important than how the composite mixture is able to resist the distresses that are prevalent in the agency's jurisdiction.

A survey conducted by the National Center for Asphalt Technology (NCAT) in 2020 identified eleven SHAs with a standard, provisional, or draft BMD specification. The Wisconsin Department of Transportation (WisDOT) began its development of BMD in 2014. Previous WHRP research projects were successful in identifying mix design factors affecting mixture durability and cracking resistance (Bonaquist, 2016), validating the feasibility of asphalt pavement performance-based specifications (Bahia et al., 2016), and supporting WisDOT's decision in implementing the regressed air voids approach (West et al., 2018). Additionally, WHRP project 0092-20-04 recommended preliminary BMD criteria for the Hamburg Wheel Tracking Test (HWTT), and Indirect Tensile Asphalt Cracking Test (IDEAL-CT). In 2021 WisDOT developed a draft special provision, the *HMA Pavement Balanced Mix Design,* to implement BMD with these two tests (Wisconsin, 2021).

Implementation of mixture performance testing for BMD is a multi-step process that requires collaboration among the highway agency, the asphalt pavement construction industry, and academia. NCAT recently completed a comprehensive guide for full implementation of a BMD specification for mix design approval and quality assurance (West et al., 2023). The two steps of the greatest interest to WisDOT in this research project are *Conducting Field Validation of Test*

Criteria and *Conducting Shadow Projects*. The former is to validate the performance test criteria on actual paving projects to ensure that they can discriminate good- and poor-performing asphalt mixtures in terms of rutting and cracking resistance. The latter allows agencies to collect data on the production variability of performance test results and permits asphalt contractors to become familiar with mixture performance testing during production. These two steps are highly beneficial toward further advancing the development and implementation of BMD in Wisconsin.

1.1 Project Objectives

The two objectives of this project are to (1) assist WisDOT in the experimental design and construction of pavement test sections for assessing the long-term field performance of BMD pavements and to validate WisDOT's preliminary BMD criteria, and (2) statistically analyze the variance of BMD test results from shadow projects. To accomplish these two objectives, the overall research approach included two parts that are presented in Chapters 2 and 3 of this report.

1.2 Report Organization

This report is organized into four chapters summarized as follows:

- *Chapter 1* encompasses an introduction, project objectives and report organization.
- *Chapter 2* presents a background, research approach and results related with the design, construction and monitoring activities of test sections for BMD validation in Wisconsin.
- *Chapter 3* presents a background, research approach, and results of the evaluation of shadow projects in Wisconsin to quantify the overall variability BMD tests being considered for use by WisDOT.
- *Chapter 4* presents a final summary of findings and recommendations from this research study.

2. TEST SECTIONS FOR BMD VALIDATION

2.1 Background

2.1.1 Full-Scale Pavement Testing

Over the years, asphalt pavement engineers and researchers have used different methods to evaluate the performance of pavement materials and designs including open-road test sections and accelerated pavement testing facilities. Accelerated pavement testing is the application of controlled moving wheel loads to a pavement or test sections at an accelerated rate compared with loading from actual traffic to determine its response in a compressed time period.

The evaluation of full-scale pavement test sections began in the United States in Arlington Virginia in 1919 and was followed by other controlled studies that included the Bates Road Test in Illinois (1929-1923), and the Western Association of State Highway Officials (WASHO) Road Test in Idaho (1952-1954). Several other pavement test facilities have been developed and used worldwide to conduct full scale testing (Metcalf, 1996). The best-known road test study is the AASHO Road Test conducted by the Association of State Highway Officials (AASHO) in the late 1950s near Ottawa, Illinois which provided the foundation for the empirical AASHTO pavement design guides that have been used since the 1960's. Each of these test roads, as well as the associated lab and field testing, have had a specific research objective and operated for limited periods of time.

In-service test roads are another approach to full-scale pavement testing to assess pavement materials, designs and construction practices. Test sections that carry actual traffic and are subjected to real environmental conditions represent the most realistic approach to field experiments. Since loading is applied by actual traffic, the only loading costs are related to traffic monitoring and weigh-in-motion devices (Mitchell, 1996). On the other hand, distresses are typically slow to develop, requiring long-term evaluations. The Long-Term Pavement Performance (LTPP) Program represents the most comprehensive pavement research program to utilize in-service test sections located in the United States and Canada (FHWA, 2015). The LTPP program monitors the long-term performance of different pavement structures under different traffic conditions, climatic factors, subgrade soils, and maintenance, and rehabilitation programs (Elkins and Ostrom, 2021). At its peak, the LTPP program included over 2,500 pavement test sections across four climatic zones (wet freeze, wet no-freeze, dry freeze, and dry no-freeze) with many sites collecting environmental data including air temperature, humidity, precipitation, solar radiation, wind direction, and wind speed to understand the influence of various environmental conditions on the performance of a specific type of pavement. Other examples of in-service test roads include the Ohio long-term pavement study also known as the Ohio SHRP Test Pavement, and the Minnesota Road Research Project (MnROAD).

Closed test tracks, like the NCAT Test Track, enable accelerated testing, allowing for quicker data collection and evaluation of pavement performance under controlled loading conditions. The sections can be built with a consistent underlying support, the mixes can be designed to meet specific criteria, and traffic and performance of the sections is closely monitored. They also enable a better evaluation of environmental factors, reducing uncontrolled variability. However, closed test tracks do not replicate the real-world distribution of loads and the rate of pavement damage may not precisely match those observed on open roads.

In Wisconsin, several full-scale pavement research projects have been built in the last two decades to achieve different objectives. Perpetual pavement test sections were constructed in 2000 and 2003 on state trunk highway (STH) 50 in Kenosha and Walworth counties, and on the entrance ramp to I-94 from the Kenosha Safety and Weigh Station Facility in southeastern Wisconsin, respectively. Outcomes of these projects were used to develop guidelines for the selection and design of asphalt perpetual pavements (Battaglia et al., 2010). Another project that involved perpetual pavement design was constructed as part of an urban highway improvement project in the City of Milwaukee, Wisconsin. The main objective of this project was to instrument the pavement to acquire the data to provide information necessary for a comprehensive mechanisticempirical pavement procedure (Crovetti et al., 2007). Phase 2 of the project focused on activities required to maintain data recording systems and programs to analyze the generated data. From this research, the dataset generated included dynamic pavement response due to traffic load, traffic information (weight and class), and environmental data for the test site. This project recommended pavement instrumentation, data collection and analysis that could be used for future structural analysis projects.

A more complete literature review of full-scale pavement test sections and accelerated pavement testing facilities can be found in the appendix of the recently completed report, *Guidelines and Recommendations for Field Validation of Test Criteria for Balanced Mixture Design (BMD) Implementation* (West et al., 2023).

2.1.2 Test Sections for BMD Validation

BMD tests serve as an indicator of a mixture's performance in the field, particularly its resistance to different types of distresses. The selection of an appropriate BMD test should rely on establishing a robust relationship between test results and field performance that allows the development of appropriate specification criteria for Quality Assurance and mix design approval. Although multiple field studies have been conducted to evaluate the performance of asphalt pavements, only a limited number of studies have conducted field experiments to establish such relationships. Texas (Epps, 2023) and Virginia (Hajj et al., 2021) have ongoing BMD field efforts but have not published findings from those studies. The Texas DOT is implementing BMD with criteria for the HWTT and the Overlay Test (OT) and has built field validation projects with multiple test sections across the state to sample mixtures and collect field performance information. In 2020, the Virginia DOT completed five pilot projects as part of their BMD implementation plan. BMD mixtures designed and produced in accordance with VDOT's special provision for surface mixtures with high RAP contents are being compared to control sections with typical dense-graded Superpave surface mixtures controls. VDOT's selected BMD tests include the Cantabro mass loss test (Cantabro test), the IDEAL-CT, and the Asphalt Pavement Analyzer (APA) test.

The national pooled-fund study on low-temperature cracking of asphalt pavements (Marasteanu et al., 2012) examined several tests for thermal cracking and recommended the disc-shaped compact tension (DCT) test, standardized as ASTM D7313, and the low-temperature Semi-Circular Bend Test, standardized as AASHTO TP 105. The study included field test sites in Illinois, Minnesota, and Wisconsin and provided preliminary criteria for the two tests based on lab to field correlations. In 2013, the Minnesota Department of Transportation (MnDOT) began an implementation plan for the DCT (Johanneck et al., 2015) but has since abandoned the plan.

The NCAT-MnROAD partnership included two complementary experiments to validate top-down cracking tests and low-temperature cracking tests in warmer and colder climates, respectively (West et al., 2021, Vrtis et al., 2023). The MnROAD top-down cracking validation study found that the BMD tests with the strongest correlation between the lab test results and field performance were the Disc-shaped Compact Tension (DCT) test, the Overlay Test, and the

IDEAL-CT for mixtures that were lab aged to simulate four to five years of in-service aging of surface mixtures in northern climates.

Wisconsin DOT developed preliminary BMD criteria for HWTT and IDEAL-CT shown in Table 1 that need to be validated with field performance. In this table, the HWTT corrected rut depth at 20,000 passes is used to ensure good rutting resistance, the HWTT number of cycles at which the stripping number (LC_{SN}) occurs is used to assess moisture susceptibility, and the IDEAL-CT CT_{Index} is proposed to ensure good resistance to load-related cracking of surface layers. A description of each test is provided below.

Table 1. WisDOT BMD Criteria

Mixture Type	HWTT[1]		IDEAL-CT[2]
	Corrected Rut Depth (CRD)@20,000 passes (mm)	Stripping Number (LC_{SN})	CT_{Index}
LT	≤ 12.0	≥ 3,000	≥ 30
MT	≤ 7.5	≥ 3,000	≥ 30
HT	≤ 5.0	≥ 3,000	≥ 30
SMA	≤ 4.0	≥ 3,000	≥ 80

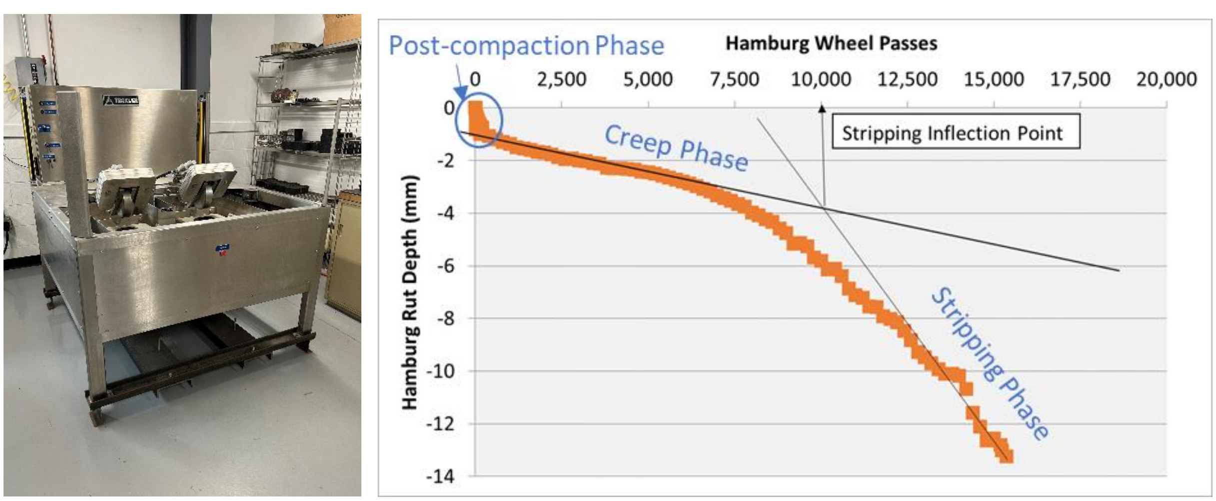
[1] AASHTO T 324 as modified in CMM 836.6.10.1; [2]ASTM D8225 as modified in CMM 836.6.10.2

2.1.2.1 Hamburg Wheel Tracking Test (HWTT)

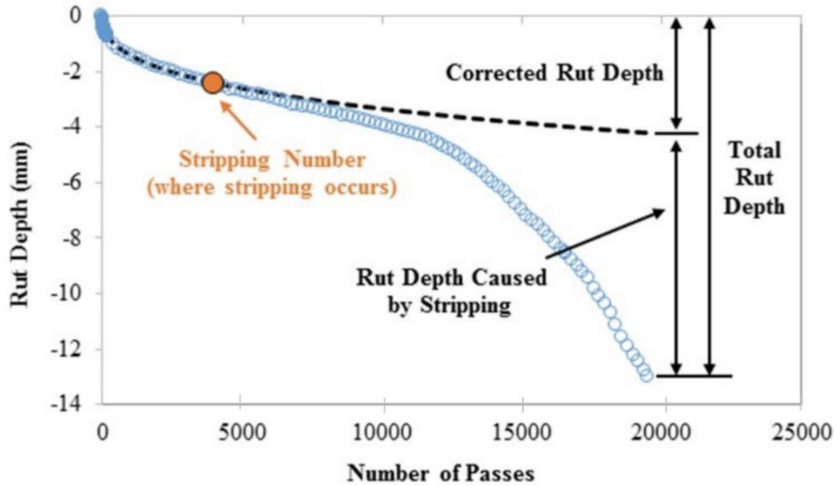
The Hamburg Wheel Tracking Test device shown in Figure 1(a) used to evaluate the rutting resistance and moisture susceptibility of asphalt mixtures. HWTT testing is performed in accordance with AASHTO T 324. WisDOT conducts the test at a temperature of 46°C per recommendations of Bahia et al. (2015) while being consistent with the Superpave PG specification of asphalt binders. Table 2 summarizes the handling and aging procedures of plant mixes for HWTT testing of BMD test sections. Two replicates are tested per mix, with each replicate consisting of two trimmed specimens (four specimens total per mix). The specimens are originally compacted using a Superpave Gyratory Compactor (SGC) to a diameter of 150 mm and a height of 62 mm. The specimen ends are then trimmed to fit in the HWTT molds for testing. The target air voids content of the HWTT specimens was 7.0 ± 0.5 percent. The specimens are tested under a 158 ± 1 pound wheel load for 10,000 cycles (20,000 passes) while submerged in a water bath maintained at 46°C. Rut depths are measured by a linear variable differential transformer (LVDT) throughout the test. After testing, the rut depth data is used to determine the point at which stripping occurred in the mixture under loading. Figure 1(b) illustrates a typical data output from the HWTT device, which shows the progression of rut depth with number of wheel passes. Two tangents are evident from the curve beyond the post-compaction phase: the steady-state rutting portion of the curve (i.e., creep phase) and the portion of the curve after stripping (i.e., stripping phase). The intersection of these two curve tangents defines the stripping inflection point (*SIP*) of the mixture.

Table 2. Handling and Aging of Plant Mixes for HWTT and IDEAL-CT Testing of BMD Test Sections at NCAT

BMD Test	Handling and Aging Procedures
HWTT	1. Reheat the plant loose mix stored in cardboard boxes in an oven at compaction temperature for approximately 2 hours until the mix becomes workable to discharge from the cardboard box. 2. Split loose mix into individual specimen sizes and place them in sealed plastic bags for storage until compaction (Note: the time between bagging and compaction was typically 1 to 2 days). 3. On the day of compaction, reheat the loose mix in an oven at compaction temperature with a calibrated thermometer in the center of the mix. 4. After the mix reaches the compaction temperature, remove it from the oven and start compaction.
IDEAL-CT	1. Reheat the plant loose mix stored in cardboard boxes in an oven at compaction temperature for approximately 2 hours until the mix becomes workable to discharge from the cardboard box. 2. Split the loose mix into individual specimen sizes. 3. Long-term age the loose mix for 6 hours at 135°C at a thickness of ¾ to 1 inch. 4. Cool the loose mix to room temperature and place them in sealed plastic bags for storage until compaction (Note: the time between bagging and compaction was typically 1 to 2 days). 5. On the day of compaction, reheat the loose mix in an oven at compaction temperature with a calibrated thermometer in the center of the mix. 6. After the mix reaches the compaction temperature, remove it from the oven and start compaction.



(a) (b)



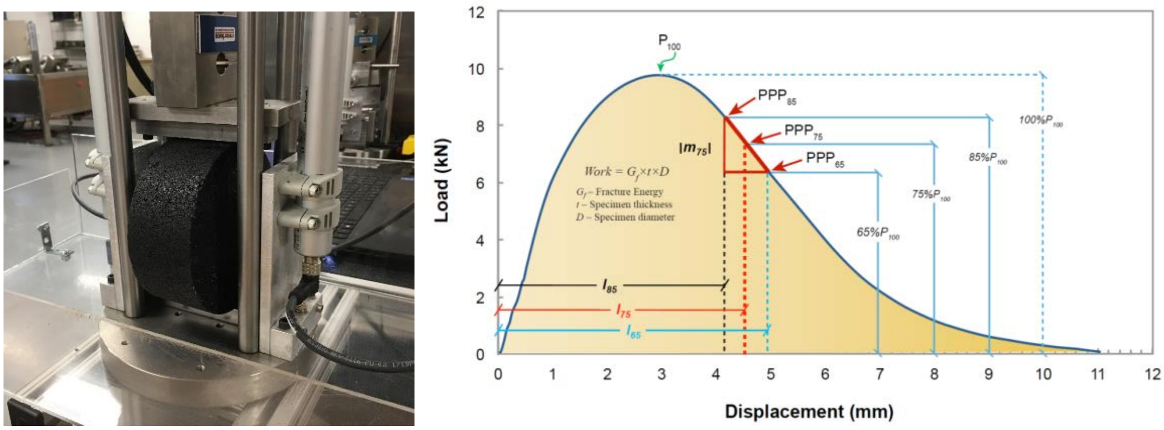
(c)

Figure 1. HWTT (a) Device at the NCAT laboratory, (b) Example rut depth data, (c) Graphical Illustration of Corrected Rut Depth (CRD_{20k}) (West et al., 2018)

Two other parameters have been suggested for analysis of HWTT results. In place of the commonly used rutting parameter, passes to 12.5 mm rut depth ($N_{12.5}$), the corrected rut depth at 20,000 passes (CRD_{20K}) isolates the rut depth due to permanent deformation from that caused by the stripping of asphalt binder from the aggregate (Yin et al., 2014; Yin et al., 2020). CRD_{20k} provides a more accurate indication of rutting resistance than the traditional rutting parameter, $N_{12.5}$. The stripping number (SN) parameter in this analysis represents the number of passes at which stripping occurs in the mixture and is determined as the inflection point of the rut depth curve. The number of load cycles at which SN occurs (LC_{SN}) is used to quantify moisture susceptibility. The calculation of CRD_{20k} and LC_{SN} is graphically shown in Figure 1c, and more details can be found elsewhere (Yin et al., 2014; West et al., 2018; Yin et al., 2020).

2.1.2.2 Indirect Tensile Asphalt Cracking Test (IDEAL-CT)

The IDEAL-CT is conducted to evaluate mixture resistance to load-related, intermediate-temperature cracking. Testing is performed in accordance with ASTM D8225-19. The test is relatively simple as it does not require additional sample preparation beyond sample compaction. For this test, 62 mm tall gyratory specimens are prepared to a target air void content of 7.0 ± 0.5%. During testing, specimens are loaded monotonically in indirect tension [Figure 2(a)] at a rate of 50 mm/min until failure while load line displacement (LLD) was recorded. Testing was performed using a device capable of sampling load and displacement data at a rapid rate (40 Hz). An example of the load versus LLD data is shown in Figure 2(b). Table 2. summarizes the handling and aging procedures of plant mixes for IDEAL-CT testing of BMD test sections.



(a) (b)

Figure 2. Indirect Tensile Asphalt Cracking Test (a) Specimen Setup, (b) Example Load versus LLD Data (Zhou, 2019)

The IDEAL-CT test parameter, cracking tolerance index (CT_{Index}), is calculated using Equation 1. There are three major parameters factored into the calculation of CT_{Index}: fracture energy (G_f) defined as the area under the load-displacement curve, post-peak slope at 75% of the peak load after the peak ($|m_{75}|$), and displacement of the specimen at 75% of the peak load after the peak (l_{75}). A higher G_f and l_{75} increase the CT_{Index} while a higher $|m_{75}|$ will lower the CT_{Index}. A higher CT_{Index} is desired for asphalt mixtures to resist intermediate-temperature cracking.

$$CT_{Index} = \frac{t}{62} * \frac{l_{75}}{D} * \frac{G_f}{|m_{75}|} * 10^6 \qquad \text{Equation 1}$$

Where:

CT_{Index} = cracking tolerance index;
G_f = fracture energy (J/m^2);
$|m_{75}|$ = absolute value of the post-peak slope m_{75} (N/m);
l_{75} = displacement at 75% of the peak load after the peak (mm);
D = specimen diameter (mm); and
t = specimen thickness (mm).

2.2 Research Approach

2.2.1 Test Sections Location, BMD Experimental Matrix, and Designs

For the validation experiment, a minimum of six test sections were recommended to establish correlations between BMD test results and field performance with a good balance between cost and experimental robustness. With six test sections, it is possible to establish lab-to-field correlations for both rutting and cracking.

The research team recommended building the test sections on a single project to avoid performance confounding effects of traffic, aging, and climate conditions. Additional recommendations for siting the project and test sections included:

1. The location of the test sections should be selected so that they will be subject to a consistent speed, should exclude intersections, have vertical grades below 2%, and should have a consistent number of lanes.
2. The minimum test section length should be 500 feet. The first and last 25 feet are transition zones that should be excluded from performance evaluations and may be used for extraction of core samples as needed. Longer test sections may be desirable from a plant production operations perspective.
3. A project that involves construction of the entire pavement cross-section should help provide a consistent pavement structure for the test sections. To verify that the site that has a consistent subgrade and granular base modulus, it is recommended that Dynamic Cone Penetration (DCP), Light Weight Deflectometer (LWD), or Falling Weight Deflectometer (FWD) tests be conducted along the test sections at 50-foot intervals. Ground Penetrating Radar (GPR) conducted throughout the roadway alinement where the proposed test sections may located may also provide useful information regarding the uniformity of the underlying subgrade, base, and existing pavement.
4. The roadway should have a suitable shoulder for roadside instrumentation infrastructure.

Experimentally, it is critical to include test sections that will have a range of expected field performance and include mixtures that have BMD test results both above and below the proposed criteria. Although some stakeholders suggest that the experimental mixtures evaluate specific mix factors (e.g., binder grades, ranges of recycled materials, or certain additives) it is more important to achieve a range of performance test results than to specify mix compositions. Ultimately, a goal of BMD is to allow agencies to specify mix criteria that are blind to mix composition.

Table **3** shows the matrix of desired ranges for the IDEAL-CT and HWTT results for the six test sections. These BMD test criteria were based on POC recommendations. All six mixtures were 12.5 mm nominal maximum aggregate size mixtures compacted to 75 design gyrations. Table 4 summarizes the contractor mix designs for the BMD validation experiment. The CT_{Index} values range from 17 to 99, while the HWT CRD_{20k} values range from 2.8 to 10.4 mm. These ranges provide a good spread of cracking and rutting resistance as desired for the validation experiment. A PG 58-28S binder was used for mixes 1 to 4, and a PG 58-28V binder was used for mixes 5 and 6. The mix design for Section 2 included 0.1% aramid fibers by mass of total mix supplied by Forta Corp. The mix design for test Section 5 did not meet the desired CT_{index} criteria of >65. All other mixtures satisfied the respective criteria in the experimental matrix. The complete mix designs are provided in Appendix A.

Table 3. Experimental Matrix with Six Test Sections

HWTT Corrected Rut Depth	IDEAL CT_{Index} (after 6-hours @ 135°C aging)	
	> 65	< 35
> 7.0 mm	①	③
< 3.5 mm	②	④
V-grade binder	⑤[1]	⑥[2]

[1] Section identical to mixture design 1 with "V" binder replacing "S" binder
[2] Section identical to mixture design 3 with "V" binder replacing "S" binder

Table 4. Summary of Contractor Mix Designs for the Six Test Sections

Test Section	CT_{Index}	HWTT Corr. Rut Depth @20k (mm)	Asphalt Content (%)	Binder Grade	Reclaimed Asphalt Pavement (RAP)Content (%)
1	69	10.4	6.5	58-28 S	8
2	99	3.3	6.3	58-28 S	15
3	29	8.1	6.0	58-28 S	0
4	21	2.8	5.3	58-28 S	27
5	56	3.7	6.5	58-28 V	8
6	17	3.2	6.0	58-28 V	0

WisDOT selected State Project Number 1693-05-72, STH 69, in Dane County, south of Verona as the site for the BMD validation experiment**.** Figure 3 shows the northern portion of this project between Paoli and Verona, WI with the highlighted area selected as the area the location for the six test sections. This is a rural two-lane road with only a few side streets and a relatively flat and consistent cross-section. Figure 4 shows a photograph of the roadway taken prior to reconstruction.

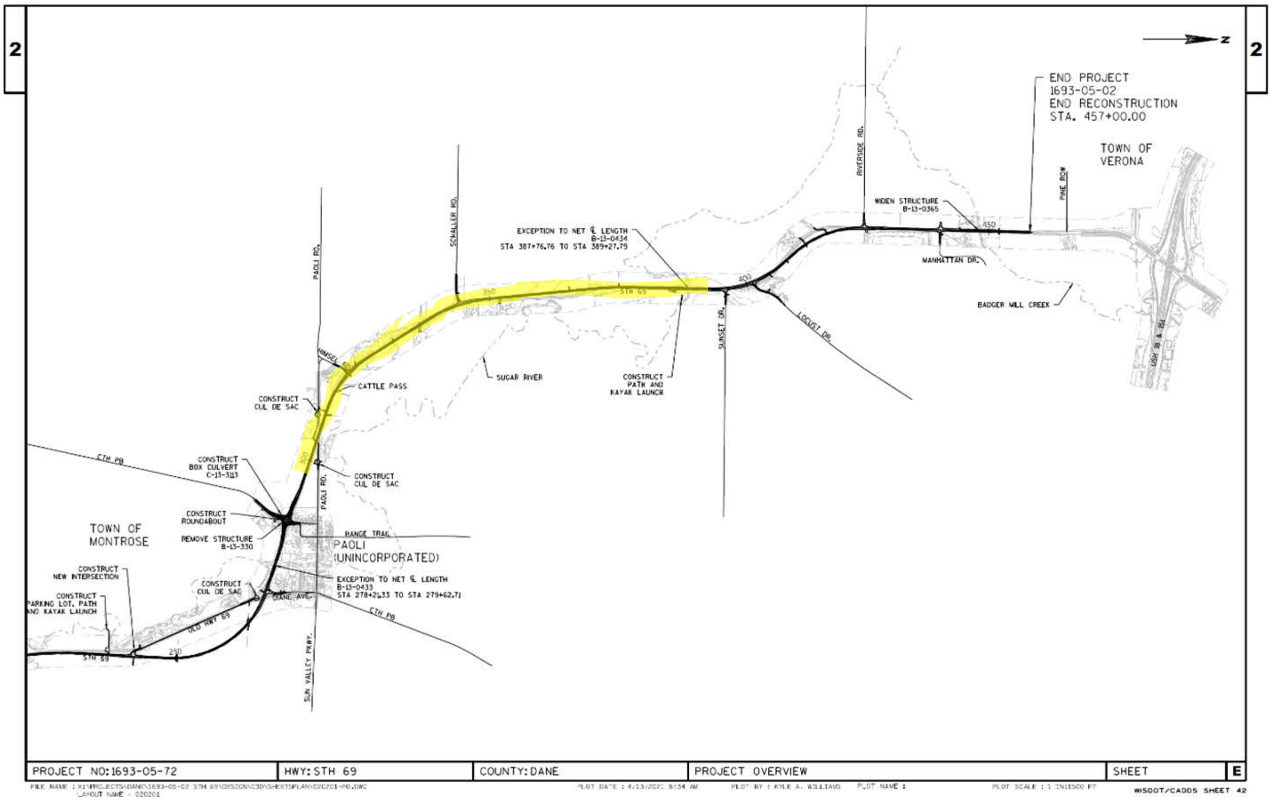


Figure 3. Selected Segment of the Project for the Test Sections

Figure 4. Photograph of STH 69 prior to Reconstruction

The designed cross-section of the reconstructed pavement is shown in Figure 5. It is a 5-inch asphalt pavement consisting of a 2-inch upper layer and a 3-inch lower layer, a 12-inch granular base constructed over 12-inches of select crushed material. The six experimental mixes were surface layers; the same medium-traffic (3 MT) mix containing a PG 58-28 S binder was used under each of the test sections.

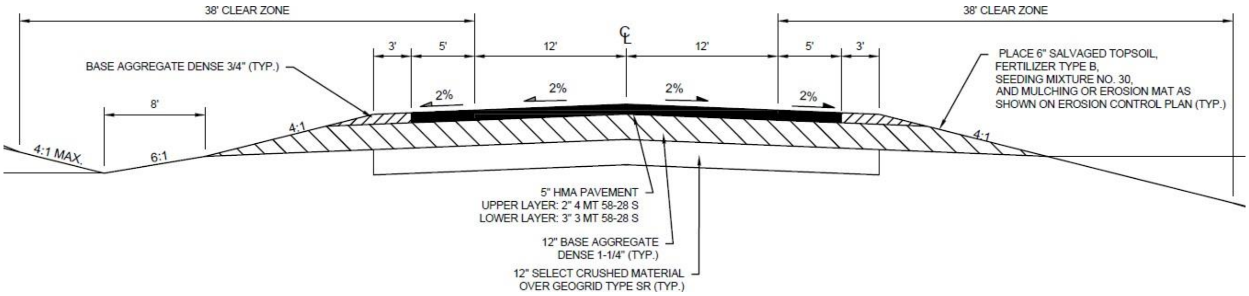


Figure 5. Cross section of the Selected Location of the Test Sections

Prior to paving, WisDOT personnel noted that different base materials were being used in the area where the test sections were planned. The 12-inch granular base was constructed in two 6-inch layers. As shown in Figure 5, in some areas the contractor used virgin crushed stone base material in both layers. In other areas, the contractor used a reprocessed (crushed concrete) base material in both layers, and other areas the contractor used virgin crushed stone in the bottom 6-inch layer and reprocessed base in the upper 6-inch layer. FWD testing was conducted by WisDOT, and the results were analyzed by the research team to assess the uniformity of the base and subgrade in the areas where the test sections were planned. Table 5 presents the results of that analysis. The area corresponding to Section C was eliminated due to the high standard deviation of the base moduli. Sections D and E were eliminated due to the low average base moduli in these areas. Therefore, the research team recommended that the test sections for the BMD validation experiment be built between station (STA) 295+00 and STA 306+00 and between STA 359+00 and STA 385+00.

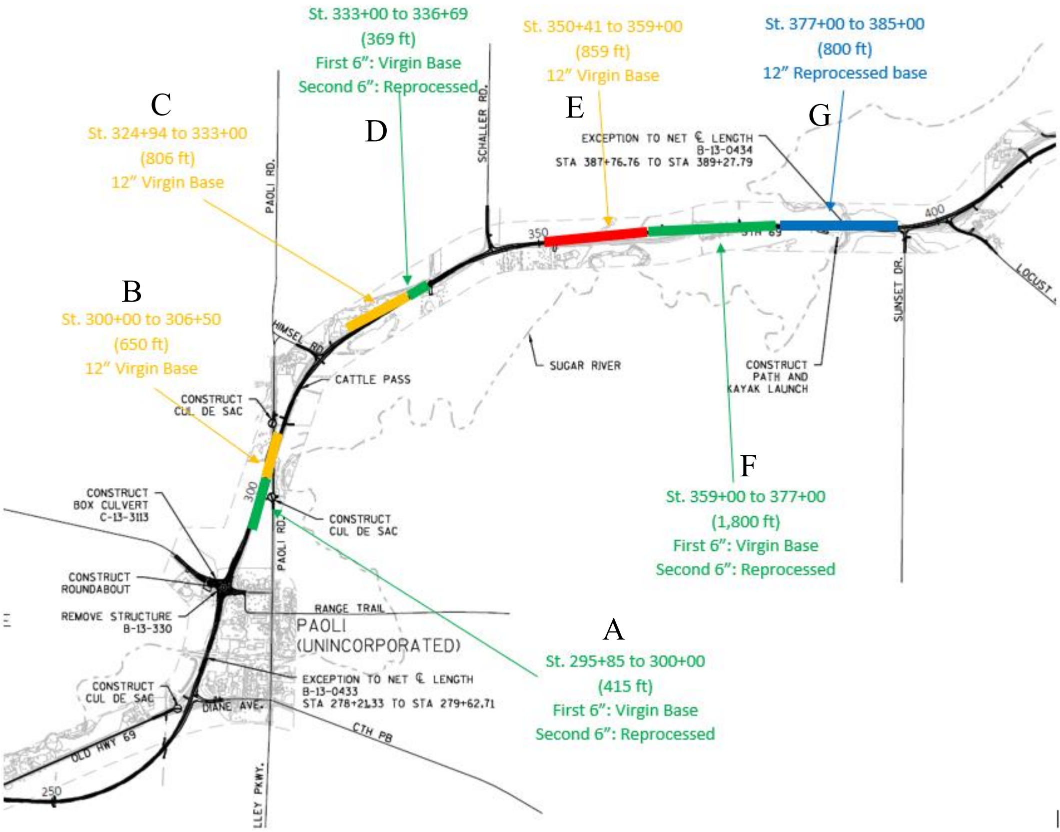


Figure 6. Project Plans Showing Areas Where Different Base Materials were Constructed

Table 5. Results of the FWD analysis for sections with different base material combinations

Section	Station Beg. -End	Length (ft.)	Base Types[1]	Base Modulus (ksi)		Subgrade Mod. (ksi)	
				Avg.	Std. Dev.	Avg.	Std. Dev.
A	295+85 to 300+00	415	V/R	45.4	3.9	13.7	1.2
B	300+00 to 306+50	650	V/V	38.8	4.3	18.9	3.1
C[2]	324+94 to 333+00	806	V/V	42.8	15.7	15.4	2.7
D[3]	333+00 to 336+69	369	V/R	27.7	4.1	35.4	12.5
E[3]	350+41 to 359+00	859	V/V	23.3	5.7	39.5	11.5
F	359+00 to 377+00	1800	V/R	34.2	5.3	22.9	5.7
G	377+00 to 385+00	800	R/R	42.5	2.4	16.9	2.1

[1] V/R = virgin base over reprocessed base; V/V = virgin base over virgin base; R/R = reprocessed base over reprocessed base
[2] Section C was excluded due to the high variability of the base modulus, [3] Sections D & E were excluded due to low base moduli

All mixtures were produced at a plant within a few miles of the project. The lower asphalt layer was paved in mid-September 2022, and five of the six test sections were paved on October 5, 2022. The last test section (Section 2 containing the aramid fiber) was paved on October 20, 2022. All six test sections were constructed in the northbound lane of STH 69 between GPS coordinates 42.928800°, -89.530663° and 42.946995°, -89.544267°. Table 6 summarizes the results of traditional asphalt mixture properties for the six test sections. Overall, these results show that the test section mixtures were produced close to the Job Mix Formula (JMF) targets for gradation and asphalt contents noting that higher % passing on some of the #50 to #200 sieves for the JMF are reported when comparing to the QC results. In addition, mix in Section 3 was the only mix that was not close to its target asphalt content which was produced 0.4% above its JMF target. In-place density results for all of the test sections were satisfactory, with average results above 93.0%, although the in-place densities of test sections 5 and 6 were two to three percent lower than for the other four test sections.

Mix samples from each test section were obtained and split three ways for BMD testing by the contractor, WisDOT's central lab, and NCAT. The results of these tests are reported in Section 2.3.

Table 6. Mix Design and Quality Control (QC) Results of Traditional Mixture Properties for the Six Test Sections

Test Section No.	1		2		3		4		5		6	
Mix Design No.	506822		506922		506722		507022		506822*		506722*	
WisDOT ID	0220		0264		0218		0222		0220		0218	
Binder Grade	58-28 S		58-28 S		58-28 S		58-28 S		58-28 V		58-28 V	
	Design	QC	Design	QC	Design	QC	Design	QC	Design	QC	Design	QC
Asphalt Content (%)	6.5	6.5	6.0	6.0	6.0	6.4	5.3	5.4	6.5	6.6	6.0	5.9
G_{mb}	2.386	2.376	2.358	2.386	2.378	2.348	2.404	2.391	2.386	2.375	2.378	2.354
G_{mm}	2.442	2.442	2.461	2.467	2.461	2.443	2.484	2.489	2.442	2.466	2.461	2.459
Air Voids (%)	2.3	2.7	4.2	3.3	3.0	3.9	3.2	3.9	2.3	2.9	3.0	4.3
Voids in the Mineral Aggregate (VMA) (%)	15.0	15.3	15.4	14.4	15.0	16.4	13.1	13.6	15.0	15.5	15.0	15.7
Voids Filled with Asphalt (VFA) (%)	84.7	82.4	72.7	77.1	80.0	76.2	75.6	71.3	84.7	81.3	80.0	72.6
% Passing 19.0 mm	100	100	100	100	100	100	100	100	100	100	100	100
% Passing 12.5 mm	95.4	92.8	96.3	95.6	95.2	95.2	96.8	96.8	95.4	93.2	95.2	93.6
% passing 9.5 mm	84.9	82.5	87.4	84.6	84.3	84.3	88.6	88.1	84.9	82.9	84.3	85.2
% Passing 4.75 mm	67.4	66.4	65.1	64.9	66.4	67.3	67.8	65.3	67.4	67.6	66.4	68.8
% Passing 2.36 mm	51.2	50.6	45.6	46.6	53.4	54.1	48.3	46.2	51.2	50.9	53.4	55.2
% Passing 1.18 mm	39.3	39.1	32.4	34.1	44.3	45.1	34.7	33.9	39.3	42.7	44.3	45.6
% Passing 0.60 mm	29.5	29.9	23.6	26.0	38.6	39.4	25.6	25.9	29.5	29.6	38.6	39.7
% Passing 0.30 mm	13.1	14.1	13.1	15.2	27.4	29.0	15.1	15.6	13.1	14.0	27.4	29.1
% Passing 0.15 mm	4.9	5.8	6.1	7.4	6.8	8.6	7.9	8.4	4.9	5.9	6.8	8.5
% Passing 0.075 mm	3.1	3.4	4.1	4.4	3.0	3.8	5.5	5.3	3.1	3.4	3.0	3.8
In-Place Density (%)		96.8		95.4		95.1		96.4		93.9		93.1

After construction of the test sections was completed, FWD tests were conducted by WisDOT so that the uniformity of the pavement structures could be evaluated. FWD testing will also be conducted every six months to help assess pavement damage and structural deterioration. The recommended FWD testing plan is shown in Figure 7. FWD tests should be conducted in both wheelpaths at 50-ft. intervals, with the left and right wheelpath locations offset by 25 feet. Twenty-five-foot transition zones at the beginning and end of each section should be excluded from structural and condition assessments.

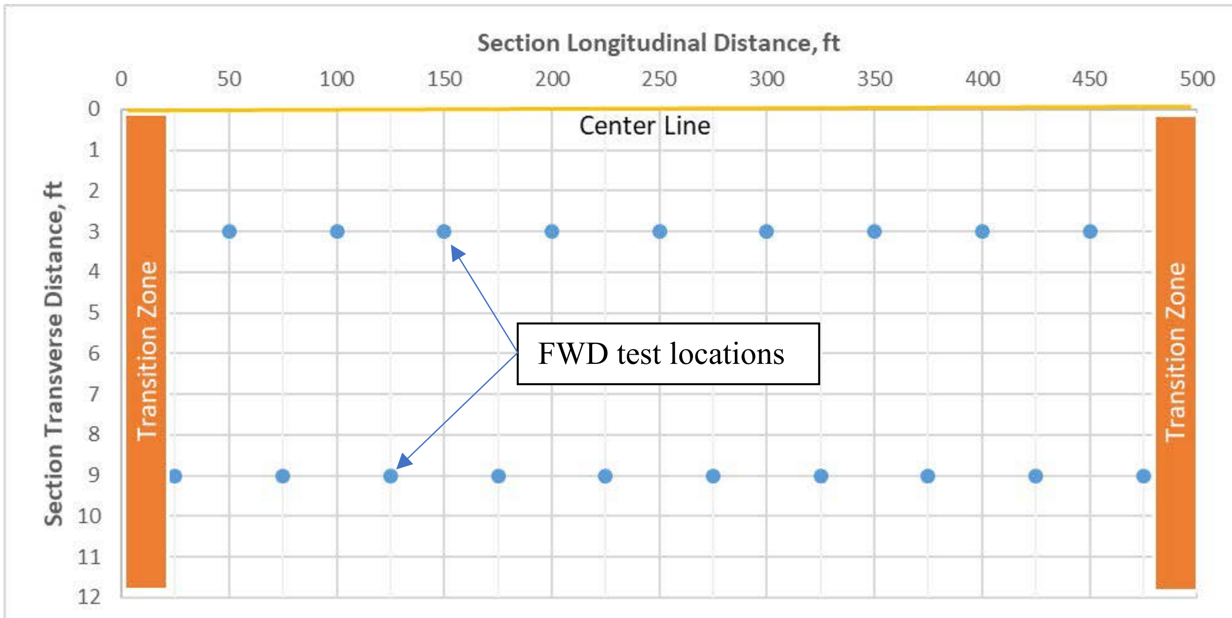


Figure 7. FWD Testing Plan

Temperature profile probe arrays were installed in each test section by the research team on May 4, 2023 to allow for accurate temperature corrections of future FWD data. The temperature probe arrays provide in-situ pavement temperatures at four depths through the structure. Figure 8 shows the four-channel data logger and an example of a temperature probe array that were installed in each test section. The temperature probe arrays were bundled to provide a thermal profile with depth including a thermocouple at the pavement surface, mid-depth of the asphalt pavement, bottom of the asphalt pavement, and at the bottom of the granular base. Data loggers collect temperature data continuously for about three months. Each test section has a temperature probe array located near the center of the section on the shoulder of the pavement as shown in Figure 9. The roadside infrastructure consists of a weather resistant box containing the four-channel thermocouple logger with high memory capacity and a reading rate of up to 4 Hz.

Figure 8. Four-Channel Data Logger and Temperature Probe Array

Figure 9. Photo of Installed Temperature Probe Array and Box Containing Datalogger

2.2.2 Back-calculated Moduli and Thickness Data

For all test sections except Section 2, WisDOT personnel conducted Ground Penetrating Radar (GPR) and FWD testing the day after paving. GPR and FWD testing of Section 2 was conducted on October 26, six days after paving. Evercalc© pavement analysis software version 5.0 (March 2001) developed by the Washington State Department of Transportation was used for the backcalculation analysis of FWD the data. Since the temperature probes were installed well after the initial FWD testing, no temperature corrections were applied as part of the backcalculation analysis described in section 2.3.2.

2.3 Results and Discussion

2.3.1 Performance Test Results of Mixtures from BMD Test Sections

Test section mixtures sampled during construction were tested using the IDEAL-CT and HWTT. The IDEAL-CT test was performed in accordance with ASTM D8225 after reheating the buckets of mixture samples for two hours to enable splitting samples to individual test portions, then aging the mixture samples at 135°C for six hours at a thickness of ¾ to 1 inch (Bahia et al., 2018), followed by SGC compaction. Hamburg tests were performed in accordance with AASHTO T 324 on samples that were reheated then compacted to 7+/-0.5% air voids with an SGC.

Results from the three labs are summarized in Table 7. The table also includes the mix design results for comparison purposes. The results of the three labs differ considerably for both tests, indicating that better instructions and training are needed to reduce lab to lab differences. The National Asphalt Pavement Association (NAPA) recently published IS 145 *Guide on Asphalt Mixture Specimen Fabrication for BMD Performance Testing* to help address this issue (Moore and Taylor, 2023). An accompanying video to this guide has also been produced and is available on NAPA's online BMD Resource Guide.

Despite the large lab-to-lab differences in CT_{Index} and HWTT results, the ranking of the mixtures, shown in parentheses in Table 6, are similar and the range of resistance to rutting and cracking indicated by these results should provide a suitable lab-to-field correlation. For example, the mix in Section 1 has a relatively high CT_{Index} and a relatively high HWTT CRD_{20k}, indicating that it should be more resistant to cracking but more susceptible to rutting compared to the other sections. In contrast, the mix in Section 4 has the lowest CT_{Index} indicating low cracking resistance but has very good resistance to rutting according the HWTT results.

Table 7. Results and (Rank) of HWTT and IDEAL-CT for the Six Experimental Mixtures

Section No.	CT_{Index}[1]					HWTT CRD_{20k}				
	Plan	Design	DOT	Cont.[2]	NCAT	Plan	Design	DOT	Cont.	NCAT
1	> 65	69	60 (2)	80 (1)	51 (2)	> 7.5	10.4	6.5 (5)	12.2 (6)	14.4 (6)
2	> 65	99	37 (5)	59 (3)	38 (3)	< 3.5	3.4	3.4 (2)	5.5 (2)	6.4 (1)
3	< 35	29	42 (3)	42 (4)	33 (4)	> 7.5	8.1	6.6 (6)	10.5 (5)	13.8 (5)
4	< 35	21	24 (6)	20 (6)	22 (6)	< 3.5	2.8	3.0 (1)	4.4 (1)	7.1 (2)
5	> 65	56	79 (1)	71 (2)	63 (1)	[3]	3.7	5.8 (4)	8.7 (3)	11.0 (3)
6	< 35	17	38 (4)	32 (4)	28 (5)	[3]	3.2	5.2 (3)	8.7 (3)	12.4 (4)

[1] After loose mix aging at 135°C for 6 hrs. [2] Contractor; [3] No HWTT criteria was specified

Figure 10 shows a BMD performance diagram with the desired regions for the six test sections shaded in green and the contractor's mix design results for the BMD tests shown as red dots. Several of the mix BMD design results were on or near the margins of the desired ranges, and the CT_{Index} for mix 5 was 9 units below the target range. Figure 11 adds the contractor's results from the plant-produced mixtures used in the test sections, shown as unfilled circles. The arrows show the changes in CT_{Index} and HWTT CRD_{20k} from the lab-produced mix design to plant production for the corresponding mixtures. Most plant-produced mixes had higher CT_{Index} and HWTT CRD_{20k} results compared to their respective mix design results, which may indicate that either (1) the short-term aging during mix design increased the binder stiffness more than the plant mixing operation, (2) a different lab was used for the mix design and QC testing, or (3) the binders used during mix design were stiffer than the binders used during mix production.

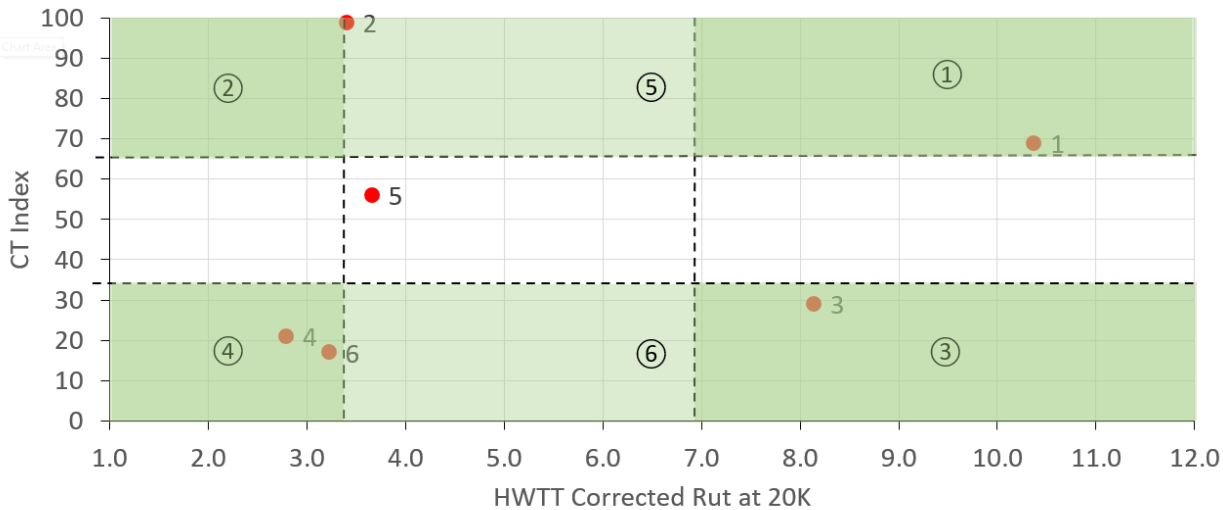


Figure 10. Mix Design BMD Results on the Desired Performance Diagram

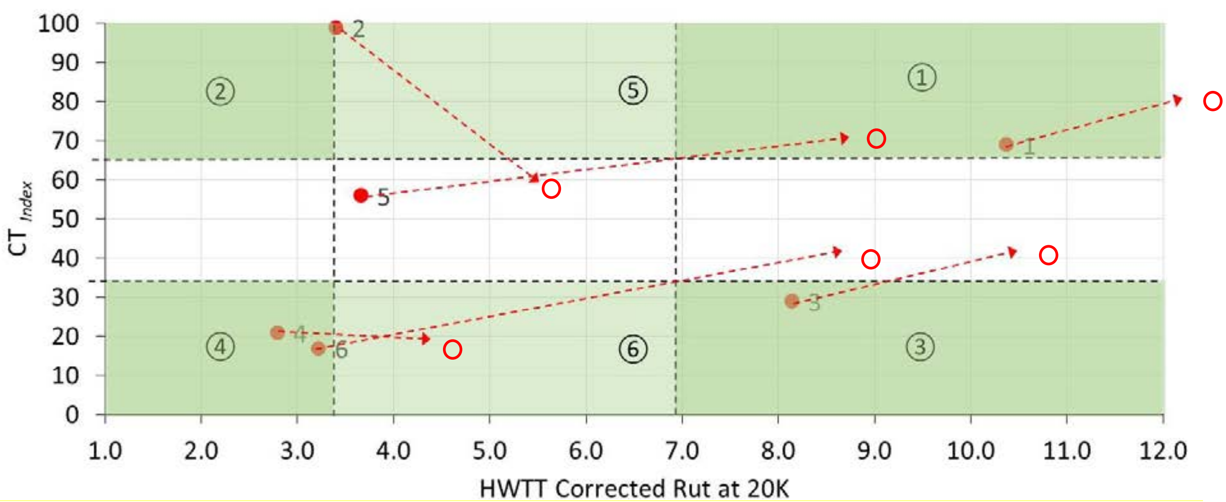


Figure 11. Mix Design and Plant-Produced BMD Results on the Performance Diagram. Arrows Indicate the Changes in CTindex and HWTT Results Between Lab-Prepared Mix Design and the Corresponding Plant-Produced Mixture.

2.3.2 Backcalculated Moduli Results

GPR and FWD data provided by WisDOT were analyzed by the research team. Results of this analysis are summarized in Table 8. For locations where GPR data were not available, the overall average thickness of 4.8 inches was input in the backcalculation software. Overall, many of the estimated moduli from the backcalculation analyses appear to be unreasonable. For example, the estimated asphalt moduli for Section 2 were about 50-60% lower than Section 1. Section 2 was paved nearly three weeks after the other sections, and five more days elapsed between paving and FWD testing of this section. Those differences could have had some effect on the results, but the BMD test results for Section 2 do not support the notion that the mix is 50-60% less stiff. Other questionable results were the large variations in moduli within sections, as evident for Sections 5 and 6. For many locations, the predicted base moduli were substantially lower than the subgrade moduli.

Table 8. Predicted Moduli of Test Section Pavement Layers from Backcalculation Analyses

Section	Right Wheelpath					Left Wheelpath				
	Dist. (ft.)	Thick-ness (in.)	Asphalt Moduli (ksi)	Base Moduli (ksi)	Subgrade Mr (ksi)	Dist. (ft.)	Thick-ness (in.)	Asphalt Moduli (ksi)	Base Moduli (ksi)	Subgrade Mr (ksi)
1	32	4.9	1800	12.5	17.8	75	n.a.	1706	13.7	17.7
	132	4.7	1857	18.5	16.7	175	n.a.	1545	14.6	16.7
	232	4.8	1792	18.5	17.6	275	n.a.	1248	18.3	18.4
	332	n.a.	1442	20.5	17.8	375	n.a.	994	22.1	17.0
	Avg.	4.8	1722	17.5	17.5	Avg.	n.a.	1373	17.2	17.4
2	30	5.1	727	21.5	19.8	75	4.9	667	22.7	19.6
	130	5.0	803	19.8	23.3	175	4.9	560	23.9	20.7
	230	4.6	673	24.0	22.1	275	4.6	756	23.0	21.9
	330	n.a.	597	22.9	18.8	375	4.6	766	26.6	20.9
	Avg.	4.9	700	22.0	21.0	Avg.	4.8	687	24.0	20.7
3	36	n.a.	1983	9.4	28.7	80	n.a.	1549	9.7	29.9
	147	n.a.	1513	9.6	27.8	122	n.a.	1717	9.4	31.0
	236	n.a.	1734	10.1	28.0	280	n.a.	1659	14.0	28.9
	336	n.a.	2539	10.5	23.8	380	n.a.	1323	15.4	29.9
	Avg.	n.a.	1942	9.9	27.1	Avg.	n.a.	1562	12.1	29.9
4	31	4.4	1245	26.8	27.7	76	4.4	832	23.4	25.8
	131	4.8	1196	9.2	21.7	176	4.8	1301	12.9	23.3
	231	5.1	968	19.9	23.0	276	5.1	1030	19.4	22.2
	331	n.a.	1096	29.9	25.4	376	5.2	819	18.1	23.7
	Avg.	4.8	1126	21.4	24.4	Avg.	4.8	995	18.4	23.7
5	29	5.0	714	21.8	23.4	75	5.1	789	17.6	22.1
	129	4.5	1299	30.0	25.7	175	4.8	1191	19.3	23.4
	229	4.5	1608	17.2	21.8	275	4.8	1233	17.0	22.1
	329	4.6	1907	16.3	21.4	375	4.8	1426	18.4	22.7

	Avg.	4.7	1382	21.3	23.1	Avg.	4.9	1160	18.1	22.6
6	30	4.8	1542	13.4	21.9	75	4.7	1432	15.1	22.7
	131	5.0	1429	18.8	21.6	175	4.5	514	38.4	18.5
	230	5.1	915	39.8	18.4	275	4.8	689	34.5	17.3
	330	5.0	756	34.5	18.6	375	4.6	1029	21.8	20.9
	Avg.	5.0	1161	26.6	20.1	Avg.	4.7	916	27.4	19.9

n.a. = not available from GPR files. Assumed to be 4.8 inches.

Although backcalculation analysis is an imperfect science, many of these results are so unreasonable that it raises concerns about potential testing errors. The researchers recommend that another round of GPR and FWD testing be conducted as soon as possible. It is important to assess the uniformity of the pavement structures among the test sections so that when distresses become evident over time, the performance difference can be attributed to the surface mixtures rather than structural differences among the test sections.

3. SHADOW PROJECTS TO ASSESS PRODUCTION VARIABILITY BMD TEST RESULTS

3.1 Background

3.1.1 Production Variability

Quantifying the production variability, also known as process variability, is needed to establish appropriate specification limits, acceptable quality limits and rejectable quality limits. AASHTO R 9 recommends quantifying process variability based on a "large number of project data" and provides an example that used 10 projects across a state to generate "typical" standard deviations for the Acceptance Quality Characteristic (AQC) of interest. R 9 states that the appropriate variability measure for developing the acceptance specifications is the "within-lot pooled standard deviation". In other words, test results from each project should be used to determine standard deviations based on the lot size used by the agency in its QA program. The within-lot standard deviations from all projects can be pooled together for a representative value to use in setting specification limits using equation 2. The pooled standard deviation estimates a single standard deviation that represents all of the independent groups of data from the shadow projects. It is a weighted average of each project's standard deviation. The weighting is based on the number of samples used in each project and gives larger groups a proportionally greater effect on the overall estimate. This approach takes into account that within-lot standard deviations will likely differ from project to project depending on the consistency of the constituent materials, plant operations, and technician skills when sampling mixtures and conducting the tests. It is also important to include projects that utilize different mix types as that may affect both the mean values and the standard deviations for the performance test results.

$$s_{pooled} = \sqrt{\frac{(n_1-1)s_1^2+(n_2-1)s_2^2+\cdots+(n_k-1)s_k^2}{n_1+n_2+\cdots+n_k-k}} \qquad \text{Equation 2}$$

where:

s_{pooled} is the pooled standard deviation,

n_1 is the number of samples/results from lot 1,

s_1 is the standard deviation from lot 1,

k is the total number of lots.

For new AQCs, it is necessary to collect this process variability data using "shadow projects" in which the new tests are conducted at the same frequency as current AQCs but the results from the new tests are not used to either adjust the production process or for pay adjustment. A shadow project is defined as project on which additional tests (i.e., the performance tests) are conducted at a frequency similar to existing acceptance testing to gather information on: (1) the logistics of conducting the new tests in a production environment, and (2) production variability of the new test results. For shadow projects, the results from the new tests are gathered for informational purposes only; the agency's standard tests and specifications are used for acceptance of materials and construction on the project. The information on the new test(s) gathered as part of shadow projects are critical to establishing reasonable acceptance criteria for the new test(s). The three goals of the shadow projects are: (1) to better familiarize both State DOT and contractor personnel with the selected tests, (2) to add to the database of test results from the benchmarking studies (another sub-step), and (3) to gather information on typical production variability. The AASHTO *Implementation Manual for Quality Assurance* referred to this as conducting "dual procedures" on selected projects in the early stages of implementation of the new tests.

It is important to recognize that any quantification of production or process variability includes variations due to multiple sources. Hughes (2005) described the sources (components) as testing variability, sampling variability, materials variability, and construction variability. Specifically, the overall production variability, quantified as overall variance ($\boldsymbol{\sigma_o^2}$), is the sum of the testing variance ($\boldsymbol{\sigma_t^2}$), sampling variance ($\boldsymbol{\sigma_s^2}$), materials variance ($\boldsymbol{\sigma_m^2}$), and construction variance ($\boldsymbol{\sigma_c^2}$), shown as Equation 3.

$$\sigma_o^2 = \sigma_t^2 + \sigma_s^2 + \sigma_m^2 + \sigma_c^2 \qquad \text{Equation 3}$$

where:

$\sigma_o^2 = overall\ variance$

$\sigma_t^2 = testing\ variance$

$\sigma_s^2 = sampling\ variance$

$\sigma_m^2 = materials\ variance$

$\sigma_c^2 = construction\ variance$

The construction variance component only applies for tests conducted in-situ or on samples obtained after placement in the pavement. For characteristics that are tested on samples obtained prior to placement on the pavement, such as samples obtained from a haul truck for asphalt content or lab-compacted air voids, construction variance is zero, and σ_c^2 may be omitted from Equation

2. It should be emphasized that the only components that affect the performance of the pavement are materials variance and construction variance, which is why it is desirable to use procedures that minimize sampling and testing variance. Sampling and testing procedures that result in large variances for these two components cloud our ability to make good judgments about the quality of the material and/or construction. Unfortunately, there is currently no established method for quantifying sampling variability.

According to R9, variability data can also be used for setting specification limits for a Percent Within Limits (PWL) specification. The example, illustrated in Figure 12, goes on to set specification criteria corresponding to an Acceptable Quality Level (AQL) of PWL=90 by multiplying the typical within-lot standard deviation by 1.645, then adding that product to the target for the upper specification limit and subtracting that product from the target value for the lower specification limit. The constant 1.645 is the standard normal Z-value corresponding to 90% of a two-tailed area beneath a normal distribution. For a one-sided specification limit (max or min. limit only), PWL=90 corresponds to a Z-value of 1.282.

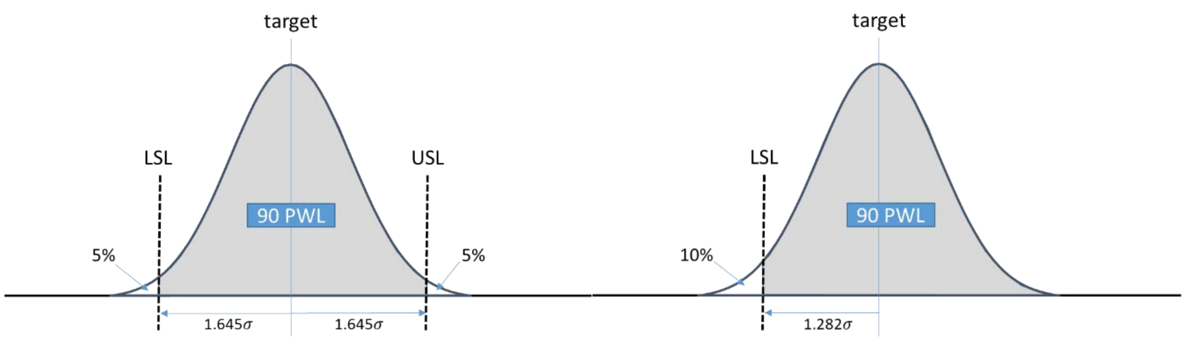


Figure 12. Using a Typical Within-Lot Standard Deviation to Set PWL Specification Limits

Ideally, sampling of mixtures for performance testing should take place at the same time and frequency used for existing acceptance testing. This will facilitate a comparison of how performance test results vary along with the traditional acceptance properties as well as provide some evidence as to the causes of the variations in the performance test results. In addition, it will also provide an understanding of the logistics necessary to conduct the selected performance tests at a particular frequency for acceptance in the future.

To determine if the variability from each of the shadow projects is due to the new testing methods or if it is normal production variability, the variability of the traditional acceptance quality characteristics (AQC) must be analyzed. As an example, in Phase I of the National Cooperative Research Program (NCHRP) Project 09-48, Mohammad et al. (2016) summarized variability data from 11 state DOTs and FHWA for common asphalt tests used in QA testing. The report notes that asphalt contents, volumetric properties, and gradations were largely obtained from tests on plant mix samples, however, details regarding the sampling location are not stated. Field density data included a mix of tests on cores and nuclear gauge measurements. It is not clear if the data reported by the DOTs were from single or multiple projects or if the standard deviations were calculated on a lot-by-lot basis. Table 9 summarizes the range of standard deviations and average standard deviation provided in the final report.

Table 9. Summary of Standard Deviations for Volumetric Properties and Gradations from Production and Construction Data (Mohammad et al. 2016).

Property	Range of St. Dev.	Avg.
Asphalt Content, %	0.17 – 0.29	0.20
Air Voids, %	0.33 – 0.99	0.62
VMA, %	0.38 – 0.64	0.54
VFA, %	3.40 – 4.92	4.03
G_{mb} (lab compacted)	0.008 – 0.018	0.015
G_{mb} (cores)	0.008 – 0.033	0.019
G_{mm}	0.005 – 0.012	0.011
Field Density (%G_{mm})	0.74 – 1.49	1.11
Percent Passing Sieve	Range of St. Dev.	Avg.
25.0 mm	1.55 – 2.66	1.86
19.0 mm	0.93 – 2.59	1.77
12.5 mm	0.99 – 3.54	2.17
9.5 mm	1.50 – 3.75	2.35
4.75 mm	1.87 – 3.48	2.62
2.36 mm	1.62 – 2.62	2.20
1.18 mm	1.70 – 2.05	1.81
0.60 mm	1.43 – 1.84	1.60
0.30 mm	1.07 – 1.22	1.16
0.15 mm	0.80 – 0.99	0.87
0.075 mm	0.32 – 0.84	0.55

Phase II of NCHRP 09-48 gathered raw materials, mixtures and roadway cores from 10 projects in six states in order to analyze differences in volumetric properties and mechanical properties among lab-mixed, lab-compacted (LL) specimens, plant-mixed, lab compacted (PL) specimens, and plant-mixed, field compacted (PF) specimens. Analysis included evaluating statistical differences among the three specimen types included t-tests with a 5% level of significance, as well as practical differences based on the d2s from the precision statement of the applicable test method. The researchers recommended new tolerances for comparing traditional mix properties of specimens prepared by the three methods.

3.1.2 Production Variability for Quality Control/Quality Acceptance in Wisconsin

WisDOT developed its hot mix asphalt (HMA) quality management program (QMP) in the early 1990s. QMP is considered a best construction practice to ensure that an agency receives quality construction materials produced by a contractor. Developing a QMP specification involved identifying key asphalt mixture parameters related to long-term pavement performance and the development of the agency's quality assurance (QA) program, including procedures for quality assurance (QA) and quality verification (QV). The asphalt pavement acceptance quality characteristics in Wisconsin's QMP are aggregate gradation, asphalt content, air voids, voids in the mineral aggregate, and in-place density (Faheem et al., 2018).

3.1.3 Production Variability of Mixtures Performance Tests

Variabilities of traditional quality characteristics such as binder content, aggregate gradation, and mixture volumetrics properties have been documented in previous studies. Overall production variability is used to measure product quality. However, very little research has been reported on the overall variabilities of new performance tests, such as asphalt mixture cracking and rutting tests.

3.1.4 IDEAL-CT Variability

A Texas A&M Transportation Institute study reported the testing variability (repeatability) of the IDEAL-CT test based on its sensitivity to asphalt mix characteristics and conditions. The CT_{Index} was sensitive to RAP and RAS content, asphalt binder type, binder content, and aging conditions. The highest within-lab coefficient of variation (COV) was 23.5%, and most COVs were less than 20% (Zhou, 2019).

The Utah Department of Transportation conducted a study comparing the IDEAL-CT and I-FIT cracking tests to determine a feasible candidate for the cracking test in their BMD implementation. The study compared within and between lab COVs. They found that the CT_{Index} within-lab COV was 15 and the between-lab COV was 25% and concluded that those were acceptable ranges of variability for a cracking test (Van Frank et al., 2020).

NCAT compared results from six different IDEAL-CT machines (Moore et al., 2021). They stated that consistent specimen preparation is key to achieving low variability. The results of tests with different machines were compared using an equivalence limit of 20% of the average CT_{Index}.

In 2018, NCAT organized a round-robin study on BMD tests being considered for implementation. This study had two phases, and fifteen labs completed IDEAL-CT testing. The within-lab COV for phase one was 19.5%, and the between-lab COV was 35.3%. For phase two, the IDEAL-CT within-lab COV was 18.8%, and the between-lab COV was 20.2%. The difference between phase one and phase two was that all specimens were made in a single laboratory for phase two, while each laboratory made its own specimens in phase one. The difference in between-lab COV between the studies highlights the importance of consistent sample preparation for CT_{Index} results (Taylor et al., 2022).

In summary, most studies have reported within-lab COVs for CT_{Index} around 20%, and between-lab COVs were up to 35%. The test is known to be sensitive to RAP content, asphalt content, asphalt binder type, specimen air voids, and aging conditions. Consistency in sample preparation is essential to reducing variability.

3.1.5 Hamburg Wheel Tracking Test Variability

The Texas Transportation Institute studied the variability of seven HWTT devices, all manufactured by Precision Metal Works, in three laboratories in Texas. The two-way analysis of variance (ANOVA) showed that the variability within and between machines increased with the increase in load cycles (Chowdhury et al., 2004).

A round-robin study conducted by the University of California Pavement Research Center (UCPRC) involved twenty laboratories in California. Each lab conducted four HWTT tests. Two tests were conducted on specimens made by UCPRC and the other two were conducted on specimens compacted by each participating laboratory. The laboratories reported rut depths at 5,000, 10,000, 15,000, and 20,000 passes, N12.5, creep slope, stripping slope, and stripping inflection point. An outlier analysis was conducted if a lab's average differed considerably from the other labs. An ANOVA was conducted to determine factors that influenced test results. The study concluded that the type of HWTT device used was significant only for rut depths at 5,000 and 10,000 passes. Single-operator variability was relatively low. Between-lab variability was relatively high for all evaluated parameters (Mateos and Jones, 2017).

In the 2018 NCAT round-robin study, 32 labs participated in the phase 1 evaluation of HWTT results. The participating labs reported using HWTT machines made by four manufacturers. At 10,000 passes, two of the 32 labs were shown as outliers; at 20,000 passes, four of the thirty-two labs were shown as outliers. The average within-lab COV for 10,000 passes was 9.0%, and for 20,000 passes, it was 9.4%. The average between-lab COV for 10,000 passes was 21.1%, and for 20,000 passes, the COV was 25.9%. The researchers stated that within-lab repeatability results for the HWTT were good, and the between-lab COV results were reasonable (Taylor et al., 2022).

The NCHRP Project 20-07/Task 361 study evaluated the capabilities of the HWTT devices available and identified issues with the AASHTO T 324 standard. It concluded that there are differences in machines in the waveform, temperature range, and reporting parameters (Mohammad et al., 2015).

A study completed by the AASHTO Materials Reference Laboratory studied the precision estimates for AASHTO T 324. The results proposed several changes to AASHTO T 324 to improve the repeatability and reproducibility of the HWTT machines. These changes included: starting location of the wheel, alignment of the wheel with respect to the specimen, measurement locations used in the analysis, variability in the cutting of the gyratory specimens, potentially increasing the specimen length, designing a new mold in terms of material and reducing the joint space between the two specimens (Azari, 2014).

In summary, several studies have shown that within-lab HWTT variability statistics are reasonably low but increase with increasing cycles. Comparisons of HWTT results from different labs on the same mix is complicated due to the higher between-lab variability which may be attributed to machine differences and operator differences but is suspected to be largely due minor differences in specimen preparation.

The remainder of this chapter deals with the analysis of results from IDEAL-CT and HWTT tests conducted on mixes sampled from ten shadow projects in Wisconsin. In addition to the analysis of IDEAL-CT and HWTT results, variabilities of the asphalt content and air voids from the contractor's QC data were examined to evaluate the production variability of the properties.

3.2 Research Approach and Methods

To quantify the overall variability of asphalt mixture BMD tests, ten shadow projects were chosen from across Wisconsin to represent the state's diversity in aggregate type, binder grades, and mix types. Wisconsin contractors obtained mix samples for the research while they also sampled mix for QC testing. For WisDOT, random samples are taken every 750 tons, representing a sublot. A typical lot in Wisconsin is made of five sublots, providing 10 to 15 mix samples per shadow project. Table 10 summarizes the shadow project county locations, the region in Wisconsin, route, mix design number, mix type, and contractor. **Figure 13** shows a map of the ten shadow project locations. The mix designs for each project can be found in Appendix B.

Table 10. Shadow Projects Description

Project	County	Region	Route	WisDOT Mix Design ID	Mix Type
1	Ozaukee	Southeast	IH 43	250-0032-2021	4 MT 58-28 S
2	Florence	North Central	STH 139	250-0263-2021	4 LT 58-28 S
3	Grant	Southwest	STH 011	250-0313-2021	4 MT 58-28 S
4	Kewaunee	Northeast	STH 029	250-0035-2022	4 MT 58-28 S
5	Waukesha	Southeast	STH 067	250-0051-2022	4 MT 58-28 S
6	La Crosse	Southwest	STH 016	250-0307-2021	4 MT 58-28 S
7	Bayfield	Northwest	USH 063	250-0145-2022	5 MT 58-34 V
8	Iowa	South Central	USH 018	250-0025-2021	4 HT 58-28 S
9	Barron	Northwest	USH 008	250-0076-2022	4 MT 58-34 V
10	Waushara	Central	IH 039	250-0107-2022	4 HT 58-28 S

Figure 13. Shadow Project Locations

The asphalt mixtures from the shadow projects were sampled during plant production while the contractor was sampling for regular QC/QA testing. Two five-gallon buckets of asphalt mix were obtained for each sublot to ensure sufficient material for testing. The contractors also provided the results of their QC tests corresponding to each sample. The mixes were shipped from the respective Wisconsin contractor to NCAT for IDEAL-CT and HWTT testing.

Each bucket of loose hot mix asphalt was heated to compaction temperature and reduced to testing size per AASHTO R47-19 *Standard Practice for Reducing Sample of Asphalt Mixtures to Testing Size.* A Quartermaster quartering device was used to reduce the sample size while ensuring representative samples for consistent laboratory results. A quartering template was used to further reduce the sampled mix to size. This sample-reducing method produced four G_{mm} samples, two G_{mb} samples, and approximately fifteen test specimens per sublot.

Once the loose plant mix was reduced to the testing size, the samples were stored in sealed, labeled plastic bags to be compacted later. Each specimen was compacted to 62 mm in height and 150 mm in diameter using a gyratory compactor, following AASHTO T 312. Each sample was made by the same engineer using the same scale, oven, and gyratory compactor to reduce specimen variability. The G_{mm} was determined for each mix following AASHTO T 209. A trial G_{mb} specimen was made using the previously reduced samples to determine the mass needed to achieve specimens with 7.0±.05 air voids, 150 mm in diameter and 62 mm in thickness.

Figure 14 shows a flow diagram of the testing procedure performed. Across the ten projects in this research study, a total of 134 sets of four replicate specimens were subjected to IDEAL-CT and HWTT testing.

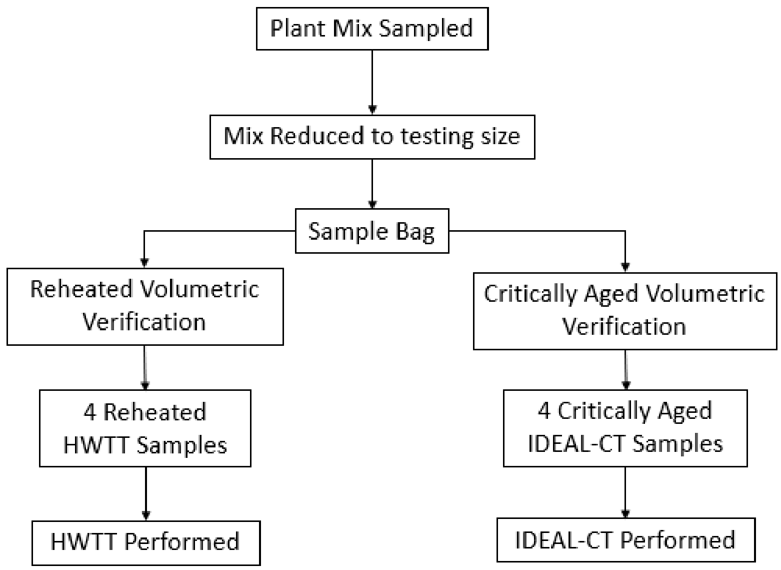


Figure 14. Testing Plan Flow Diagram

3.2.1 HWTT Testing Procedure

The HWTT specimens were reheated to compaction temperatures provided by the contractors. Each specimen's air voids were checked using AASHTO T166. Each HWTT specimen was cut to fit into the HWTT mold. All HWTTs were conducted on NCAT's Troxler HWTT machine following AASHTO T 324 at a test temperature of 46°C. Table 11 summarizes the handling and aging procedures of plant mixes for HWTT testing of shadow projects.

Table 11. Handling and Aging of Plant Mixes for HWTT, IDEAL-CT, and HT-IDT Testing of Shadow Projects at NCAT

BMD Test	Handling and Aging Procedures
HWTT	1) Reheat the plant loose mix stored in cardboard boxes in an oven at compaction temperature for approximately 2 hours until the mix becomes workable to discharge from the cardboard box. 2) Split loose mix into individual specimen sizes and place them in sealed plastic bags for storage until compaction (Note: the time between bagging and compaction was typically 1 to 2 days). 3) On the day of compaction, reheat the loose mix in an oven at compaction temperature with a calibrated thermometer in the center of the mix. 4) After the mix reaches the compaction temperature, remove it from the oven and start compaction.
IDEAL-CT	1) Reheat the plant loose mix stored in cardboard boxes in an oven at compaction temperature for approximately 2 hours until the mix becomes workable to discharge from the cardboard box. 2) Split the loose mix into individual specimen sizes. 3) Long-term age the loose mix for 6 hours at 135°C at a thickness of ¾ to 1 inch. 4) Cool the loose mix to room temperature and place them in sealed plastic bags for storage until compaction (Note: the time between bagging and compaction was typically 1 to 2 days). 5) On the day of compaction, reheat the loose mix in an oven at compaction temperature with a calibrated thermometer in the center of the mix. 6) After the mix reaches the compaction temperature, remove it from the oven and start compaction.
HT-IDT	Same as HWTT, except the specimens were made using the leftover mixes (after storage for months) from the HWTT and IDEAL-CT tests.

3.2.2 IDEAL-CT Testing Procedure

For IDEAL-CT test specimens, the loose plant mix was critically aged for 6 hours at 275°F. Critically aging is a long-term aging procedure to simulate four to five years of in-service aging of surface mixtures. The critical aging procedure followed recommendations from a previously conducted WHRP project on Wisconsin mixtures (Bahia, 2018). A maximum specific gravity (G_{mm}) test and a bulk specific gravity (G_{mb}) test were performed on asphalt samples produced from the critically aged mixture. Once the quantity of loose mix needed to produce 150 mm diameter compacted specimens to a height of 62 mm with 7.0% +/- 0.5% air voids, four specimens were compacted for IDEAL-CT testing. The IDEAL-CT test was conducted according to ASTM D8225 using a Troxler IDEAL Plus unit. Table 11summarizes the handling and aging procedures of plant mixes for IDEAL-CT testing of shadow projects.

3.2.3 HT-IDT Testing Procedure

In addition to the HWTT and IDEAL-CT tests that were planned in the original scope of work, the research team also conducted high-temperature indirect tensile strength (HT-IDT) tests on mixtures from the shadow projects for projects that had sufficient mixture samples remaining. Only four sublots did not have enough mix available to test a minimum of three replicates. The HT-IDT is a rapid rutting test that is more conducive for BMD testing during production. The variability of the HT-IDT was investigated alongside the original tests in the testing plan to collect data for informational purposes. The HT-IDT was performed in accordance with ALDOT Method 458. This test is currently under review to become an ASTM specification as of July 2023. This test can be performed using a standard Marshall load frame at 50 mm per minute loading rate and indirect tension jig. A minimum of three specimens were tested per mix and were conditioned for 1 hour at 46°C in a water bath prior to testing. This temperature matched the temperature of the HWTT testing for a correlation of results from the two methods. The indirect tensile strength (ITS) is calculated from the peak load and specimen dimensions using Equation 4. The ALDOT BMD Special Provision recommends a minimum ITS of 20 psi for lab-compacted specimens and 17 psi for plant-mixed specimens tested at 50°C (NAPA, 2023; Powell et al., 2021). Table 11 summarizes the handling and aging procedures of plant mixes for HT-IDT testing of shadow projects.

$$ITS(psi) = \frac{\mathbf{2\ x\ Peak\ Load\ (lb)}}{\boldsymbol{\pi}\ \mathbf{x\ Specimen\ Diameter\ (in.)\ x\ Specimen\ Height\ (in.)}} \quad \text{Equation 4}$$

3.2.4 CDF of Production Results Standard Deviation and Coefficients of Variation

The cumulative distribution frequency (CDF) for all project’s standard deviations and coefficients of variation were plotted using Minitab software. Cumulative distribution frequencies are used to evaluate the distribution of a dataset and can help analyze the percentage of the results above or below a particular value. The steepness or slope of the CDF can indicate how close the observations are to the mean.

3.3 Results and Discussion

3.3.1 Results and Analysis of Variabilities from the Shadow Projects

3.3.1.1 Summary of Averages, Standard Deviations, and Coefficients of Variation

For each shadow project, the contractors provided samples for two or three lots, and for each lot, there were five sublots. Therefore, the within-lot average, standard deviation, and COV were calculated from the results of five sublots.

Table 12 summarizes the asphalt content results for each project. The pooled within-lot standard deviation for asphalt content was 0.18%. The asphalt content has the lowest overall within-lot COV among the mixture tests, with an average within-lot COV of 2.8% and a maximum within-lot COV of 7.2%. The pooled within-lot standard deviation for this project compares well with the average production (overall) standard deviation (0.20%) reported by Mohammad et al. (2016).

Table 12. Summary of Asphalt Content Results

Project	Lot	Average	Std. Dev.	COV
1	Lot 1	6.1	0.2	2.6%
	Lot 2	6.3	0.2	3.8%
2	Lot 2	5.6	0.1	1.3%
	Lot 3	5.7	0.1	2.5%
3	Lot 2	5.8	0.2	2.6%
	Lot 3	6.0	0.4	7.2%
	Lot 4	5.9	0.3	5.9%
4	Lot 2	5.9	0.1	1.7%
	Lot 3	6.0	0.1	1.9%
	Lot 4	6.0	0.1	1.4%
5	Lot 4	5.7	0.2	3.4%
	Lot 5	5.8	0.2	3.1%
	Lot 6	5.8	0.1	1.9%
6	Lot 9&11	6.0	0.1	2.2%
	Lot 10	5.9	0.2	2.8%
7	Lot 3&6	6.6	0.1	1.3%
	Lot 4	6.7	0.1	1.8%
	Lot 5	6.8	0.1	1.3%
8	Lot 3	5.8	0.2	4.0%
	Lot 4	5.8	0.1	1.9%
	Lot 5	5.7	0.2	2.7%
9	Lot 8	5.6	0.1	2.1%
	Lot 9	5.6	0.1	2.3%
	Lot 10	5.4	0.3	5.8%
10	Lot 8	6.2	0.2	2.7%
	Lot 9	6.2	0.1	2.1%
	Lot 10	6.2	0.2	3.0%

Table 13 summarizes the air voids results for each project. The pooled within-lot standard deviation for air voids was 0.34%. Air voids had an average within lot COV of 10.4% and the maximum within-lot COV was 20.3%. The pooled within-lot standard deviation for air voids for this study is about half of the average production (overall) standard deviation (0.62%) reported by Mohammad et al. (2016). The range of within-lot standard deviation for air voids for this study was 0.1 to 0.6 compared to the range (0.33 to 0.99%) reported by Mohammad et al. This suggests that the Wisconsin contractors were able to control air voids during production better than many other contractors.

Table 13. Summary of Air Voids Results

Project	Lot	Average	Std. Dev.	COV
1	Lot 1	3.3	0.4	12.8%
	Lot 2	3.1	0.3	10.2%
2	Lot 2	2.8	0.1	4.1%
	Lot 3	2.9	0.2	6.7%
3	Lot 2	2.9	0.2	7.9%
	Lot 3	2.9	0.1	4.5%
	Lot 4	2.8	0.4	15.8%
4	Lot 2	2.9	0.3	10.3%
	Lot 3	3.0	0.1	2.9%
	Lot 4	3.2	0.1	1.7%
5	Lot 4	3.3	0.3	8.3%
	Lot 5	3.2	0.2	6.8%
	Lot 6	3.3	0.3	9.0%
6	Lot 9&11	2.9	0.3	10.1%
	Lot 10	2.4	0.4	15.5%
7	Lot 3&6	3.1	0.5	16.5%
	Lot 4	2.8	0.5	16.8%
	Lot 5	2.6	0.3	9.9%
8	Lot 3	3.0	0.4	14.9%
	Lot 4	2.7	0.6	21.3%
	Lot 5	2.9	0.6	19.5%
9	Lot 8	3.1	0.2	6.2%
	Lot 9	2.8	0.4	14.6%
	Lot 10	3.0	0.3	10.8%
10	Lot 8	3.0	0.1	3.6%
	Lot 9	2.8	0.3	10.6%
	Lot 10	2.8	0.3	10.0%

Table 14 summarizes the CT_{Index} results for each project. The pooled within-lot standard deviation for CT_{Index} was 10.9. The average within-lot COV for CT_{Index} was 13.3%, with the smallest within-lot COV being 4.4% and the largest being 39.7%. A recent round-robin study by NCAT (Rodezno et al., 2023) found that the within-lab (single operator) COV for CT_{Index} was 20.5% which is substantially greater than the overall production variability for the Wisconsin shadow projects. It seems impossible for the overall variability of CT_{Index} to be less than the within-lab variability. This unexpected outcome may be due to the fact that all of the IDEAL-CT tests in this study were conducted by the same engineer with the same equipment which produced artificially low variability results.

Table 14. Summary of CT_{Index} Results

Project	Lot	Average CT_{Index}	Std. Dev.	COV
1	Lot 1	47.0	7.4	15.6%
	Lot 2	48.0	4.0	8.4%
2	Lot 2	58.2	9.1	15.7%
	Lot 3	62.8	19.6	31.1%
3	Lot 2	62.7	6.4	10.2%
	Lot 3	69.7	27.7	39.7%
	Lot 4	73.3	17.8	24.3%
4	Lot 2	86.2	7.6	8.8%
	Lot 3	83.8	10.7	12.8%
	Lot 4	89.0	6.0	6.7%
5	Lot 4	40.1	4.3	10.7%
	Lot 5	44.3	8.8	19.9%
	Lot 6	51.3	5.2	10.1%
6	Lot 9&11	46.2	3.6	7.8%
	Lot 10	51.2	7.7	15.1%
7	Lot 3&6	106.7	16.8	15.7%
	Lot 4	113.5	7.8	6.9%
	Lot 5	120.4	8.9	7.4%
8	Lot 3	45.1	2.0	4.4%
	Lot 4	51.0	4.6	9.1%
	Lot 5	42.2	2.8	6.5%
9	Lot 8	51.5	8.9	17.2%
	Lot 9	58.9	5.2	8.8%
	Lot 10	57.5	5.5	9.5%
10	Lot 8	113.2	11.6	10.3%
	Lot 9	118.4	14.5	12.2%
	Lot 10	119.5	16.4	13.7%

Table 15 summarizes the HWTT CRD_{20k} results for each project. The pooled within-lot standard deviation for CRD_{20k} was 1.60 mm. The average within-lot COV for CRD_{20k} was 10.9%, with a maximum within-lot COV of 26.4%, and a minimum within-lot COV of 4.1%. For comparison, the NCAT round robin study reported that the within-lab COV for HWTT total rut depth at 20,000 passes was 9.5%.

Table 15. Summary of CRD_{20k} Results

Project	Lot	Average CRD_{20k}	Std. Dev.	COV
1	Lot 1	10.7	2.2	20.4%
	Lot 2	11.0	1.4	13.1%
2	Lot 2	16.4	2.8	16.8%
	Lot 3	16.2	0.7	4.4%
3	Lot 2	9.0	0.4	4.1%
	Lot 3	11.0	0.4	4.1%
	Lot 4	10.6	1.2	11.7%
4	Lot 2	15.9	1.6	10.3%
	Lot 3	16.2	1.3	8.0%
	Lot 4	17.3	3.0	17.6%
5	Lot 4	10.5	1.0	9.9%
	Lot 5	11.2	0.7	5.8%
	Lot 6	10.5	0.7	7.0%
6	Lot 9&11	11.3	1.0	8.7%
	Lot 10	11.6	1.6	13.5%
7	Lot 3&6	11.7	0.7	5.6%
	Lot 4	13.1	3.4	26.4%
	Lot 5	16.4	3.3	20.1%
8	Lot 3	10.2	1.2	11.9%
	Lot 4	10.2	1.0	10.0%
	Lot 5	8.4	1.2	14.3%
9	Lot 8	9.7	0.9	9.3%
	Lot 9	11.0	1.1	9.6%
	Lot 10	12.0	1.3	10.6%
10	Lot 8	11.6	0.6	4.9%
	Lot 9	13.3	1.4	10.6%
	Lot 10	12.6	0.6	5.1%

Table **16** summarizes the HWTT $N_{12.5}$. The pooled within-lot standard deviation for $N_{12.5}$ was 1838. The average within-lot COV for $N_{12.5}$ was 16.6%, with a maximum of 35.8% and a minimum of 2.8%.

Table 16. Summary of $N_{12.5}$ Results

Project	Lot	Average	Std. Dev.	COV
1	Lot 1	11416	4086	35.8%
	Lot 2	9662	3298	34.1%
2	Lot 2	5670	952	16.8%
	Lot 3	4785	906	18.9%
3	Lot 2	14580	2753	18.9%
	Lot 3	11188	909	8.1%
	Lot 4	11642	2576	22.1%
4	Lot 2	5682	52	9.2%
	Lot 3	6200	735	11.9%
	Lot 4	4800	486	10.1%
5	Lot 4	13972	2769	19.8%
	Lot 5	10662	2671	25.0%
	Lot 6	11266	1865	16.5%
6	Lot 9&11	8460	609	7.2%
	Lot 10	9018	1618	17.9%
7	Lot 3&6	7192	215	3.0%
	Lot 4	6592	1294	19.6%
	Lot 5	4726	1197	25.3%
8	Lot 3	9188	2272	24.7%
	Lot 4	9056	1569	17.3%
	Lot 5	11278	1974	17.5%
9	Lot 8	10870	1189	10.9%
	Lot 9	9278	1829	19.7%
	Lot 10	9370	1464	15.6%
10	Lot 8	9990	1407	14.1%
	Lot 9	8302	235	2.8%
	Lot 10	8840	553	6.3%

Table 17 summarizes the HWTT *SIP* for each project. The pooled within-lot standard deviation for *SIP* was 1712. The average within-lot COV for *SIP* was 19.9% with within-lot COVs ranging from 4.1% to 38.1%. For comparison, the HWTT precision study by Azari (2014) reported that the single operator COV for *SIP* was 23.9%. For the average overall production variability from the Wisconsin projects to be less than the single-operator variability again points to the issue of using a single engineer and single set of equipment to conduct this study. However, this inconsistency may have been affected by improvements in the HWTT test procedure and equipment over the past nine years.

Table 17. Summary of Stripping Inflection Point (*SIP*) Results

Project	Lot	Average *SIP*	Std. Dev.	COV
1	Lot 1	9479	2834	29.9%
	Lot 2	7843	2990	38.1%
2	Lot 2	4988	776	15.6%
	Lot 3	4080	665	16.3%
3	Lot 2	13206	2807	21.3%
	Lot 3	9223	1417	15.4%
	Lot 4	8429	2325	27.6%
4	Lot 2	4471	417	9.3%
	Lot 3	5149	707	13.7%
	Lot 4	3896	565	14.5%
5	Lot 4	11254	3420	30.4%
	Lot 5	7739	1385	17.9%
	Lot 6	8598	1504	17.5%
6	Lot 9&11	6280	1189	18.9%
	Lot 10	6578	1528	23.2%
7	Lot 3&6	5934	396	6.7%
	Lot 4	5443	971	17.8%
	Lot 5	3864	915	23.7%
8	Lot 3	6712	1707	25.4%
	Lot 4	6913	1715	24.8%
	Lot 5	8936	2310	25.8%
9	Lot 8	7452	1844	24.7%
	Lot 9	7198	2055	28.6%
	Lot 10	7327	1157	15.8%
10	Lot 8	7818	1357	17.4%
	Lot 9	6500	774	11.9%
	Lot 10	6845	282	4.1%

Table 18 summarizes the HWTT Stripping Number (LC_{SN}) for each project. The pooled within-lot standard deviation for LC_{SN} was 1436. The mean within-lot COV for LC_{SN} was 33.5% with within-lot COVs ranging from 8.2% to 62.5%.

Table 18. Summary of Stripping Number (LC_{SN}) Results

Project	Lot	Average LC_{SN}	Std. Dev. LC_{SN}	COV
1	Lot 1	4342	1868	43.0%
	Lot 2	3644	1135	31.1%
2	Lot 2	4232	1692	40.0%
	Lot 3	3188	1356	42.5%
3	Lot 2	6011	3483	57.9%
	Lot 3	4348	935	21.5%
	Lot 4	4424	1002	22.6%
4	Lot 2	3101	797	25.7%
	Lot 3	4502	1898	42.2%
	Lot 4	3089	1638	53.0%
5	Lot 4	7997	2723	34.1%
	Lot 5	5743	3587	62.5%
	Lot 6	5828	2706	46.4%
6	Lot 9&11	3289	487	14.8%
	Lot 10	4045	1819	45.0%
7	Lot 3&6	2530	440	17.4%
	Lot 4	2426	590	24.3%
	Lot 5	2476	203	8.2%
8	Lot 3	2995	951	31.8%
	Lot 4	3138	1205	38.4%
	Lot 5	3150	770	24.4%
9	Lot 8	3955	1149	29.1%
	Lot 9	3460	860	24.9%
	Lot 10	4104	1436	35.0%
10	Lot 8	4364	982	22.5%
	Lot 9	4729	1985	42.0%
	Lot 10	4624	1084	23.4%

Table 19 summarizes the HT-IDT results. The pooled within-lot standard deviation for HT-IDT strength was 2.29 psi. The average within-lot COV for HT-IDT strength was 13.5%. The minimum and maximum within-lot COV for HT-IDT strength were 6.2% and 25.1%, respectively. For comparison, the recent NCAT round-robin study (Rodezno et al., 2023) found that the within-lab COV for HT-IDT strength was 8.3%. In this case, the overall production variability from the Wisconsin shadow projects is slightly greater than the within-lab variability for HT-IDT strength, as expected. Nonetheless, the variability results for the Wisconsin shadow projects were likely reduced by the fact that a single laboratory conducted all of the tests.

Table 19. Summary of HT-IDT Strength Results

Project	Lot	Average, psi	Std. Dev., psi	COV
1	Lot 1	21.7	2.6	12%
	Lot 2	20.1	3.1	16%
2	Lot 2	12.6	1.7	14%
	Lot 3	11.5	1.6	14%
3	Lot 2	16.6	2.3	14%
	Lot 3	15.5	2.3	15%
	Lot 4	15.3	1.8	12%
4	Lot 2	14.0	1.4	10%
	Lot 3	16.4	2.2	13%
	Lot 4	14.2	2.1	15%
5	Lot 4	18.2	2.1	12%
	Lot 5	17.2	3.3	19%
	Lot 6	18.6	1.9	10%
6	Lot 9&11	16.6	4.2	25%
	Lot 10	15.4	1.7	11%
7	Lot 3&6	13.0	1.7	13%
	Lot 4	13.8	1.5	13%
	Lot 5	9.5	1.3	11%
8	Lot 3	18.3	2.6	14%
	Lot 4	16.3	1.8	14%
	Lot 5	17.3	1.3	11%
9	Lot 8	17.4	3.3	19%
	Lot 9	16.5	2.5	15%
	Lot 10	17.1	2.5	15%
10	Lot 8	16.0	2.7	17%
	Lot 9	16.6	1.0	9%
	Lot 10	17.2	2.0	12%

3.3.1.2 Examining Potential Relationships between Variability of Asphalt Content and Air Voids with IDEAL-CT and HWTT

To determine if asphalt content and air voids influenced the variabilities of IDEAL-CT and HWTT results, their respective COVs of each lot were plotted against each other in scatterplots. Best-fit linear regression equations were determined for these correlation plots using Excel. The scatterplots of CT_{Index} COV versus asphalt content and air voids COVs are shown in Figure 15 and Figure 16, respectively. The scatterplots of HWTT CRD_{20k} COV versus asphalt content and air voids COVs are shown in Figure 17 and Figure 18, respectively. All these figures include the coefficient of determination (R^2) as an indication of how well the regression equation explains the relationship between the two variables. R^2 can be interpreted as the percentage of the change in the dependent variable, for Figure 15 for example, CT_{Index} COV can be attributed to the independent variable, asphalt content COV. In general, based on the results presented in Figure 15 to Figure 18 the low R^2 values indicate that the variabilities of asphalt content and air voids had little to no influence on the variabilities of CT_{Index} and HWTT CRD_{20k}.

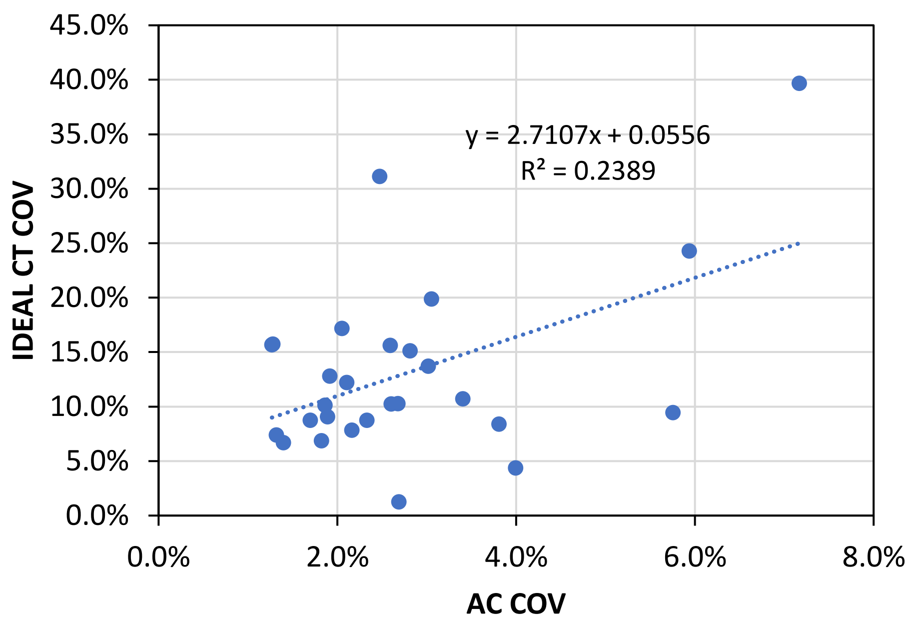


Figure 15. IDEAL-CT CT_{Index} COV vs. AC COV

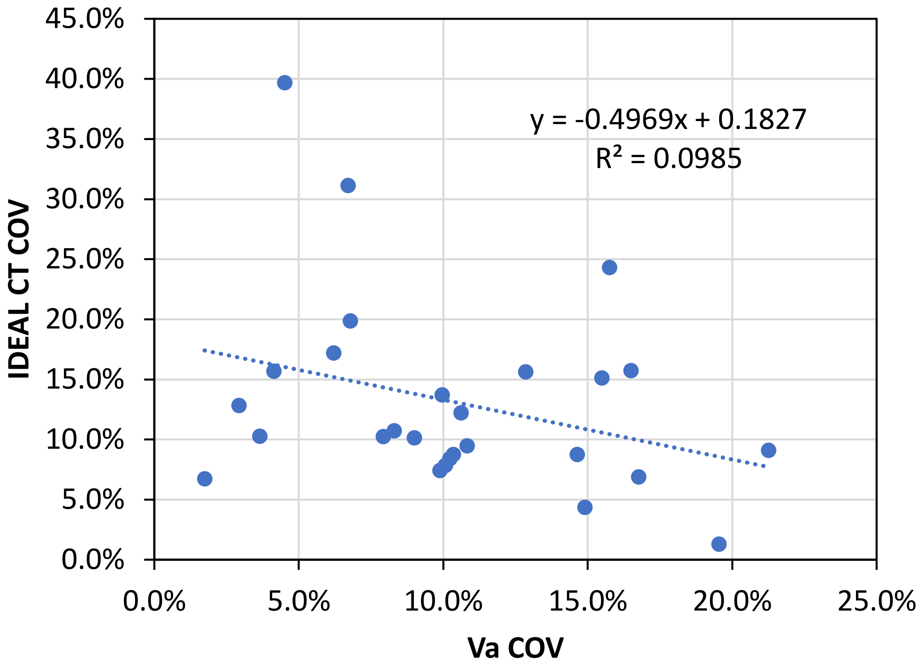


Figure 16. IDEAL-CT CT_{Index} COV vs. Va COV

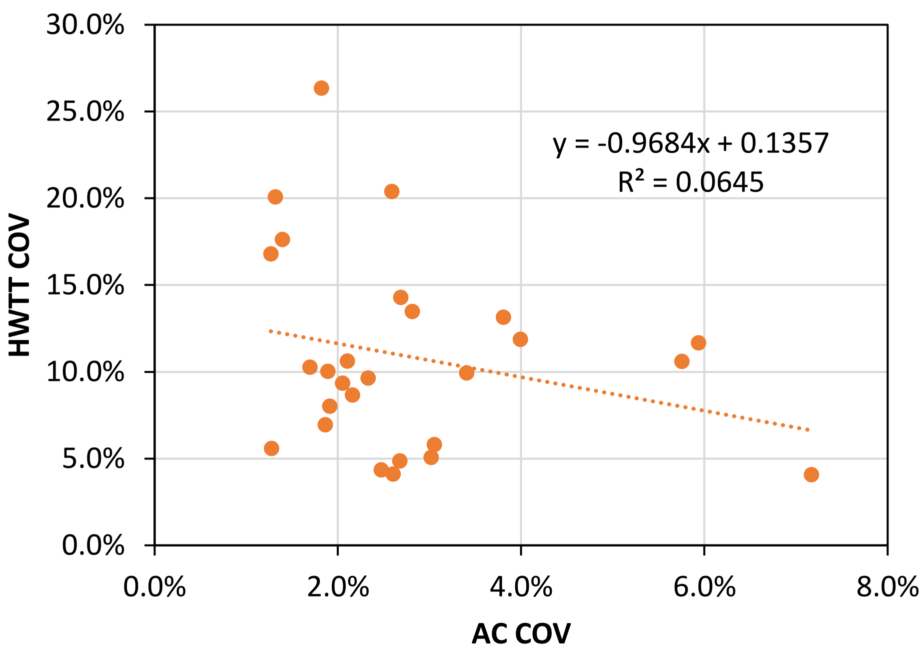


Figure 17. HWTT CRD_{20k} COV vs. AC COV

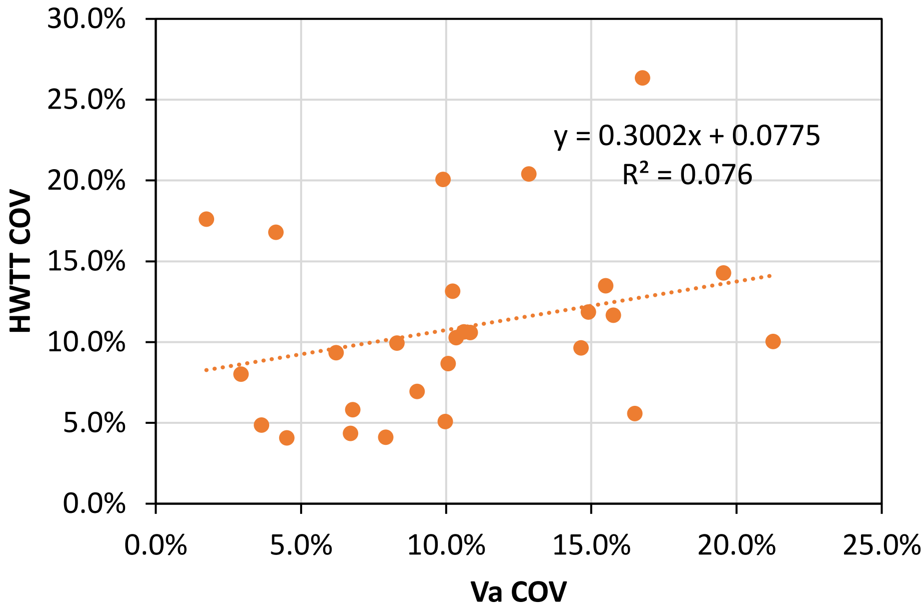


Figure 18. HWTT CRD_{20k} COV vs. Air Voids COV

3.3.1.3 Cumulative Distribution Frequencies of Production Standard Deviations and COVs

To assess the production variability of the test results, Cumulative Distribution Frequencies (CDF) were plotted for each lot standard deviation and COV for CT_{Index}, CRD_{20k}, *SIP*, LC_{SN}, air voids, asphalt content, and HT-IDT strength.

Figure 19 and Figure 20 show CT_{Index} the standard deviation and COV, respectively for each lot. The 50th percentile for the CT_{Index} standard deviation corresponding to the median of the test results was 7.75. The 50th percentile for CT_{Index} COV was 10.3% with approximately 80% of the lots having a COV below 20%.

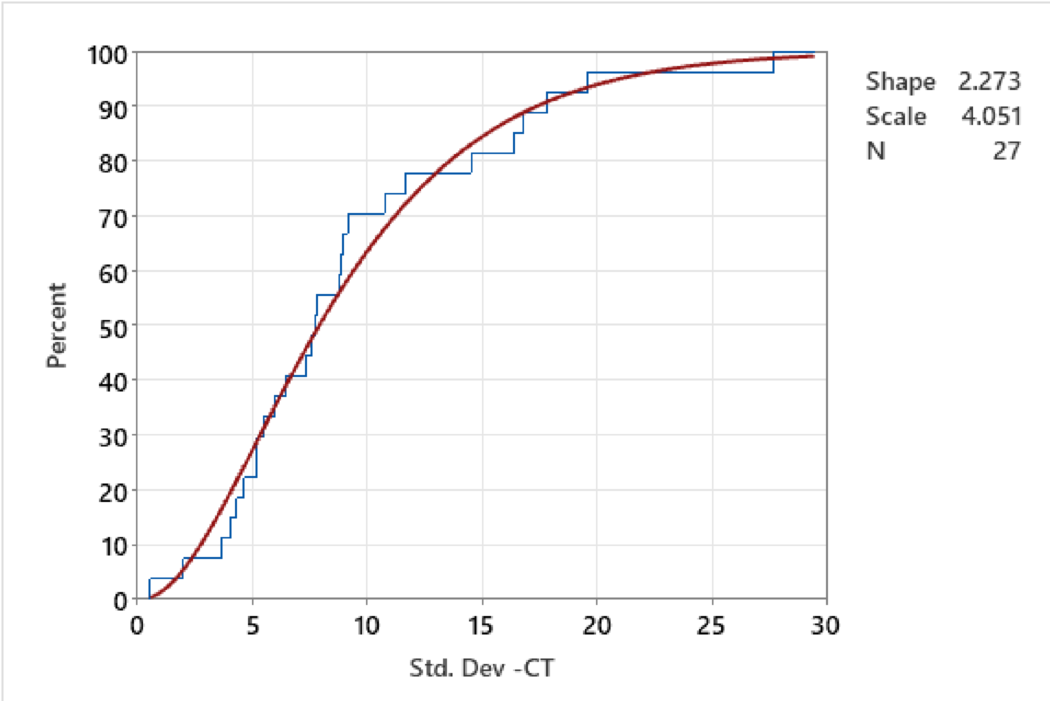


Figure 19. CDF of Std. Dev. for CT_{Index}

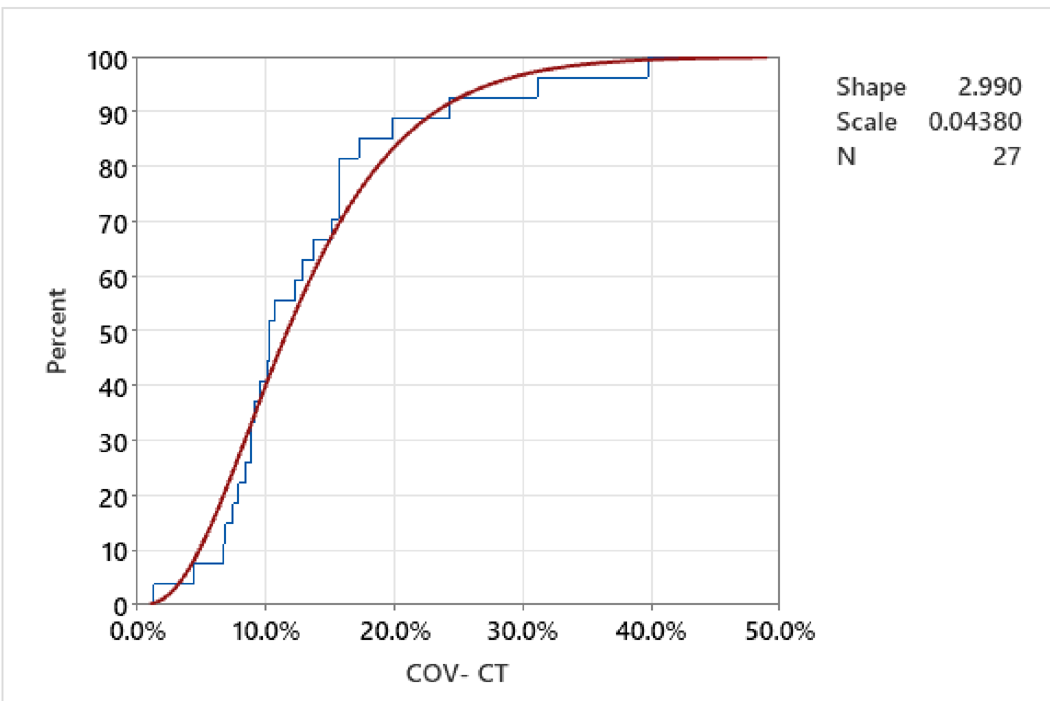


Figure 20. CDF of COV for CT_{Index}

Figure 21 and Figure 22 show the CDF plots of the within-lot standard deviation and COV for HWTT CRD_{20k}, respectively. The 50th percentile standard deviation for CRD_{20k} was 1.20. The 50th percentile COV for CRD_{20k} was 10.0% with approximately 80% of the lots having a COV below 15%.

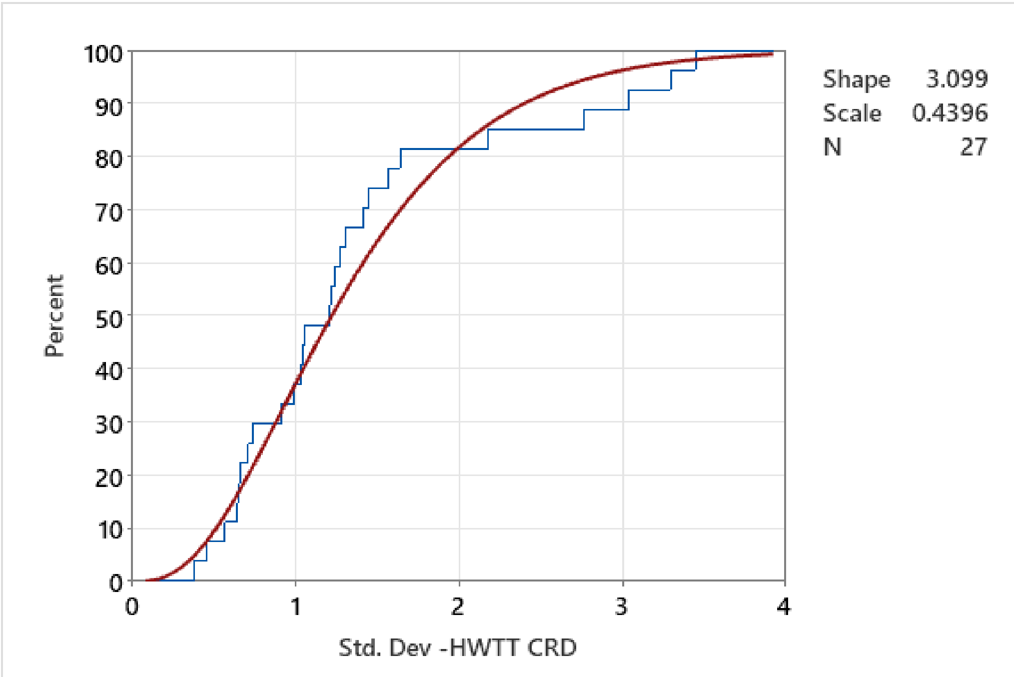


Figure 21. CDF of Std. Dev. for HWTT CRD_{20k}

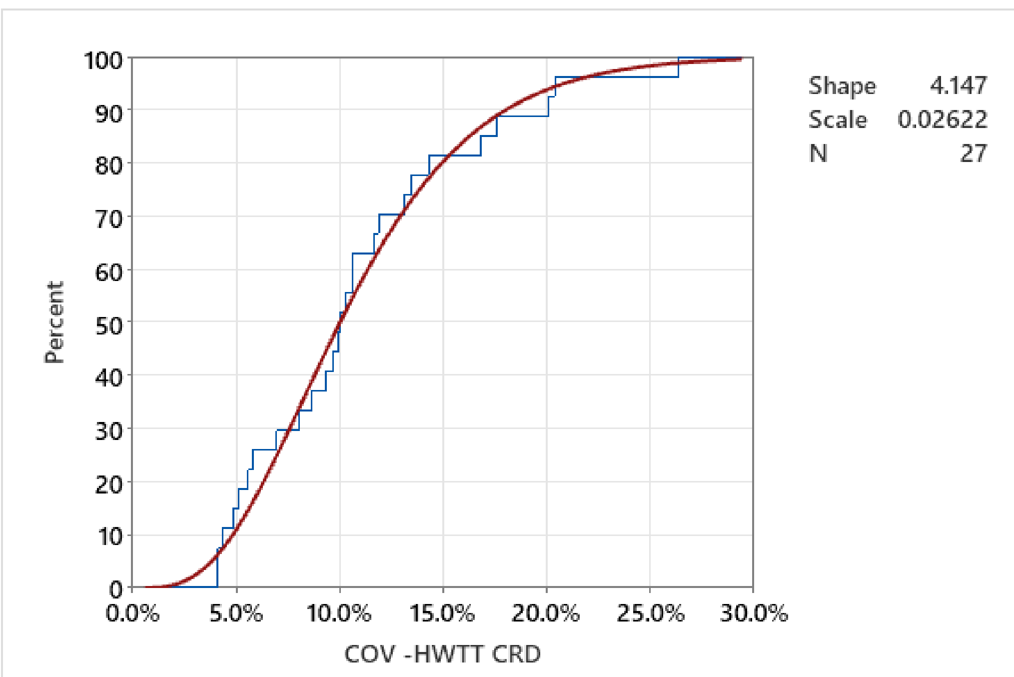


Figure 22. CDF of COV for HWTT CRD_{20k}

Figure 23 and Figure 24 show the CDF plots of within-lot standard deviation and COV for HWTT $N_{12.5}$, respectively. The 50th percentile standard deviation was 1407 passes. The 50th percentile COV for HWTT $N_{12.5}$ was 17.3%.

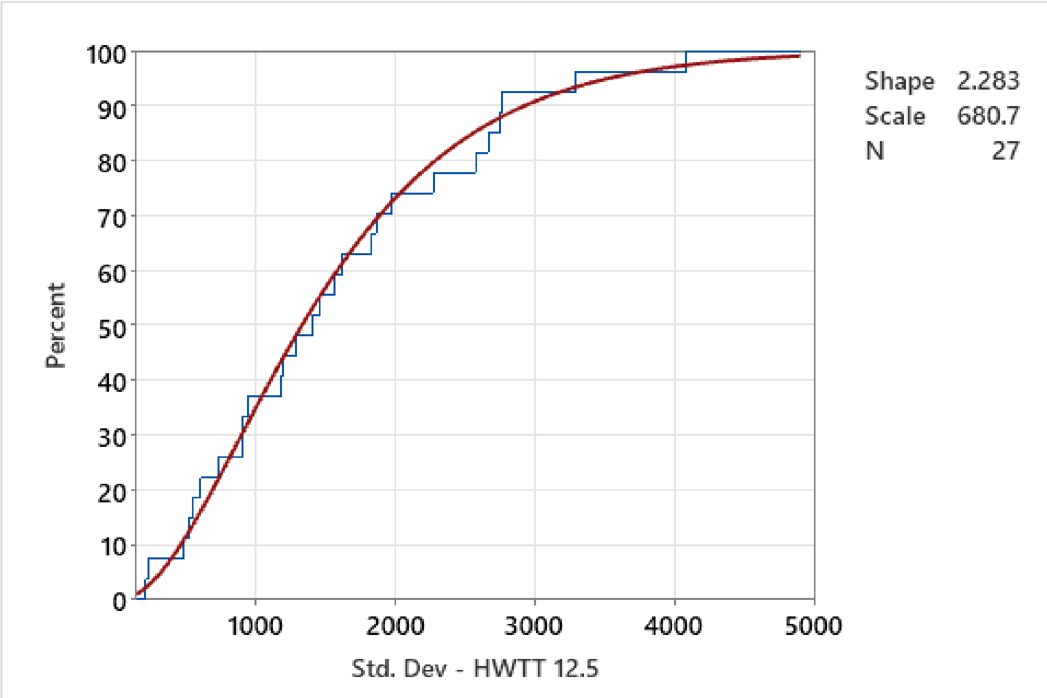


Figure 23. CDF of Std. Dev. for HWTT Passes to 12.5 mm

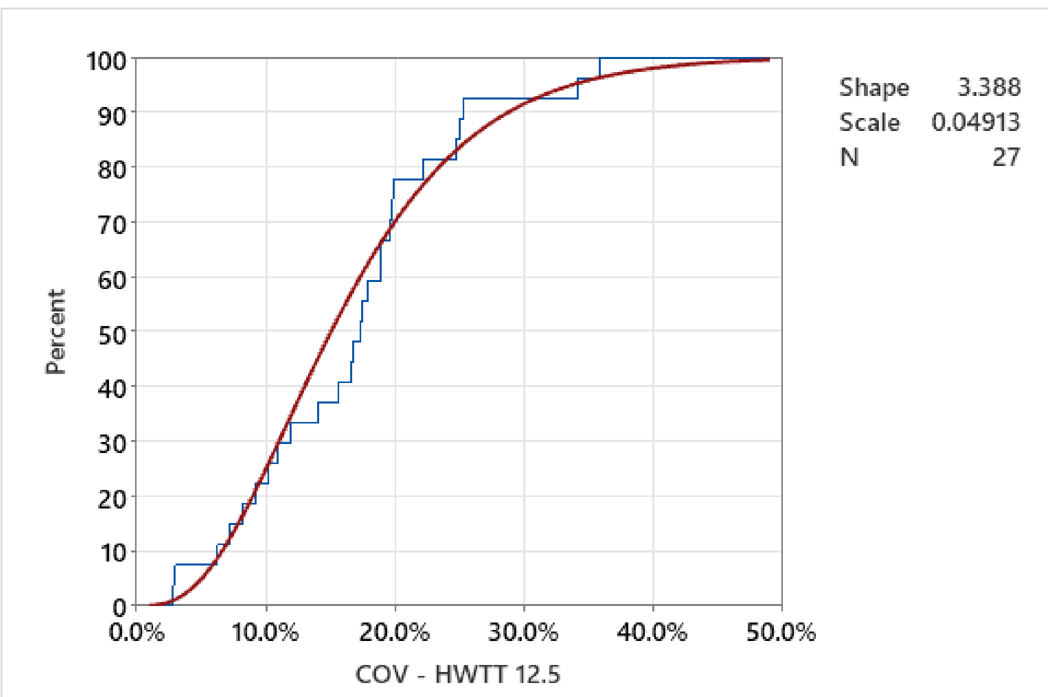


Figure 24. CDF of COV for HWTT Passes to 12.5 mm

Figure 25 and Figure 26 display the CDF plots of the within-lot standard deviation and COV of the HWTT SIP, respectively. The 50th percentile standard deviation for SIP was 1,385 and the 50th percentile COV for SIP was 17.9%.

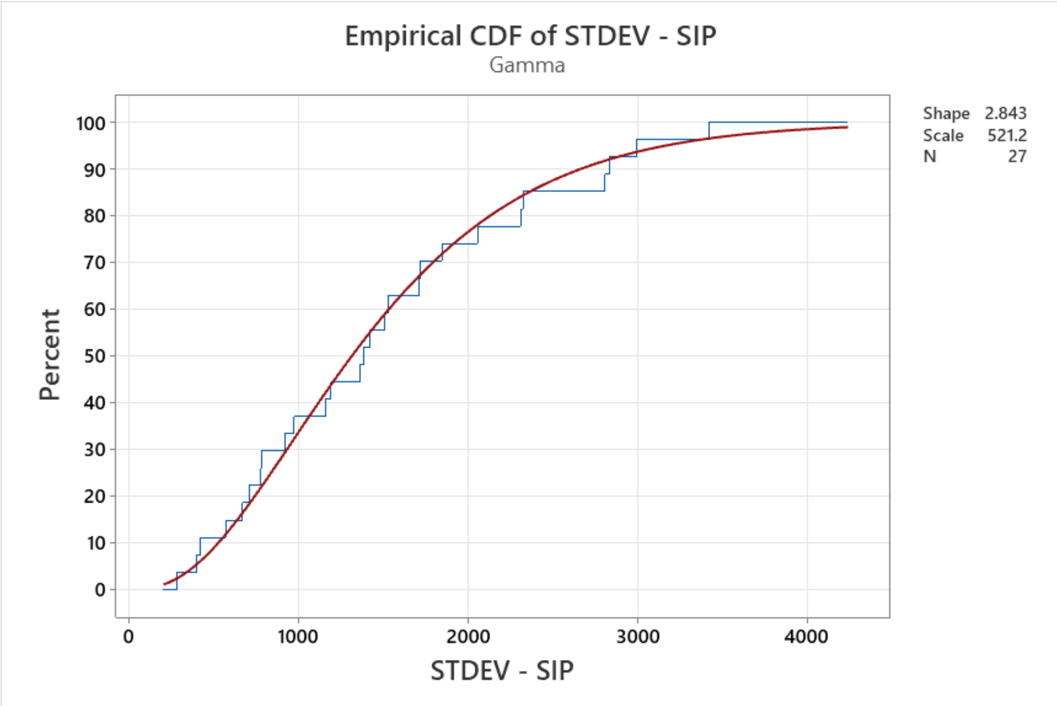


Figure 25. CDF of Std. Dev. for SIP

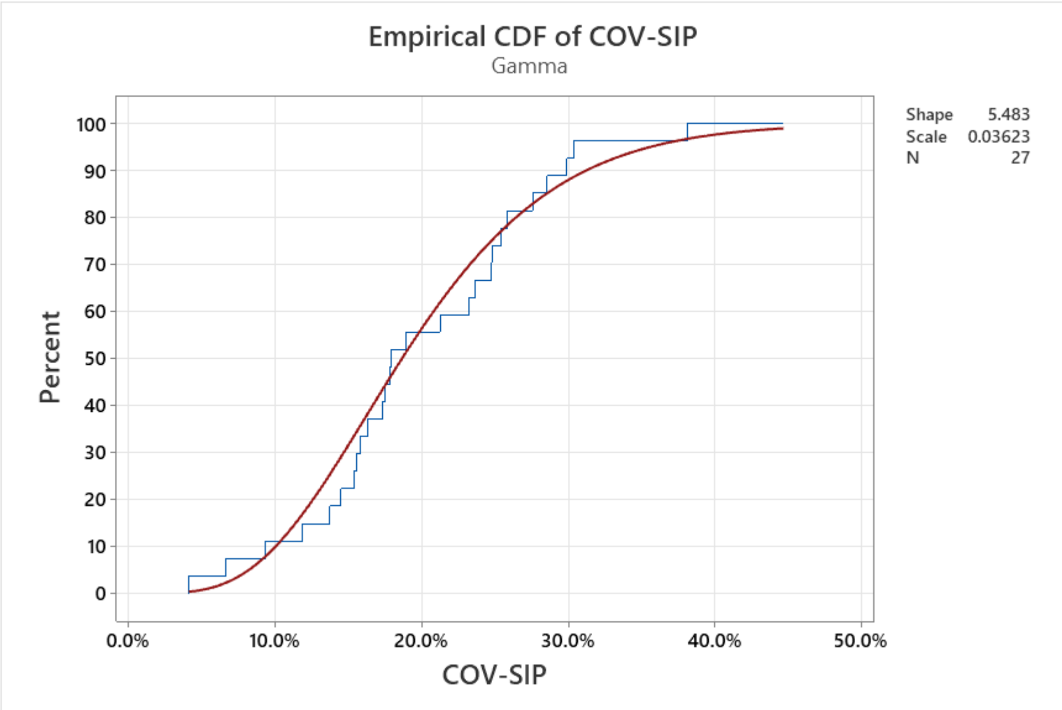


Figure 26. CDF of COV for SIP

Figure 25 and Figure 28 display the CDF plots of the within-lot standard deviation and COV of the HWTT Stripping Number, respectively. The 50th percentile standard deviation for LC_{SN} was 1,134 and the 50th percentile COV for LC_{SN} was 31.6%.

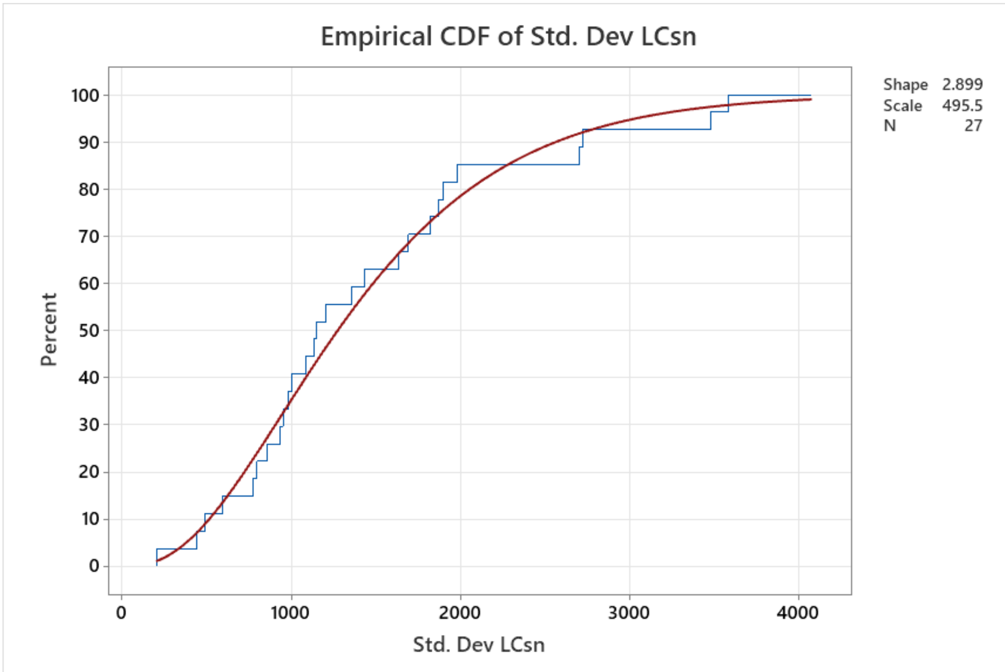


Figure 27. CDF of Std. Dev. of HWTT Stripping Number

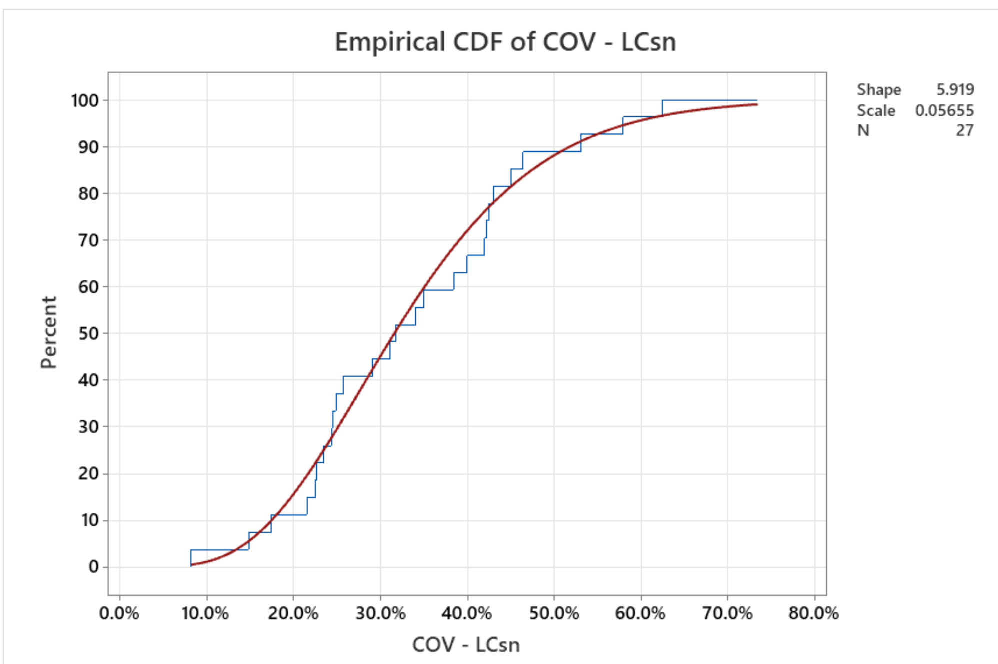


Figure 28. CDF of COV of HWTT Stripping Number

Figure 29 and Figure 30 display the CDF plots of the within-lot standard deviation and COV of asphalt content, respectively. The 50th percentile standard deviation for asphalt content was 0.14 and the 50th percentile COV for asphalt content was 2.5%. These results indicate that asphalt content is the quality characteristic with the lowest variability.

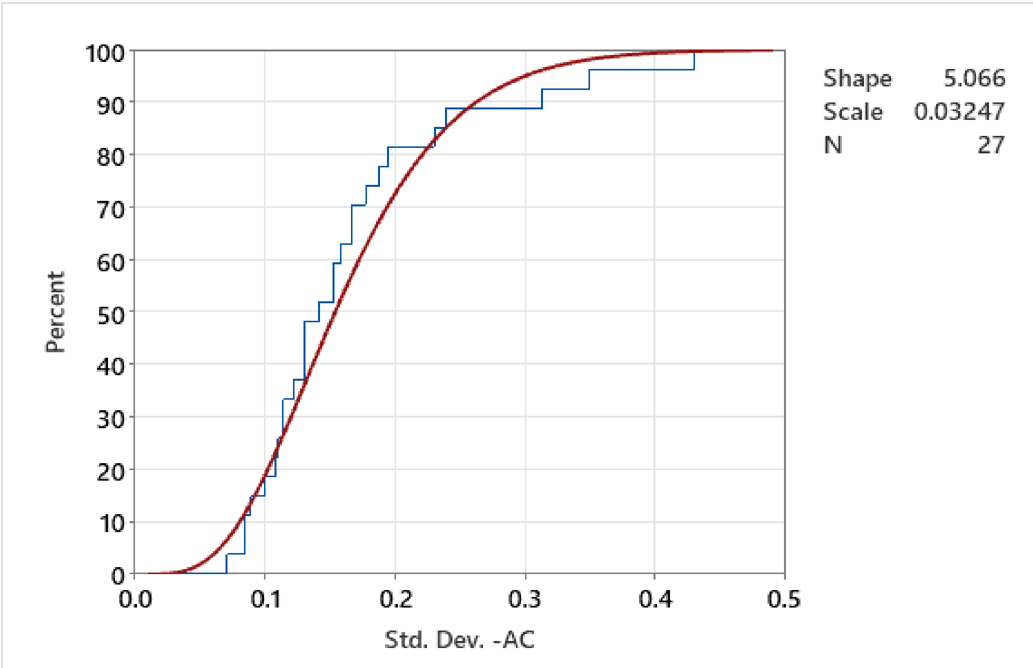


Figure 29. CDF of Std. Dev. for Asphalt Content

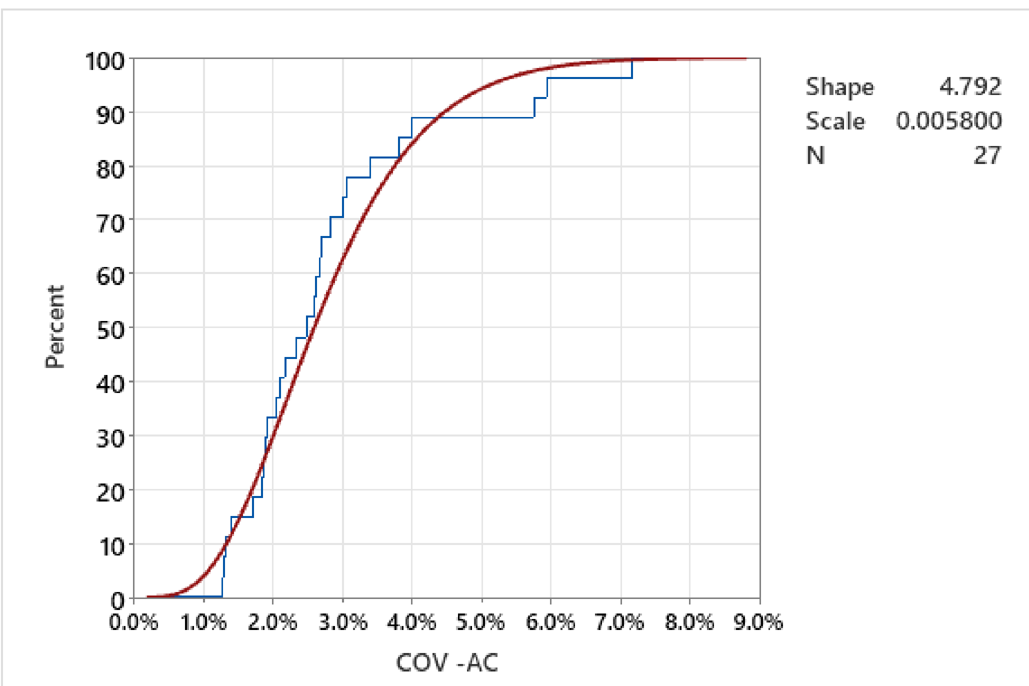


Figure 30. CDF of COV for Asphalt Content

Figure 31 and Figure 32 show the CDF plots of the within-lot standard deviation and COV of air voids, respectively. The 50th percentile standard deviation for air voids was 0.30 and the 50th percentile COV for air voids was 10.1%.

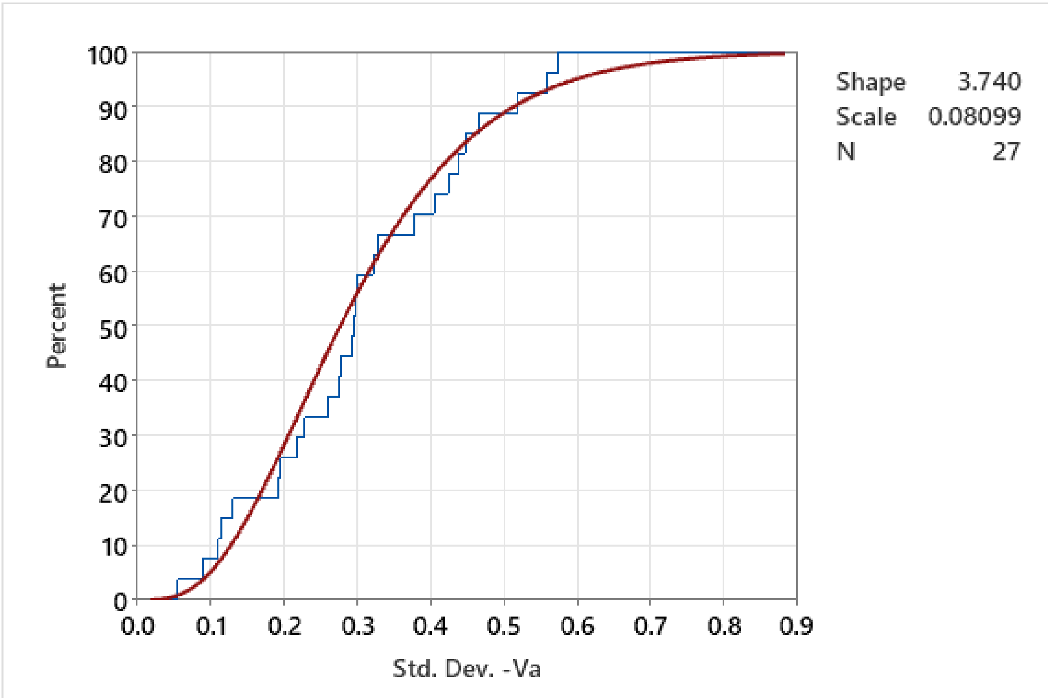


Figure 31. CDF of Std. Dev. for Air Voids

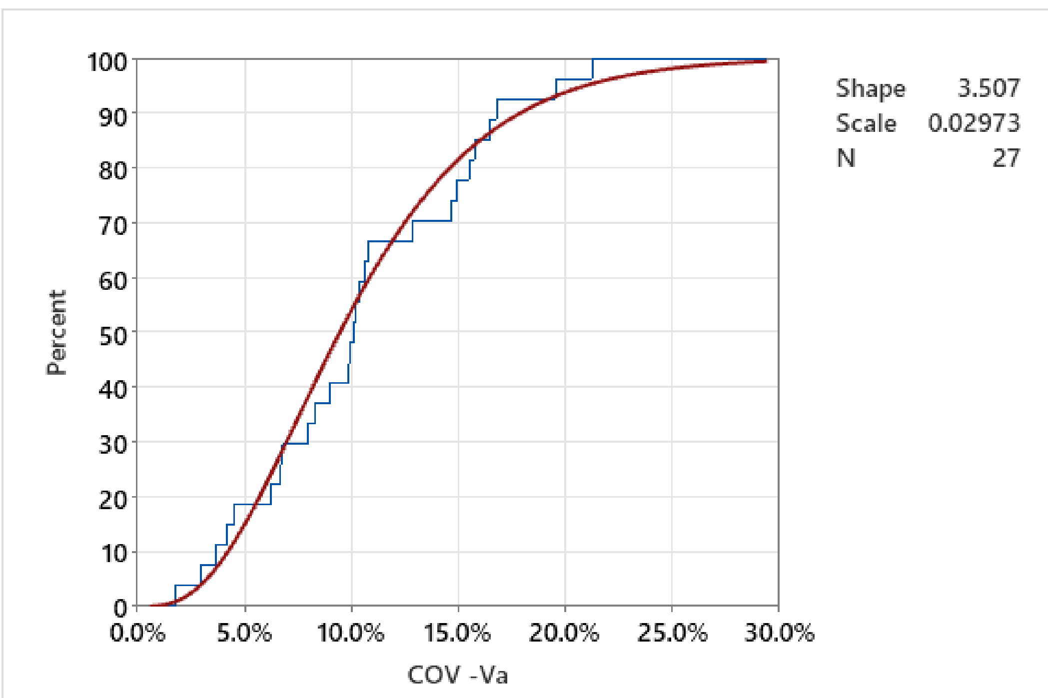


Figure 32. CDF of COV for Air Voids

Figure 33 and Figure 34 display the variability of the HT-IDT strength results. The 50th percentile within-lot standard deviation and COV were 2.1 psi and 13.5%, respectively.

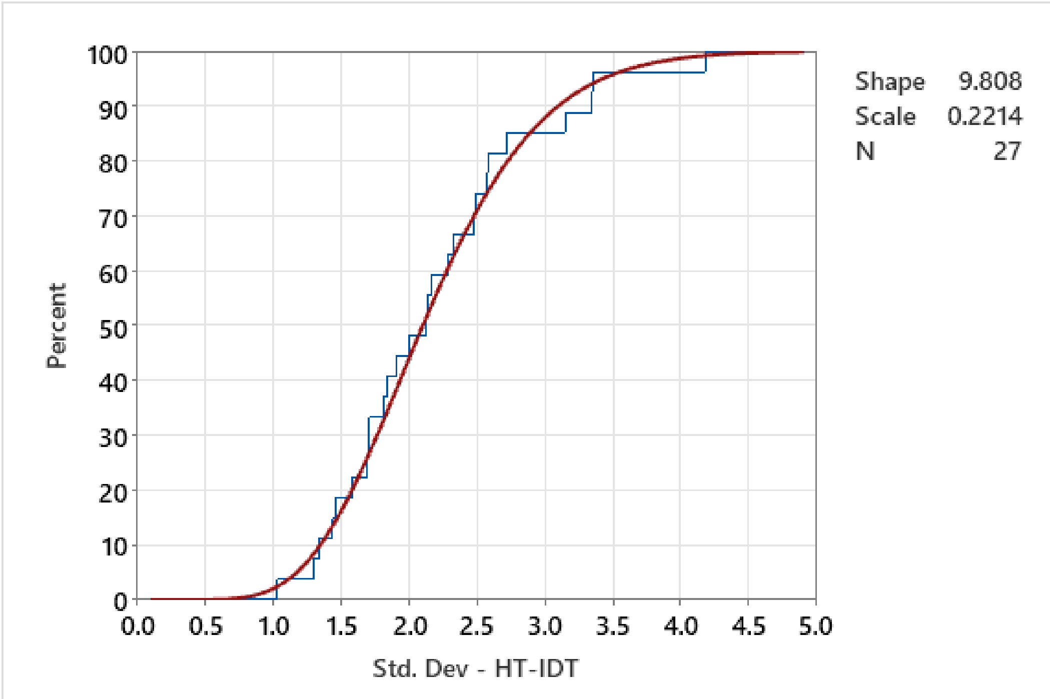


Figure 33. CDF of Std. Dev. of HT-IDT Strength, psi

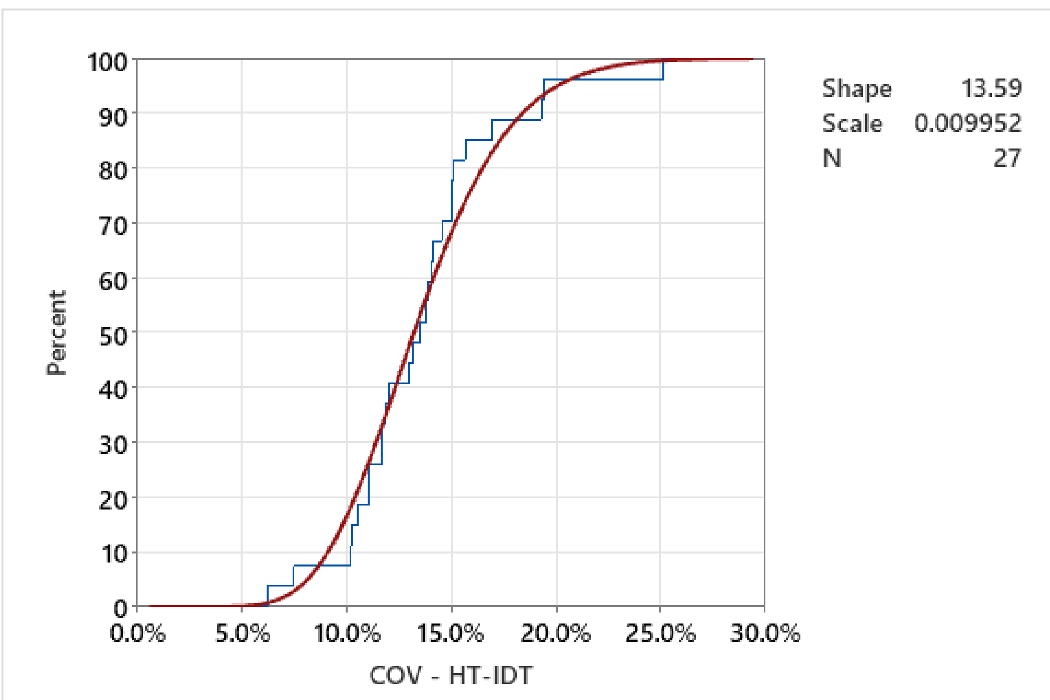


Figure 34. CDF of COV of HT-IDT Strength, psi

A combined plot of best-fit CDFs of within-lot COVs of CT_{index}, HWTT CRD_{20k}, HWTT $N_{12.5}$, HWTT *SIP*, HWTT LC_{SN}, asphalt content, air voids, and HT-IDT strength are shown in Figure 35. It can be seen in Figure 35 that the asphalt content COV was the lowest, air voids, HT-IDT and HWTT CRD_{20k} had very similar COV distributions, and the HWTT LC_{SN} COV was the highest. With similar variability results, the HT-IDT could be considered as a viable replacement for the HWTT due its faster testing time.

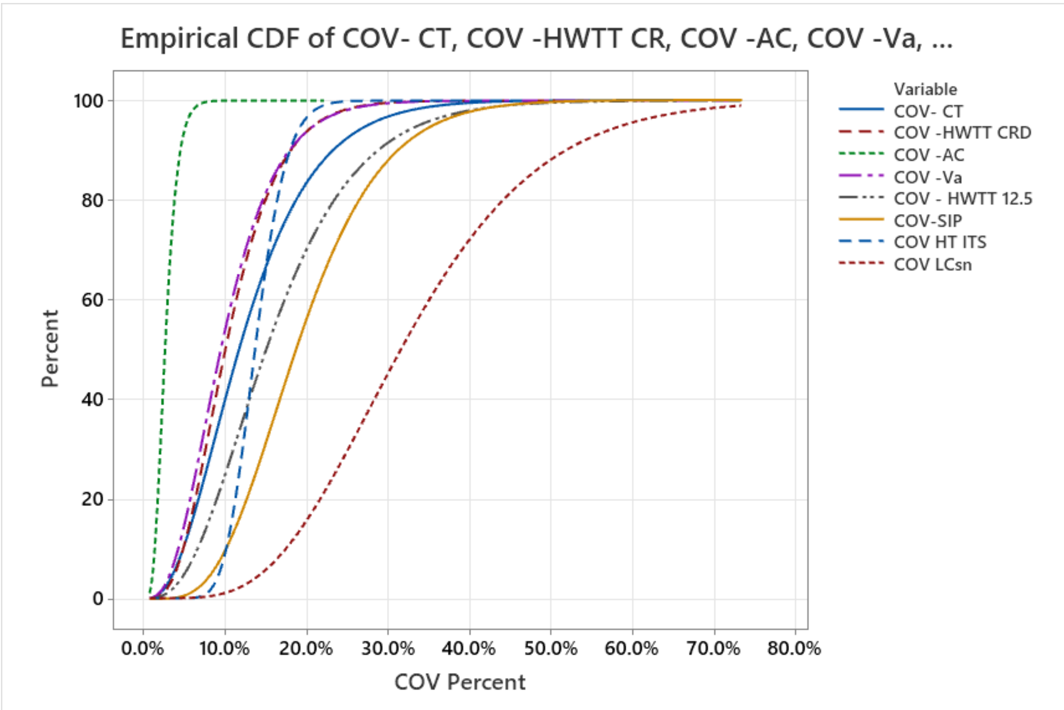


Figure 35. CDFs of COV for CT_{Index}, HWTT CRD_{20k}, HWTT $N_{12.5}$, HWTT *SIP*, HWTT LC_{SN}, Asphalt Content, Air Voids, and HT-IDT Strength

3.3.1.4 Correlation between HT-IDT and HWTT CRD_{20K}

Since the HT-IDT is a much quicker test than the HWTT, several DOTs are considering adopting it for BMD purposes. One crucial question regarding this potential move is about the correlation between the HT-IDT strength results and the rutting susceptibility determined from HWTT testing. Therefore, the correlation between the HT-IDT strength and the HWTT CRD_{20K} is shown in Figure 36. The goodness-of-fit statistic, R^2 for this correlation is moderate indicating that only about 45% of the range in CRD_{20k} parameter can be attributed to the HT-IDT strength. An article in NCAT's Spring 2023 newsletter reported a much stronger correlation between HT-IDT strength and HWTT Total Rut Depth at 20,000 passes (Chen et al., 2023). Ultimately, whether the CRD_{20k} or HT-ITS are good indicators of rutting resistance should be judged based on lab-to-field correlations.

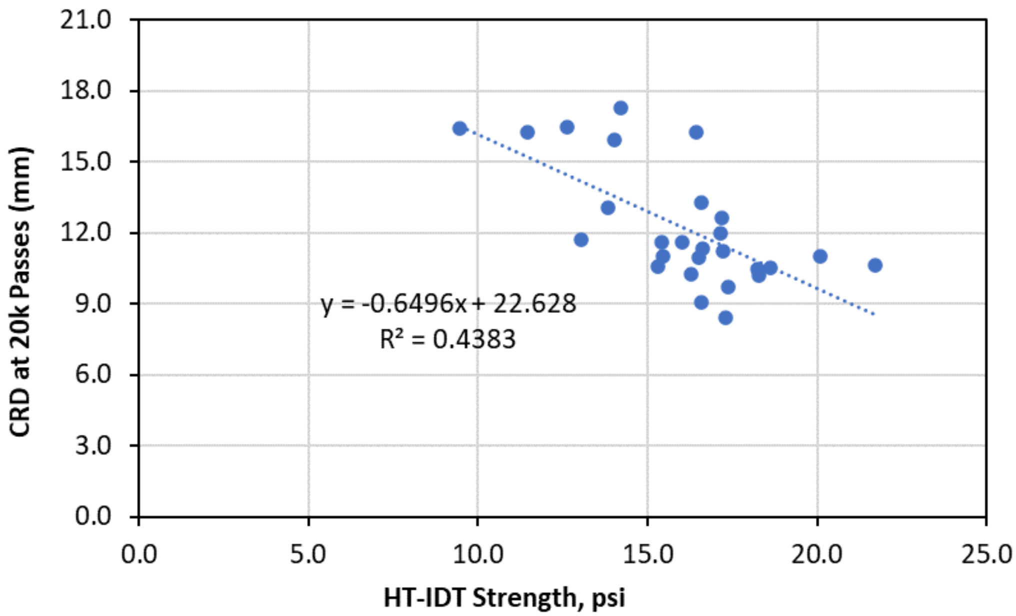


Figure 36. Correlation between HT-IDT Strength and HWTT CRD 20K

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The objectives of this study were (1) to assist WisDOT with the design and construction of BMD test sections to validate the preliminary BMD criteria, and (2) to statistically analyze the overall variabilities of the selected BMD test results from ten shadow projects in Wisconsin.

To accomplish the first objective, the research team assisted WisDOT in the experimental design and preliminary testing of six test sections on STH 69 south of Verona, WI. The research team provided guidelines for locating a suitable highway project, the number of test sections, test section lengths, roadway geometrics to avoid, desired cross-sections, testing of the underlying layers, and the mix criteria for the experimental test sections.

The BMD validation test sections were constructed as part of State Project Number 1693-05-72 on STH 69 in Dane County, south of Verona, WI. When WisDOT project personnel noted that different granular base materials were being used in the area where the test sections were planned, FWD testing was conducted and analyzed which confirmed that the base layers had different stiffnesses. The locations and layout of the test sections was subsequently adjusted. Paving of the common lower layer of asphalt occurred in mid-September 2022 and the six experimental test sections were paved on October 5 and October 20, 2022. All six test sections were constructed in the northbound lane of STH 69 between GPS coordinates 42.928800°, -89.530663° and 42.946995°, -89.544267°.

The contractor designed five of the six mixtures according to the specified CT_{Index} and HWTT rut depth targets, missing the CT_{Index} criterion for the mix in Section 5. The mixtures were produced very close the JMF asphalt contents and gradations, except for the mix in Section 3 which had an asphalt content 0.4% above the JMF target.

Mixture samples from the test sections were split and tested by the contractor, the WisDOT central lab and NCAT in accordance with the IDEAL-CT and HWTT procedures described in this report. The CT_{Index} and HWTT CRD_{20k} results from the three labs were dissimilar which suggests that better sample handling procedures and training are needed to reduce testing differences between labs. NAPA recently published IS 145 *Guide on Asphalt Mixture Specimen Fabrication for BMD Performance Testing* and accompanying videos to help address this issue (NAPA 2023).

Despite the large lab-to-lab differences in CT_{Index} and CRD_{20k}, there are generally consistent rankings among test sections and the ranges in rutting and cracking resistance, as indicated by the BMD tests, may yield sufficient differences in field performance to provide a suitable lab-to-field correlation.

In order to assess the uniformity of the pavement structures within and between the six test sections, GPR and FWD tests were conducted by WisDOT and analyzed by the research team to estimate pavement layer moduli. The estimated moduli from the backcalculation analyses were unreasonably low for Section 2 and highly variable for Sections 5 and 6. These questionable results could possibly be attributed to numerous factors such as incorrect assumptions of the pavement temperature, errors in estimated thickness from GPR data, errors with the FWD sensors, changes in bonding conditions between the asphalt layers, and other issues. For this reason, another round of GPR and FWD testing should be conducted as soon as the damaged temperature dataloggers are replaced.

The Wisconsin DOT should monitor the condition of each of the six BMD test sections using their Automated Road and Pavement Condition Survey vehicles at least four times each year. Although the Pavement Condition Index (PCI) method is suitable for a general assessment of pavement conditions, it is critical to record rut depths and cracking extent and severity for each test section, excluding the first and last 25 feet of the sections as transition zones. WisDOT pavement and maintenance engineers should also regularly drive the project to visually assess if pavement conditions are changing, at which time more frequent data collection with the automated pavement condition surveys should be scheduled. WisDOT maintenance should be instructed to do nothing to the test sections until directed by the Statewide Asphalt Pavement Engineer.

To accomplish the second objective, the research team provided guidance on the selection of 10 shadow projects and instructions for contractors to sample mixtures during production. From those shadow projects scattered across Wisconsin, 134 mixture samples were obtained and sent to NCAT for BMD testing which included IDEAL-CT, HWTT, and HT-IDT. The contractors reported the asphalt contents and air voids for each sublot corresponding to the samples sent to NCAT. Summary statistics of the results included within-lot averages, standard deviations, coefficients of variation, pooled standard deviation, and cumulative distribution frequencies of within-lot standard deviations and COVs for the test parameters. **Error! Reference source not found.** summarizes the key overall production variability statistics for the BMD tests generated from the Wisconsin shadow projects and references for other studies that have reported on the within-lab testing variabilities for these parameters.

Table 20. Summary of Key Statistics for Overall Production Variability

Test	Parameter	Pooled within-lot standard deviation	50th percentile within-lot COV	Within-lab (single operator) COV	Reference for single operator statistics
IDEAL-CT	CT_{Index}	10.9	10.3%	20.5%	Rodezno, et al., 2023
HWTT	CRD_{20k}	1.60 mm	10.0%	9.5%[1]	Rodezno, et al., 2023
	LC_{SN}	1436	31.6%	n.a.	n.a.
	$N_{12.5}$	1837	17.3%	16.6%	Azari, 2014
	SIP	1712	17.9%	23.9%	Azari, 2014
HT-IDT	ITS	2.29 psi	13.5%	8.3%	Rodezno, et al., 2023
T 308	Asphalt Content	0.18%	2.5%	0.069%[2]	AASHTO T 309
T 269	Air Voids	0.34%	10.1%	0.21%[3]	AASHTO T 269

[1] for total rut depth at 20,000 passes; [2] single operator precision standard deviation; [3] single operator precision standard deviation using T 269 Method A. n.a.- no published data is available on the variability of this parameter.

From the key statistics in **Error! Reference source not found.**, the following conclusions are made:

- AC content is the least variable quality characteristic, with a 50th percentile within-lot COV of 2.5%.
- Air voids and CRD_{20k} had similar overall production variabilities with 50th percentile within lot COVs of 10.0% and 10.1%, respectively.
- HT-IDT strength and CT_{Index} had similar overall variabilities, with 50th percentile within-lot COVs of 13.5% and 10.3%, respectively.
- The quality characteristic with the next highest overall production variability was the HWTT $N_{12.5}$, which had a 50th percentile COV of 17.3%.
- The quality characteristic with the highest overall variability was the HWTT Stripping Number, which had a 50th percentile within-lot COV of 31.6%. By comparison, the HWTT *SIP* had a much lower mean COV of 17.9%.

It must be noted that the within-lot variabilities for the BMD tests used in this study were likely lower than they would have been if different labs had conducted the tests. A consistent conclusion from numerous studies has been that BMD tests are sensitive to differences in sample handling and specimen preparation techniques from lab to lab which points to the need for more precise instructions and better training on the new tests.

As a possible indicator of mixture rutting resistance, the HT-IDT test has a significant advantage over the HWTT test in terms of time to complete the tests. The production variability statistics indicate that HT-IDT strength is slightly less variable than HWTT $N_{12.5}$ but slightly more variable than HWTT CRD_{20k}. There was a moderate correlation between HT-IDT strength and HWTT CRD_{20k}. Further research is needed to determine which test and parameter best correlates to rutting in the field.

The most important information to draw from the results of this part of the research is how contractors should set their targets for mix production if these tests are used for acceptance quality characteristics. For a PWL specification with a 100% pay factor based on 90% within limits, the population mean should target at least 1.282 × σ above a lower specification limit, or 1.282 × σ below an upper specification limit, where σ is the within-lot standard deviation for that test parameter. Therefore, based on WisDOT's preliminary BMD criteria and the results from the shadow project testing, contractors should target mix production with the results shown in **Error! Reference source not found.**.

Table 21. WisDOT Preliminary BMD Criteria and Recommended Production Targets

Mix Type	HWTT CRD_{20k} (s=1.6 mm)		HWTT LC_{SN} (s = 1436)		IDEAL-CT CT_{Index} (s = 10.9)	
	Criteria	Target	Criteria	Target	Criteria	Target
LT	≤ 12.0 mm	≤ 9.9 mm	≥ 3,000	≥ 4,441	≥ 30	≥ 44
MT	≤ 7.5 mm	≤ 5.4 mm				
HT	≤ 5.0 mm	≤ 2.9 mm				
SMA	≤ 4.0 mm	n.a.				

n.a. (not available) SMA mixtures were not included in any of the shadow projects, therefore the standard deviations for this mix type are unknown.

4.2 Recommendations for Future Research

Another round of GPR and FWD testing should be conducted on the STH 69 test sections as soon as the damaged dataloggers are replaced following the suggested spacing plan for the FWD tests. There is concern that the different granular base materials used in the area of the test sections could influence pavement response under traffic loads. Analysis of the FWD data results will be needed to evaluate pavement layer moduli uniformity within each test section and to compare section to section. The backcalculated asphalt layer moduli should not be significantly different from section to section based on the mixes in the test sections.

WisDOT should closely monitor the rutting and cracking performance of the test sections with the state's Automated Road and Pavement Condition Survey vehicles to provide consistent measures of pavement condition over time. It is desirable to capture changes in rutting and cracking distresses as they develop, but the rate of damage accumulation is hard to predict. Therefore, it is a good idea for an experienced WisDOT pavement engineer to drive through the project every week or so to visually check for rutting and cracking. Late evenings are a good time to observe rutting when the low angle of the sun can accentuate shadows that make rutting more evident. Cracking can be much more evident after a rain when the pavement is beginning to dry.

The lab-to-lab differences in CT_{Index} and HWTT rutting results for the test section mixtures should be further investigated to determine the possible causes. The investigation should begin with a review of each lab's procedures for mix reheating, splitting, sample preparation and conditioning. Since there are no current standard procedures for these processes, it is likely that there are differences in each lab's methods and techniques. If a common set of instructions can be established, a mini round robin experiment should be conducted to compare results and determine if improvements were made. Once the big differences are resolved, one of the labs should retest the mix samples from the test sections to establish the values that will be used for the future lab to field correlations.

Field performance of the shadow projects should also be monitored as they may also provide useful information about the ability of the BMD test parameters to indicate the resistance of the mixtures to rutting, cracking, and moisture damage. In particular, the shadow projects may help determine if HWTT CRD_{20k} or the HT-IDT is a better indicator of rutting resistance, and if HWTT *SIP* or LC_{SN} is a better indicator of stripping resistance.

A formal technician training program for the IDEAL-CT, HWTT, and possibly HT-IDT should be prepared and conducted. This will be critical as more pilot and shadow projects are conducted. To provide more appropriate production variability data, another set of shadow projects should be planned with contractors performing the selected BMD tests.

REFERENCES

Azari, H (2014). Precision Estimates of AASHTO T 324, Hamburg Wheel-Track Testing of Compacted Hot Mix Asphalt (HMA). Transportation Research Board. Washington, D.C.

Bahia, H., Teymourpour, P., Swiertz, D., Ling, C., Varma, R., Mandal, T., Chaturabong, P., Lyngdal, E. and Hanz, A. (2016). Analysis and feasibility of asphalt pavement performance-based specifications for WisDOT (No. 0092-15-04). Wisconsin. Dept. of Transportation.

Bahia, H., P. Teymourpour, D. Swiertz, C. Ling, R. Varma, T. Mandal, P. Chaturabong, E. Lyngdal, A. Hanz (2016). Analysis and Feasibility of Asphalt Pavement Performance-Based Specifications for WisDOT. WHRP 0092-15-04 Final Report.

Bahia, H., H. Sadek, M. Z. Rahaman, Z. Lemke, D. Swiertz, and S. Reichelt (2018). Field Aging and Oil Modification Study. WHRP Project 0092-17-04.

Battaglia, I., B. Bischoff, J. Ryan, and Signe Reichelt (2010). Evaluation of a Hot Mix Asphalt Perpetual Pavement. Report No. FEP-01-10. WisDOT Research Study # FEP-02-02. Wisconsin Department of Transportation.

Bonaquist, R. (2016). Critical Factors Affecting Asphalt Concrete Durability. WHRP 0092-14-06 Final Report.

Chen, C., A. Taylor, and N. Moore, (2023). Validation of Rapid Rutting Test Procedures Using Plant Mixtures from the 2021 NCAT Test Track, Asphalt Technology News, Spring 2023, Vol. 35, No. 1, Auburn University.

Chowdhury, A., J. Button, and J. Wikander (2004). Variability of Hamburg Wheel Tracking Devices. Report No. FHWA/TX-04/5-4977-01-1.

Crovetti, J., N.J. Hornyak, D. Newman, and J. Schabelski (2007). Perpetual Pavement Instrumentation for the Marquette Interchange Project-Phase 1. WHRP 07-11. Milwaukee, Wisconsin, Marquette University, Department of Civil, Construction, and Environmental Engineering.

Elkins, G. E., and B. Ostrom (2021). Long-Term Pavement Performance Information Management System User Guide. FHWA-HRT-21-038.

Epps, J., Balanced Mix Design (BMD) Implementation Process for Texas, Presented at the Montana Asphalt Conference, Missoula, Montana, March 14, 2023.

EVERSERIES© USER'S GUIDE (2005). Pavement Analysis Computer Software and Case Studies. Washington State Department of Transportation.

Faheem, A., A. Hosseini, H. Titi, and S. Schwandt. (2015). Evaluation of WisDOT Quality Management Program (QMP) Activities and Impacts on Pavement Performance. WHRP Project 0092-15-05.

FHWA (2015). The Long-Term Pavement Performance Program, FHWA-HRT-15-049, Federal Highway Administration.

Hajj, E.Y., T.B. Aschenbrener, D. Nener-Plante (2021) Case Studies in the Implementation of Balanced Mix Design and Performance Tests for Asphalt Mixtures: Virginia Department of Transportation (VDOT), WRSC-TR-21-08, University of Nevada, Reno.

Hughes, C.S. (2005). State Construction Quality Assurance Programs. NCHRP Synthesis 346. Transportation Research Board.

Johanneck, L., J. Geib, D. Van Deusen, J. Garrity, C. Hanson, and E. Dave. (2015) DCT Low Temperature Fracture Testing Pilot Project. Minnesota Department of Transportation Research Services.

Marasteanu, M., W. Buttlar, H. Bahia, C. Williams, K.H. Moon, E.Z. Teshale, A.C. Falchetto, M. Turos, E. Dave, G. Paulino, and S. Ahmed (2012) Investigation of Low Temperature Cracking in Asphalt Pavements, National Pooled Fund Study–Phase II, Minnesota Department of Transportation, MN/RC 2012-23.

Mateos, A., and D. Jones (2017). Support for Superpave Implementation: Round Robin Hamburg Wheel-Track Testing. Research Report: UCPRC-RR-2016-05. University of California Pavement Research Center, UC Davis.

Metcalf, J.B. (1996). NCHRP Synthesis of Highway Practice 235: Application of Full-Scale Accelerated Pavement Testing, Transportation Research Board of the National Academies, D. C, Washington D.C., 120pp.

Mitchell, Terry. Test Roads: Designing the Pavements of the Future; Public Rods, Vol. 60, No.2, Fall 1996.

Mohammed, L. N., M. A. Elseifi, S. B. Cooper III, C. S. Hughes, J. W. Button, and E. L. Dukatz (2016). Comparing the Volumetric and Mechanical Properties of Laboratory and Field Specimens of Asphalt Concrete. Rep. No. 818. Washington, DC: National Cooperative Highway Research Program.

Mohammad, L., M. Elseifi, A. Raghavendra, and M. Ye. (2015). NCHRP Web-Only Document 219: Hamburg Wheel-Track Test Equipment Requirements and Improvements to AASHTO T 324. Transportation Research Board, Washington, D.C.

Moore, N., R. Steger, B. Bowers, A. Taylor (2021). Investigation of IDEAL-CT Device Equivalence: Are All Devices Equal? Transportation Research Record 2676(5), 1-12.

Moore, N., and A. Taylor (2023). *Guide on Asphalt Mixture Specimen Fabrication for BMD Performance Testing*, IS 145, National Asphalt Pavement Association.

NAPA. *BMD Resource Guide – Implementation Efforts*. Accessed August 18, 2023. National Asphalt Paving Association.
https://www.asphaltpavement.org/expertise/engineering/resources/bmd-resource-

guide/implementation-efforts.

Powell, B., A. Murphree, and J. Barfield (2021). Implementation Spotlight: Balanced Mix Design for Alabama Counties. Asphalt Technology News, Spring 2021, Vol. 33, No. 1, Auburn University.

Rodezno, C. A. Taylor, and N. Moore. (2023). NCAT Completes Second Mixture Performance Test Round Robin. Asphalt Technology News, Spring 2023, Vol. 35, No. 1, Auburn University.

Taylor, A., J. Moore, and N. Moore (2022). NCAT Performance Testing Round Robin. NCAT Report 22-01. National Center for Asphalt Technology, Auburn, AL.

Van Frank, K., P. Romero (2020). Balanced Asphalt Concrete Mix Performance in Utah, Phase IV: Cracking Indices for Asphalt Mixtures. Report N. UT-20.13. Utah Department of Transportation Research & Innovation Division.

Vrtis, M., C. Rodezno, R. West, J. Podolsky, J. Calvert and D. Van Deusen (2023). MnROAD Cracking Group Experiment: Validation of Low-Temperature Cracking Tests for Balanced Mix Design. NCAT Report 23-03, National Center for Asphalt Technology, Auburn, AL.

West, R., F. Yin, J. Musselman (2023) Guide for Implementing Balanced Mix Design Specifications, NCHRP Project 10-107, National Center for Asphalt Technology, Auburn, AL.

West, R., N. Tran, F. Yin, C. Rodezno, T. Harman (2023), Guidelines and Recommendations for Field Validation of Test Criteria for Balanced Mixture Design (BMD) Implementation, Report No. CAPRI-23.001-R, Consortium for Asphalt Pavement Research and Implementation.

West, R., D. Timm, B. Powell, N. Tran, F. Yin, B. Bowers, C. Rodezno, F. Leiva, A. Vargas, F. Gu, R. Moraes, M. Nakhaei (2021). Phase VII (2018-2021) NCAT Test Track Findings. NCAT Report 21-03, National Center for Asphalt Technology, Auburn, AL.

West, R., C. Rodezno, F. Leiva, and A. Taylor (2018). Regressing Air Voids for Balanced HMA Mix Design. Report No. WHRP 0092-16-06.

WisDOT. Special Provision Article 33. HMA Pavement Balanced Mix Design, 2021.

Yin, F., E. Arámbula, R. Lytton, A. E. Martin, and L. G. Cucalon (2014). Novel Method for Moisture Susceptibility and Rutting Evaluation Using Hamburg Wheel Tracking Test. Transportation Research Record: Journal of the Transportation Research Board, No. 2446(1), Transportation Research Board of the National Academies, pp.1-7.

Yin, F., Chen, C., West, R., Martin, A. E., & Arambula-Mercado, E. (2020). Determining the relationship among Hamburg wheel-tracking test parameters and correlation to field performance of asphalt pavements. Transportation Research Record, 2674(4), 281-291.

Yin, F., and R. West (2021) Balanced Mix Design Resource Guide, National Asphalt Pavement Association, IS-143.

Zhou, F. (2019). Development of an IDEAL Cracking Test for Asphalt Mix Design, Quality Control, and Quality Assurance. NCHRP IDEA Project 195, Transportation Research Board.

APPENDICES

APPENDIX A – MIX DESIGNS OF TEST SECTIONS

Mix 1 and 5

Reviewed By: Jeffery. R. Anderson

C-5 4MT 506822 NOT VERIFIED.xlsx

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

WisDOT Project #:	1693-05-72/73		Design Lab or Company:		WisDOT Mix Design ID:	
Mix Design ID:	506822		*Mix Designer:		WisDOT Design Verification Date:	
Mix Type:	MT		Designer HTCP Cert ID#:			
NMAS:	4 - 12.5 mm		Producer:			
Virgin Binder PG:	58-28	Primary AC Source/ Type	Plant #/location:		Design Amended Date:	
Binder Designation:	S		Design Date:	7/23/2022	Last JMF Change Date:	
Virgin Binder Gb:	1.017		*Note: Typed not Signature Block		Instructions: Cells that are light blue are data field for user to enter data all other cells are locked.	
Virgin Binder Source:	Flint Hills Debuque					

AGGREGATE COMPONENT GRADATION DATA

		Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Blend %s (0.1)		20.0	8.0	8.0	55.5	0.5				8.0				100.0
Material Description		5/8" Chip	3/8" Chip	MFG'd Sand	Natural Sand	DEG				RAP				
Source ID/Name (needs to match 225 report)		Oregon	Oregon	Oregon	Oregon	40005				40005				
P or Q or MF or Dust (RAM plant ID)		P	P	P	P	DEG				RAM 1 (RAP)			Gse:	2.706
WisDOT Agg Test ID (225-xxxx-xxxx)		225-0059-2022	225-0059-2022	225-0059-2022									SE:	94
RAM Extracted % Binder										4.9			(T112)	0.1
													PI (T89/90)	
Sieve	(mm)												(mm)	
1 1/2"	37.5	100.0	100.0	100.0	100.0	100.0				100.0			37.5	100.0
1"	25.0	100.0	100.0	100.0	100.0	100.0				100.0			25.0	100.0
3/4"	19.0	100.0	100.0	100.0	100.0	100.0				100.0			19.0	100.0
1/2"	12.5	77.0	100.0	100.0	100.0	100.0				100.0			12.5	95.4
3/8"	9.5	27.0	97.0	100.0	100.0	100.0				97.0			9.5	84.9
#4	4.75	2.0	17.0	95.0	92.0	100.0				81.0			4.75	67.4
#8	2.36	1.0	4.0	63.0	72.0	100.0				65.0			2.36	51.2
#16	1.18	1.0	3.0	40.0	56.0	100.0				51.0			1.18	39.3
#30	0.60	1.0	2.0	27.0	42.0	100.0				40.0			0.60	29.5
#50	0.30	1.0	2.0	15.0	16.0	100.0				27.0			0.30	13.1
#100	0.15	1.0	2.0	5.0	4.0	100.0				18.0			0.15	4.9
#200	0.075	0.5	1.5	2.6	1.9	100.0				13.5			0.075	3.1
Gsb:		2.600	2.580	2.640	2.640	2.640				2.611			Gsb:	2.625
CAA 1F (%):		98	99										CAA 1F (%):	98.3
CAA 2F (%):		97	97										CAA 2F (%):	97.0
FAA:				46	40					40			FAA:	41
Moisture Abs. (%):		2	2.4	1.2	0.9					1			Abs. (%):	1.3
Thin/Elong. (%):		0.5	0.5										T/E. (%):	0.1

JMF PROPERTIES AT OPTIMUM % BINDER FOR 4.0% AIR VOIDS HMA OR 4.5% AIR VOIDS FOR SMA

Laboratory	HMA/SMA	Warm Mix	SMA Draindown (%)		* Temp. of Plant		For calc. with Opt. AC% at either 4.0% Av HMA or 4.5% Av SMA
Rec. Mix Temp(F):	280-320		*Temp.°C		Pbr:	6.0	
Compact Temp(F):	255-295		1		Pbe:	5.4	min. 5.5% (SMA)
			2		Pba:	1.2	
*Type Additive:		(WMA, Anti-Strip,	Avg.		Dust/Binder (DP):	0.6	0.6-1.2/1.2-2.0
*Amt. Additive:		Cellulose Fibers)	plus 15°C	15			
* Additive used in initial bid			1		Gmm Dryback Corr.:		
Additional additives may be added in the comments section or "Alternate AC Sources"			2				
			Avg.				

Alternate AC Sources (* additive for alternate Binder can be done using JMF form)

Alternate AC Source	AC Type	Gb	TSR **	# of Gry.(N)	Additive*	Amt. Additive
CRM MKE/GRB/Gladstone	58-28 S/H/V/E					
CRM MKE/GRB/Gladstone	58-34 S/H/V/E					

** TSR Values are required when a change in source is from a modified AC to a unmodified AC or per CMM 866.2.3.2

TRIAL AC DATA

	Total %	Added % Binder	Gmm	Gmb	% Air Voids	% VMA	%VFB/VFA
Trial 1	6.5	6.1	2.442	2.386	2.3	15	84.7
Trial 2							
Trial 3							
Trial 4							
OPT. @ 4.0% Va	6.5	6.1	2.442	2.386	2.3	15.0	84.7

COMPACTION EFFORT/LEVELS -Primary Binder (TSR & Performance Test Results)

			Nini		Nmax	
	# of Gyrations (N)		7	---	115	
TSR T283 (psi)	%Gmm at Optimum		89.1	---	95.3	# of Gry.(N)
Wet Strength:	73.7	Dry Strength:	78.2	TSR:	0.94	13
Hamburg (T324):	Finial Rut Depth (mm):		10.37		Number of Passes:	20000
Cracking Tolerance Index (D8225):	CI:		69			
Comments:	Recommended and compaction temperatures are for lab purposes only; field production temperatures will vary; Evotherm or rediset added in at 0.3-0.5% of total AC as a cold					

Mix 2

Reviewed By: Jeffery. R. Anderson

C-5 4MT 506922 NOT VERIFIED.xlsx

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

WisDOT Project #:	1693-05-72	Design Lab or Company:		WisDOT Mix Design ID:	250-0264-2022
Mix Design ID:	506922	*Mix Designer:		WisDOT Design Verification Date:	10/16/2022
Mix Type:	MT	Designer HTCP Cert ID#:			
NMAS:	4 - 12.5 mm	Producer:			
Virgin Binder PG:	58-28	Plant #/location:		Design Amended Date:	
Binder Designation:	S	Design Date:	10/13/2022	Last JMF Change Date:	
Virgin Binder Gb:	1.035		*Note: Typed not Signature Block		
Virgin Binder Source:	Flint Hills Dubuque				

Primary AC Source/ Type

Instructions: Cells that are light blue are data field for user to enter data all other cells are locked.

AGGREGATE COMPONENT GRADATION DATA

		Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Blend %s (0.1)		16.0	16.0	36.0	16.5	0.5				15.0				100.0
Material Description		5/8" Chip	3/8" Chip	MFG'd Sand	Natural Sand	DEG				RAP				
Source ID/Name (needs to match 225 report)		Oregon	Oregon	Oregon	Oregon	40005				40005				
P or Q or MF or Dust (RAM plant ID)		P	P	P	P	DEG				RAM 1 (RAP)			Gse:	2.699
WisDOT Agg Test ID		225-0059-2022	225-0059-2022										SE:	94
RAM Extracted % Binder										4.9			(T112)	0.1
													PI (T89/90)	
Sieve	(mm)												(mm)	
1 1/2"	37.5	100.0	100.0	100.0	100.0	100.0				100.0			37.5	100.0
1"	25.0	100.0	100.0	100.0	100.0	100.0				100.0			25.0	100.0
3/4"	19.0	100.0	100.0	100.0	100.0	100.0				100.0			19.0	100.0
1/2"	12.5	77.0	100.0	100.0	100.0	100.0				100.0			12.5	96.3
3/8"	9.5	27.0	97.0	100.0	100.0	100.0				97.0			9.5	87.4
#4	4.75	2.0	17.0	95.0	92.0	100.0				81.0			4.75	65.1
#8	2.36	1.0	4.0	63.0	72.0	100.0				65.0			2.36	45.6
#16	1.18	1.0	3.0	40.0	56.0	100.0				51.0			1.18	32.4
#30	0.60	1.0	2.0	27.0	42.0	100.0				40.0			0.60	23.6
#50	0.30	1.0	2.0	15.0	16.0	100.0				27.0			0.30	13.1
#100	0.15	1.0	2.0	5.0	4.0	100.0				18.0			0.15	6.1
#200	0.075	0.5	1.5	2.6	1.9	100.0				13.5			0.075	4.1
Gsb:		2.600	2.580	2.640	2.640	2.640				2.611			Gsb:	2.619
CAA 1F (%):		98	99										CAA 1F (%):	98.5
CAA 2F (%):		97	97										CAA 2F (%):	97.0
FAA:				46	40					40			FAA:	43
Moisture Abs. (%):		2	2.4	1.2	0.9					1			Abs. (%):	1.4
Thin/Elong. (%):		0.5	0.5										T/E. (%):	0.1

JMF PROPERTIES AT OPTIMUM % BINDER FOR 4.0% AIR VOIDS HMA OR 4.5% AIR VOIDS FOR SMA

Laboratory	HMA/SMA	Warm Mix
Rec. Mix Temp(F):	280-320	
Compact Temp(F):	255-295	

*Type Additive:	Forta Fibers	(WMA, Anti-Strip,
*Amt. Additive:	0.10%	Cellulose Fibers)

* Additive used in initial bid

Additional additives may be added in the comments section or "Alternate AC Sources"

SMA Draindown (%)	* Temp. of Plant
*Temp.°C	
1	
2	
Avg.	
plus 15°C	15
1	
2	
Avg.	

Pbr:	12.3	Pbr calc. with Opt. AC% at either 4.0% Av HMA or 4.5% Av SMA
Pbe:	4.9	min. 5.5% (SMA)
Pba:	1.2	
Dust/Binder (DP):	0.8	0.6-1.2/1.2-2.0
Gmm Dryback Corr.:		

Alternate AC Sources (* additive for alternate Binder can be done using JMF form)

Alternate AC Source	AC Type	Gb	TSR **	# of Gry.(N)	Additive*	Amt. Additive
CRM MKE/GRB/Gladstone	58-28 S/H/V/E					
CRM MKE/GRB/Gladstone	58-34 S/H/V/E					

** TSR Values are required when a change in source is from a modified AC to a unmodified AC or per CMM 866.2.3.2

TRIAL AC DATA

	Total %	Added % Binder	Gmm	Gmb	% Air Voids	% VMA	%VFB/VFA
Trial 1	6.0	5.3	2.461	2.358	4.2	15.4	72.7
Trial 2							
Trial 3							
Trial 4							
OPT. @ 4.0% Va	6.0	5.3	2.461	2.358	4.2	15.4	72.7
OPT. @ 3.0% Va		-0.70				100.0	97.0

COMPACTION EFFORT/LEVELS -Primary Binder (TSR & Performance Test Results)

		Nini		Nmax	
	# of Gyrations (N)	7	---	115	
TSR T283 (psi)	%Gmm at Optimum	87.8	---	96.8	# of Gry.(N)
Wet Strength:	94.9	Dry Strength: 105.8	TSR:	0.90	32
Hamburg (T324):	Finial Rut Depth (mm):	3.4		Number of Passes:	20000
Cracking Tolerance Index (D8225):	CI:	99			

Comments: Recommended and compaction temperatures are for lab purposes only; field production temperatures will vary; Evotherm or rediset added in at 0.3-0.5% of total AC as a cold

Mix 3 and 6

Reviewed By: Jeffery. R. Anderson

C-5 4MT 506722 NOT VERIFIED.xlsx

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

WisDOT Project #:	1693-05/72/73	Design Lab or Company:		WisDOT Mix Design ID:	
Mix Design ID:	506722	*Mix Designer:		WisDOT Design Verification Date:	
Mix Type:	MT	Designer HTCP Cert ID#:			
NMAS:	4 - 12.5 mm	Producer:			
Virgin Binder PG:	58-28	Plant #/location:		Design Amended Date:	
Binder Designation:	S	Design Date:	7/27/2022	Last JMF Change Date:	
Virgin Binder Gb:	1.017	*Note: Typed not Signature Block			
Virgin Binder Source:	Flint Hill Debuque				

Primary AC Source/ Type

Instructions: Cells that are light blue are data field for user to enter data all other cells are locked.

AGGREGATE COMPONENT GRADATION DATA

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)	JMF BLEND
Blend %s (0.1)	21.0	14.0	10.0	29.0	25.5	0.5						100.0
Material Description	5/8" Chip	3/8" Chip	1/4" Screenings	MFG'd Sand	Natural Sand	DEG						
Source ID/Name (needs to match 225 report)	Oregon	Oregon	Waterloo (Michels)	Oregon	Manchester (Michels)	40005						
P or Q or MF or Dust (RAM plant ID)	P	P	Q	P	P	DEG						Gse: 2.695
WisDOT Agg Test ID	225-0059-2022	225-0059-2022										SE: 93
RAM Extracted % Binder												(T112) 0.1
												PI (T89/90)

Sieve	(mm)	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1	RAM 2	RAM 3	(mm)	JMF BLEND
1 1/2"	37.5	100.0	100.0	100.0	100.0	100.0	100.0						37.5	100.0
1"	25.0	100.0	100.0	100.0	100.0	100.0	100.0						25.0	100.0
3/4"	19.0	100.0	100.0	100.0	100.0	100.0	100.0						19.0	100.0
1/2"	12.5	77.0	100.0	100.0	100.0	100.0	100.0						12.5	95.2
3/8"	9.5	27.0	97.0	100.0	100.0	100.0	100.0						9.5	84.3
#4	4.75	2.0	17.0	100.0	95.0	100.0	100.0						4.75	66.4
#8	2.36	1.0	4.0	83.7	63.0	100.0	100.0						2.36	53.4
#16	1.18	1.0	3.0	63.6	40.0	99.0	100.0						1.18	44.3
#30	0.60	1.0	2.0	47.5	27.0	98.0	100.0						0.60	38.6
#50	0.30	1.0	2.0	31.9	15.0	74.0	100.0						0.30	27.4
#100	0.15	1.0	2.0	18.0	5.0	10.0	100.0						0.15	6.8
#200	0.075	0.5	1.5	10.4	2.6	1.4	100.0						0.075	3.0

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1	RAM 2	RAM 3		JMF BLEND
Gsb:	2.600	2.580	2.676	2.640	2.648	2.648						Gsb:	2.629
CAA 1F (%):	98	99										CAA 1F (%):	98.4
CAA 2F (%):	97	97										CAA 2F (%):	97.0
FAA:			49	46	40							FAA:	44
Moisture Abs. (%):	2	2.4		1.2	0.4							Abs. (%):	1.2
Thin/Elong. (%):	0.5	0.5										T/E. (%):	0.2

JMF PROPERTIES AT OPTIMUM % BINDER FOR 4.0% AIR VOIDS HMA OR 4.5% AIR VOIDS FOR SMA

Laboratory	HMA/SMA	Warm Mix
Rec. Mix Temp(F):	280-320	
Compact Temp(F):	255-295	
*Type Additive:		(WMA, Anti-Strip,
*Amt. Additive:		Cellulose Fibers)

* Additive used in initial bid

Additional additives may be added in the comments section or "Alternate AC Sources"

SMA Draindown (%) * Temp. of Plant

*Temp.°C	
1	
2	
Avg.	
plus 15°C	15
1	
2	
Avg.	

Pbr:		For calc. with Opt. AC% at either 4.0% Av HMA or 4.5% Av SMA
Pbe:	4.8	min. 5.5% (SMA)
Pba:	1.0	
Dust/Binder (DP):	0.6	0.6-1.2/1.2-2.0
Gmm Dryback Corr.:		

Alternate AC Sources (* additive for alternate Binder can be done using JMF form)

Alternate AC Source	AC Type	Gb	TSR **	# of Gry.(N)	Additive*	Amt. Additive
CRM MKE/GRB/Gladstone	58-28 S/H/V/E					
CRM MKE/GRB/Gladstone	58-34 S/H/V/E					

** TSR Values are required when a change in source is from a modified AC to a unmodified AC or per CMM 866.2.3.2

TRIAL AC DATA

	Total %	Added % Binder	Gmm	Gmb	% Air Voids	% VMA	%VFB/VFA
Trial 1	5.2	5.2	2.482	2.340	5.7	15.6	63.5
Trial 2	5.7	5.7	2.463	2.364	4.0	15.2	73.7
Trial 3	6.2	6.2	2.444	2.385	2.4	15.2	83.9
Trial 4							
OPT. @ 4.0% Va	5.7	5.7	2.463	2.365	4.0	15.2	73.7
OPT. @ 3.0% Va	6.0	6.03	2.451	2.378	3.0	15.0	80.0

COMPACTION EFFORT/LEVELS -Primary Binder (TSR & Performance Test Results)

		Nini		Nmax	
	# of Gyrations (N)	7	---	115	
TSR T283 (psi)	%Gmm at Optimum	91.3	---	96.4	# of Gry.(N)
Wet Strength:	70.3	Dry Strength: 84.9	TSR:	0.83	9
Hamburg (T324):	Finial Rut Depth (mm):	8.14	Number of Passes:		20000
Cracking Tolerance Index (D8225):	CI:	29			

Comments: Recommended and compaction temperatures are for lab purposes only; field production temperatures will vary; Evotherm or rediset added in at 0.3-0.5% of total AC as a cold

Mix 4

Reviewed By: Jeffery. R. Anderson

C-5 4MT 507022 NOT VERIFIED.xlsx

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

WisDOT Project #:	1693-05-72/73	Design Lab or Company:	
Mix Design ID:	507022	*Mix Designer:	
Mix Type:	MT	Designer HTCP Cert ID#:	
NMAS:	4 - 12.5 mm	Producer:	
Virgin Binder PG:	58-28	Plant #/location:	
Binder Designation:	S	Design Date:	7/23/2022
Virgin Binder Gb:	1.017		*Note: Typed not Signature Block
Virgin Binder Source:	Flint Hills Dubuque		

Primary AC Source/ Type

WisDOT Mix Design ID:	
WisDOT Design Verification Date:	
Design Amended Date:	
Last JMF Change Date:	

Instructions: Cells that are light blue are data field for user to enter data all other cells are locked.

AGGREGATE COMPONENT GRADATION DATA

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Blend %s (0.1)	14.0	13.0	35.0	10.5	0.5				27.0				100.0
Material Description	5/8" Chip	3/8" Chip	MFG'd Sand	Natural Sand	DEG				RAP				
Source ID/Name (needs to match 225 report)	Oregon	Oregon	Oregon	Oregon	40005				40005				
P or Q or MF or Dust (RAM plant ID)	P	P	P	P	DEG				RAM 1 (RAP)			Gse:	2.706
WisDOT Agg Test ID (225-xxxx-xxxx)	225-0059-2022	225-0059-2022	225-0059-2022									SE:	94
RAM Extracted % Binder									4.9			(T112)	0.1
												PI (T89/90)	

Sieve	(mm)	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)	(mm)	JMF BLEND
1 1/2"	37.5	100.0	100.0	100.0	100.0	100.0				100.0			37.5	100.0
1"	25.0	100.0	100.0	100.0	100.0	100.0				100.0			25.0	100.0
3/4"	19.0	100.0	100.0	100.0	100.0	100.0				100.0			19.0	100.0
1/2"	12.5	77.0	100.0	100.0	100.0	100.0				100.0			12.5	96.8
3/8"	9.5	27.0	97.0	100.0	100.0	100.0				97.0			9.5	88.6
#4	4.75	2.0	17.0	95.0	92.0	100.0				81.0			4.75	67.8
#8	2.36	1.0	4.0	63.0	72.0	100.0				65.0			2.36	48.3
#16	1.18	1.0	3.0	40.0	56.0	100.0				51.0			1.18	34.7
#30	0.60	1.0	2.0	27.0	42.0	100.0				40.0			0.60	25.6
#50	0.30	1.0	2.0	15.0	16.0	100.0				27.0			0.30	15.1
#100	0.15	1.0	2.0	5.0	4.0	100.0				18.0			0.15	7.9
#200	0.075	0.5	1.5	2.6	1.9	100.0				13.5			0.075	5.5

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Gsb:	2.600	2.580	2.640	2.640	2.640				2.611			Gsb:	2.619
CAA 1F (%):	98	99										CAA 1F (%):	98.4
CAA 2F (%):	97	97										CAA 2F (%):	97.0
FAA:			46	40					40			FAA:	43
Moisture Abs. (%):	2	2.4	1.2	0.9					1			Abs. (%):	1.4
Thin/Elong. (%):	0.5	0.5										T/E. (%):	0.1

JMF PROPERTIES AT OPTIMUM % BINDER FOR 4.0% AIR VOIDS HMA OR 4.5% AIR VOIDS FOR SMA

Laboratory	HMA/SMA	Warm Mix
Rec. Mix Temp(F):	280-320	
Compact Temp(F):	255-295	

*Type Additive: (WMA, Anti-Strip,
*Amt. Additive: Cellulose Fibers)

* Additive used in initial bid

Additional additives may be added in the comments section or "Alternate AC Sources"

SMA Draindown (%)	* Temp. of Plant
*Temp.°C	
1	
2	
Avg.	
plus 15°C	15
1	
2	
Avg.	

Pbr calc. with Opt. AC% at either 4.0% Av HMA or 4.5% Av SMA

Pbr:	25.0	
Pbe:	4.1	min. 5.5% (SMA)
Pba:	1.3	
Dust/Binder (DP):	1.3	0.6-1.2/1.2-2.0
Gmm Dryback Corr.:		

Alternate AC Sources (* additive for alternate Binder can be done using JMF form)

Alternate AC Source	AC Type	Gb	TSR **	# of Gry.(N)	Additive*	Amt. Additive
CRM MKE/GRB/Gladstone	58-28 S/H/V/E					
CRM MKE/GRB/Gladstone	58-34 S/H/V/E					

** TSR Values are required when a change in source is from a modified AC to a unmodified AC or per CMM 866.2.3.2

TRIAL AC DATA

	Total %	Added % Binder	Gmm	Gmb	% Air Voids	% VMA	%VFB/VFA
Trial 1	5.3	4.0	2.484	2.404	3.2	13.1	75.6
Trial 2							
Trial 3							
Trial 4							
OPT. @ 4.0% Va	5.3	4.0	2.484	2.404	3.2	13.1	75.6

COMPACTION EFFORT/LEVELS -Primary Binder (TSR & Performance Test Results)

		Nini		Nmax	
	# of Gyrations (N)	7	---	115	
TSR T283 (psi)	%Gmm at Optimum	89.6	---	97.4	# of Gry.(N)
Wet Strength:	111.6	Dry Strength: 130.1	TSR:	0.86	19
Hamburg (T324):	Finial Rut Depth (mm):	2.79		Number of Passes:	20000
Cracking Tolerance Index (D8225):	CI:	21			

Comments: Recommended and compaction temperatures are for lab purposes only; field production temperatures will vary; Evotherm or rediset added in at 0.3-0.5% of total AC as a cold

APPENDIX B - SHADOW PROJECT MIX DESIGNS

Project 1

Reviewed By: Jeffery. R. Anderson

Copy of (Project 1)4MT 801621_Not Verified

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

WisDOT Project #:	2709-05-70	Design Lab or Company:		WisDOT Mix Design ID:	
Mix Design ID:	801621	*Mix Designer:		WisDOT Design Verification Date:	
Mix Type:	MT	Designer HTCP Cert ID#:			
NMAS:	4 - 12.5 mm	Producer:			
Virgin Binder PG:	58-28	Plant #/location:		Design Amended Date:	
Binder Designation:	S	Design Date:	1/26/2021	Last JMF Change Date:	
Virgin Binder Gb:	1.030		*Note: Typed not Signature Block		
Virgin Binder Source:	CRM Green Bay				

Primary AC Source/ Type

Instructions: Cells that are light blue are data field for user to enter data all other cells are locked.

AGGREGATE COMPONENT GRADATION DATA

		Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Blend %s (0.1)		12.0	8.0	8.0	24.0	35.0	1.0			12.0				100.0
Material Description		13.64 5/8" Chip	9.09 3/8" Chip	9.09 1/4" Chip	27.27 MFG'd Sand	39.77 Natural Sand	1.14 DEG			RAP				100.0
Source ID/Name (needs to match 225 report)		Jackson	Jackson	Jackson	Jackson	Wissota	DEG			40015				
P or Q or MF or Dust (RAM plant ID)		Q	Q	Q	Q	P	Dust			40015			Gse:	2.756
WisDOT Agg Test ID (xxx-xxxx-xxxx)		225-0088-2019	225-0088-2019	225-0088-2019									SE:	94
RAM Extracted % Binder										4.8			(T112)	0.01
													PI (T89/90)	
Sieve	(mm)												(mm)	
1 1/2"	37.5	100.0	100.0	100.0	100.0	100.0	100.0			100.0			37.5	100.0
1"	25.0	100.0	100.0	100.0	100.0	100.0	100.0			100.0			25.0	100.0
3/4"	19.0	100.0	100.0	100.0	100.0	100.0	100.0			100.0			19.0	100.0
1/2"	12.5	75.6	100.0	100.0	100.0	100.0	100.0			100.0			12.5	97.1
3/8"	9.5	26.5	96.0	100.0	100.0	100.0	100.0			96.0			9.5	90.4
#4	4.75	4.3	7.8	61.2	100.0	99.0	100.0			75.0			4.75	74.7
#8	2.36	3.2	4.4	10.9	75.9	83.4	100.0			58.0			2.36	57.0
#16	1.18	2.8	3.4	4.2	45.9	68.6	100.0			44.0			1.18	42.3
#30	0.60	2.5	3.0	2.7	26.0	52.1	100.0			34.0			0.60	30.3
#50	0.30	2.3	2.9	2.4	13.9	25.2	100.0			24.0			0.30	16.7
#100	0.15	2.0	2.6	2.0	5.6	6.5	100.0			15.0			0.15	7.0
#200	0.075	1.6	2.1	1.6	3.2	2.9	100.0			10.9			0.075	4.6
Gsb:		2.661	2.671	2.710	2.731	2.687	2.687			2.700			Gsb:	2.696
CAA 1F (%):		100	100	100									CAA 1F (%):	100.0
CAA 2F (%):		100	100	100									CAA 2F (%):	100.0
FAA:					47.3	40				42			FAA:	43
Moisture Abs. (%):		1.5	1.7	1.3	0.9	0.7				0.8			Abs. (%):	1.0
Thin/Elong. (%):		0.2	0.2							0.1			T/E. (%):	0.0

JMF PROPERTIES AT OPTIMUM % BINDER FOR 4.0% AIR VOIDS HMA OR 4.5% AIR VOIDS FOR SMA

Laboratory	HMA/SMA	Warm Mix	SMA Draindown (%)	* Temp. of Plant		Pbr calc. with Opt. AC% at either 4.0% Av HMA or 4.5% Av SMA
Rec. Mix Temp(F):	280-320		*Temp.°C		Pbr:	10.7	
Compact Temp(F):	255-295		1		Pbe:	4.6	min. 5.5% (SMA)
			2		Pba:	0.8	
*Type Additive:		(WMA, Anti-Strip,	Avg.		Dust/Binder (DP):	1.0	0.6-1.2/1.2-2.0
*Amt. Additive:		Cellulose Fibers)	plus 15°C	15			
			1		Gmm Dryback Corr.:		
			2				
			Avg.				

* Additive used in initial bid

Additional additives may be added in the comments section or "Alternate AC Sources"

Alternate AC Sources (* additive for alternate Binder can be done using JMF form)

Alternate AC Source	AC Type	Gb	TSR **	# of Gry.(N)	Additive*	Amt. Additive
CRM MKE/GRB/Gladstone	58-28 S/H/V/E					
CRM MKE/GRB/Gladstone	58-34 S/H/V/E					

** TSR Values are required when a change in source is from a modified AC to a unmodified AC or per CMM 866.2.3.2

TRIAL AC DATA

	Binder	Added % Binder	Gmm	Gmb	% Air Voids	% VMA	%VFB/VFA
Trial 1	5.2	4.6	2.537	2.422	4.5	14.8	69.6
Trial 2	5.7	5.1	2.517	2.441	3.0	14.6	79.5
Trial 3	6.2	5.6	2.498	2.458	1.6	14.5	89.0
Trial 4							
OPT. @ 4.0% Va	5.4	4.8	2.529	2.428	4.0	14.8	73.0
OPT. @ 3.0% Va	5.7	5.07	2.517	2.441	3.0	14.6	79.4

COMPACTION EFFORT/LEVELS -Primary Binder (TSR & Performance Test Results)

		Nini		Nmax	
	# of Gyrations (N)	7	---	115	
TSR T283 (psi)	%Gmm at Optimum	89.1	---	96.8	# of Gry.(N)
Wet Strength:	187.5	Dry Strength: 197.7	TSR:	0.95	15
Hamburg (T324):	Finial Rut Depth (mm):	20.05		Number of Passes:	13,815
Cracking Tolerance Index (D8225):	CI:				

Comments: Recommended and compaction temperatures are for lab purposes only; field production temperatures will vary; Evotherm or rediset added in at 0.3-0.5% of total AC as a cold

Project 2

Reviewed By: Jeffery. R. Anderson

(Project 2)4LT 806821_Not Verified

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

WisDOT Project #:	9110-10-72	Design Lab or Company:		WisDOT Mix Design ID:	
Mix Design ID:	806821	*Mix Designer:		WisDOT Design Verification Date:	
Mix Type:	LT	Designer HTCP Cert ID#:			
NMAS:	4 - 12.5 mm	Producer:			
Virgin Binder PG:	58-28	Plant #/location:		Design Amended Date:	
Binder Designation:	S	Design Date:	7/2/2021	Last JMF Change Date:	
Virgin Binder Gb:	1.030				
Virgin Binder Source:	CRM Green Bay				

Primary AC Source/ Type

*Note: Typed not Signature Block

Instructions: Cells that are light blue are data field for user to enter data all other cells are locked.

AGGREGATE COMPONENT GRADATION DATA

		Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Blend %s (0.1)		12.0	13.0	11.0	43.5	0.5				20.0				100.0
Material Description		5/8" Chip	3/8" Chip	Screenings	Natural Sand	DEG				RAP				
Source ID/Name (needs to match 225 report)		Popple River	Popple River	Popple River	Popple River	DEG				40021				
P or Q or MF or Dust (RAM plant ID)		P	P	P	P	Dust				40021			Gse:	2.73
WisDOT Agg Test ID		225-0240-2021	225-0240-2021										SE:	90
RAM Extracted % Binder										5.0			(T112)	0.03
													PI (T89/90)	
Sieve	(mm)												(mm)	
1 1/2"	37.5	100.0	100.0	100.0	100.0	100.0				100.0			37.5	100.0
1"	25.0	100.0	100.0	100.0	100.0	100.0				100.0			25.0	100.0
3/4"	19.0	100.0	100.0	100.0	100.0	100.0				100.0			19.0	100.0
1/2"	12.5	55.9	100.0	100.0	100.0	100.0				100.0			12.5	94.7
3/8"	9.5	8.4	75.8	100.0	100.0	100.0				96.0			9.5	85.1
#4	4.75	2.4	8.2	89.2	86.3	100.0				77.0			4.75	64.6
#8	2.36	2.1	3.0	59.9	74.2	100.0				61.7			2.36	52.3
#16	1.18	1.9	2.4	42.0	62.6	100.0				49.6			1.18	42.8
#30	0.60	1.8	2.2	31.4	46.1	100.0				36.9			0.60	31.9
#50	0.30	1.6	2.1	23.7	18.7	100.0				20.5			0.30	15.8
#100	0.15	1.3	1.7	15.5	6.9	100.0				12.7			0.15	8.1
#200	0.075	0.9	1.2	10.5	3.9	100.0				9.6			0.075	5.5
Gsb:		2.735	2.715	2.687	2.647	2.675				2.725			Gsb:	2.686
CAA 1F (%):		86	91										CAA 1F (%):	88.5
CAA 2F (%):		84	90										CAA 2F (%):	87.0
FAA:				49	41					43			FAA:	43
Moisture Abs. (%):		0.9	0.8	1.0	0.9					0.6			Abs. (%):	0.8
Thin/Elong. (%):		1.2	2.7										T/E. (%):	0.5

JMF PROPERTIES AT OPTIMUM % BINDER FOR 4.0% AIR VOIDS HMA OR 4.5% AIR VOIDS FOR SMA

Laboratory	HMA/SMA	Warm Mix
Rec. Mix Temp(F):	280-320	
Compact Temp(F):	255-295	

*Type Additive: (WMA, Anti-Strip, Cellulose Fibers)

*Amt. Additive:

* Additive used in initial bid

Additional additives may be added in the comments section or "Alternate AC Sources"

SMA Draindown (%)	
*Temp.°C	
1	
2	
Avg.	
plus 15°C	15
1	
2	
Avg.	

* Temp. of Plant

Pbr calc. with Opt. AC% at either 4.0% Av HMA or 4.5% Av SMA

Pbr:	18.9	
Pbe:	4.7	min. 5.5% (SMA)
Pba:	0.6	
Dust/Binder (DP):	1.2	0.6-1.2/1.2-2.0
Gmm Dryback Corr.:		

Alternate AC Sources (* additive for alternate Binder can be done using JMF form)

Alternate AC Source	AC Type	Gb	TSR **	# of Gry.(N)	Additive*	Amt. Additive
CRM MKE/GRB/Gladstone	58-28 S/H/V/E					
CRM MKE/GRB/Gladstone	58-34 S/H/V/E					

** TSR Values are required when a change in source is from a modified AC to a unmodified AC or per CMM 866.2.3.2

TRIAL AC DATA

	Binder	Added % Binder	Gmm	Gmb	% Air Voids	% VMA	%VFB/VFA
Trial 1	5.1	4.1	2.516	2.404	4.5	15.1	70.2
Trial 2	5.6	4.6	2.497	2.421	3.0	14.9	79.9
Trial 3	6.1	5.2	2.479	2.445	1.4	14.5	90.3
Trial 4							
OPT. @ 4.0% Va	5.3	4.3	2.508	2.408	4.0	15.1	73.5
OPT. @ 3.0% Va	5.6	4.63	2.498	2.423	3.0	14.9	79.8

COMPACTION EFFORT/LEVELS -Primary Binder (TSR & Performance Test Results)

		Nini		Nmax	
	# of Gyrations (N)	6	---	60	
TSR T283 (psi)	%Gmm at Optimum	91.4	---	96.8	# of Gry.(N)
Wet Strength: 329.7	Dry Strength:	346.4	TSR:	0.95	8
Hamburg (T324):	Finial Rut Depth (mm):			Number of Passes:	
Cracking Tolerance Index (D8225):	CI:				

Comments: Recommended and compaction temperatures are for lab purposes only; field production temperatures will vary; Evotherm or rediset added in at 0.3-0.5% of total AC as a cold

Project 3

Reviewed By: Jeffery. R. Anderson

(Project 3)601-21-4MTR301(249 form)

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

WisDOT Project #:	1706-00-70	Design Lab or Company:		WisDOT Mix Design ID:	
Mix Design ID:	601-21-4MTR301	*Mix Designer:		WisDOT Design Verification Date:	
Mix Type:	MT	Designer HTCP Cert ID#:			
NMAS:	4 - 12.5 mm	Producer:			
Virgin Binder PG:	58-28	Plant #/location:		Design Amended Date:	
Binder Designation:	S	Design Date:	8/27/2021	Last JMF Change Date:	
Virgin Binder Gb:	1.029	*Note: Typed not Signature Block			
Virgin Binder Source:	MIA - La Crosse				

Primary AC Source/ Type

Instructions: Cells that are light blue are data field for user to enter data all other cells are locked.

AGGREGATE COMPONENT GRADATION DATA

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Blend %s (0.1)	28.0	33.0	17.0						22.0				100.0
Material Description	1/2" Washed Chips(1248)	3/16" Washed Man Sand(1403)	1/2" Screened Sand(5502)						RAP(7206)				
Source ID/Name (needs to match 225 report)	Browns Bottom Quarry 24,88,3E Dubuque, IA	Browns Bottom Quarry 24,88,3E Dubuque, IA	Tegeler Pit 26,89,3W Deleware, IA						Plant 1 RAP				
P or Q or MF or Dust (RAM plant ID)	Q	Q	P						RAP			Gse:	2.733
WisDOT Agg Test ID (225-xxx-xxxx)	225-57-2021	225-57-2021										SE:	88
RAM Extracted % Binder									6			(T112)	0.5
												PI (T89/90)	

Sieve	(mm)	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)	(mm)	JMF BLEND
1 1/2"	37.5	100.0	100.0	100.0						100.0			37.5	100.0
1"	25.0	100.0	100.0	100.0						100.0			25.0	100.0
3/4"	19.0	100.0	100.0	100.0						100.0			19.0	100.0
1/2"	12.5	92.0	100.0	100.0						94.0			12.5	96.4
3/8"	9.5	60.0	100.0	100.0						88.0			9.5	86.2
#4	4.75	13.0	97.0	98.0						69.0			4.75	67.5
#8	2.36	2.1	67.0	86.0						58.0			2.36	50.1
#16	1.18	1.4	42.0	70.0						51.0			1.18	37.4
#30	0.60	1.3	28.0	46.0						41.0			0.60	26.4
#50	0.30	1.2	18.0	14.0						30.0			0.30	15.3
#100	0.15	1.1	8.0	1.8						16.0			0.15	6.8
#200	0.075	1.0	2.7	1.0						9.7			0.075	3.5

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Gsb:	2.698	2.755	2.616						2.671			Gsb:	2.696
CAA 1F (%):	100	100	25						99			CAA 1F (%):	99.0
CAA 2F (%):	100	100	23						99			CAA 2F (%):	99.0
FAA:		49.7	40.5						43.2			FAA:	43.8
Moisture Abs. (%):	1.1	0.9	0.7						0.98			Abs. (%):	0.9
Thin/Elong. (%):	0.9		0.1						0.1			T/E. (%):	0.2

JMF PROPERTIES AT OPTIMUM % BINDER FOR 4.0% AIR VOIDS HMA OR 4.5% AIR VOIDS FOR SMA

Laboratory	HMA/SMA	Warm Mix
Rec. Mix Temp(F):	275-300	
Compact Temp(F):	275	

*Type Additive: (WMA, Anti-Strip, Cellulose Fibers)

*Amt. Additive:

* Additive used in initial bid

Additional additives may be added in the comments section or "Alternate AC Sources"

SMA Draindown (%)	* Temp. of Plant
*Temp.°C	
1	
2	
Avg.	
plus 15°C	15
1	
2	
Avg.	

Pbr:	24.4	Pbr calc. with Opt. AC% at either 4.0% Av HMA or 4.5% Av SMA
Pbe:	4.9	min. 5.5% (SMA)
Pba:	0.5	
Dust/Binder (DP):	0.7	0.6-1.2/1.2-2.0
Gmm Dryback Corr.:		

Alternate AC Sources (* additive for alternate Binder can be done using JMF form)

Alternate AC Source	AC Type	Gb	TSR **	# of Gry.(N)	Additive*	Amt. Additive
MIA - La Crosse	PG 52S-34	1.023				
MIA - La Crosse	PG 58S-34	1.02				
MIA - La Crosse	PG 58H-28	1.031				

** TSR Values are required when a change in source is from a modified AC to a unmodified AC or per CMM 866.2.3.2

TRIAL AC DATA

	Binder	Added % Binder	Gmm	Gmb	% Air Voids	% VMA	%VFB/VFA
Trial 1	5.0	3.7	2.525	2.391	5.3	15.7	66.5
Trial 2	5.5	4.2	2.505	2.412	3.7	15.4	76
Trial 3	6.0	4.7	2.487	2.433	2.2	15.2	85.8
Trial 4	6.5	5.2	2.468	2.442	1.0	15.3	93.2
OPT. @ 4.0% Va	5.4	4.1	2.509	2.409	4.0	15.5	74.1
OPT. @ 3.0% Va	5.7	4.44	2.496	2.421	3.0	15.4	80.5

COMPACTION EFFORT/LEVELS -Primary Binder (TSR & Performance Test Results)

		Nini		Nmax	
	# of Gyrations (N)	7	---	115	
TSR T283 (psi)	%Gmm at Optimum	90.4	---	96.8	# of Gry.(N)
Wet Strength:	91.8	Dry Strength:	107.7	TSR: 0.86	23
Hamburg (T324):	Finial Rut Depth (mm):			Number of Passes:	
Cracking Tolerance Index (D8225):	CI:				

Comments: Note: 0.2% Evotherm added as a compaction aid.

Project 4

Reviewed By: Jeffery. R. Anderson

Copy of (Project 4)4MT 802022_Not Verifie

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

WisDOT Project #:	4125-14-60	Design Lab or Company:	
Mix Design ID:	802022	*Mix Designer:	
Mix Type:	MT	Designer HTCP Cert ID#:	
NMAS:	4 - 12.5 mm	Producer:	
Virgin Binder PG:	58-28	Plant #/location:	
Binder Designation:	S	Design Date:	3/2/2022
Virgin Binder Gb:	1.030		
Virgin Binder Source:	CRM Green Bay		

Primary AC Source/ Type

*Note: Typed not Signature Block

WisDOT Mix Design ID:	
WisDOT Design Verification Date:	
Design Amended Date:	
Last JMF Change Date:	

Instructions: Cells that are light blue are data field for user to enter data all other cells are locked.

AGGREGATE COMPONENT GRADATION DATA

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Blend %s (0.1)	10.0	11.0	20.0	34.5	0.5				24.0				100.0
Material Description	5/8" Chip	3/8" Chip	MFG'd Sand	Natural Sand	DEG				RAP				
Source ID/Name (needs to match 225 report)	Denmark	Denmark	Denmark	Ahrndt Pit	DEG				40037				
P or Q or MF or Dust (RAM plant ID)	Q	Q	Q	P	Dust				40037			Gse:	2.788
WisDOT Agg Test ID	225-0008-2020	225-0008-2020										SE:	89
RAM Extracted % Binder									5			(T112)	0.2
												PI (T89/90)	

Sieve	(mm)	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)	(mm)	JMF BLEND
1 1/2"	37.5	100.0	100.0	100.0	100.0	100.0				100.0			37.5	100.0
1"	25.0	100.0	100.0	100.0	100.0	100.0				100.0			25.0	100.0
3/4"	19.0	100.0	100.0	100.0	100.0	100.0				100.0			19.0	100.0
1/2"	12.5	80.0	100.0	100.0	100.0	100.0				100.0			12.5	98.0
3/8"	9.5	20.0	89.0	100.0	100.0	100.0				97.0			9.5	90.1
#4	4.75	1.6	6.1	90.0	100.0	100.0				75.9			4.75	72.0
#8	2.36	1.3	1.7	46.6	96.3	100.0				58.1			2.36	57.3
#16	1.18	1.2	1.5	22.5	90.6	100.0				45.7			1.18	47.5
#30	0.60	1.2	1.5	11.5	74.6	100.0				36.1			0.60	37.5
#50	0.30	1.1	1.4	6.5	21.3	100.0				23.1			0.30	15.0
#100	0.15	1.1	1.3	3.6	4.0	100.0				16.8			0.15	6.9
#200	0.075	1.0	1.2	1.7	2.3	100.0				11.1			0.075	4.5

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Gsb:	2.775	2.765	2.776	2.667	2.667				2.739			Gsb:	2.727
CAA 1F (%):	100	100										CAA 1F (%):	100.0
CAA 2F (%):	100	100										CAA 2F (%):	100.0
FAA:			46	41					44			FAA:	43
Moisture Abs. (%):	0.8	1.0	0.6	1.0					0.7			Abs. (%):	0.8
Thin/Elong. (%):	0.4	1.5										T/E. (%):	0.2

JMF PROPERTIES AT OPTIMUM % BINDER FOR 4.0% AIR VOIDS HMA OR 4.5% AIR VOIDS FOR SMA

Laboratory	HMA/SMA	Warm Mix
Rec. Mix Temp(F):	280-320	
Compact Temp(F):	255-295	

*Type Additive:	
*Amt. Additive:	

(WMA, Anti-Strip, Cellulose Fibers)

* Additive used in initial bid

Additional additives may be added in the comments section or "Alternate AC Sources"

SMA Draindown (%)	*Temp. of Plant
*Temp.°C	
1	
2	
Avg.	
plus 15°C	15
1	
2	
Avg.	

Pbr calc. with Opt. AC% at either 4.0% Av HMA or 4.5% Av SMA

Pbr:	21.8	
Pbe:	4.7	min. 5.5% (SMA)
Pba:	0.8	
Dust/Binder (DP):	1.0	0.6-1.2/1.2-2.0
Gmm Dryback Corr.:		

Alternate AC Sources (* additive for alternate Binder can be done using JMF form)

Alternate AC Source	AC Type	Gb	TSR **	# of Gry.(N)	Additive*	Amt. Additive
CRM MKE/GRB/Gladstone	58-28 S/H/V/E					
CRM MKE/GRB/Gladstone	58-34 S/H/V/E					

** TSR Values are required when a change in source is from a modified AC to a unmodified AC or per CMM 866.2.3.2

TRIAL AC DATA

	Binder	Added % Binder	Gmm	Gmb	% Air Voids	% VMA	%VFB/VFA
Trial 1	5.2	4.0	2.561	2.434	5.0	15.4	67.5
Trial 2	5.7	4.5	2.541	2.452	3.5	15.2	77.0
Trial 3	6.2	5.0	2.521	2.463	2.3	15.3	85.0
Trial 4							
OPT. @ 4.0% Va	5.5	4.3	2.550	2.448	4.0	15.2	73.6
OPT. @ 3.0% Va	5.9	4.72	2.532	2.456	3.0	15.3	80.3

COMPACTION EFFORT/LEVELS -Primary Binder (TSR & Performance Test Results)

		Nini		Nmax	
	# of Gyrations (N)	7	---	115	
TSR T283 (psi)	%Gmm at Optimum	90.4	---	96.9	# of Gry.(N)
Wet Strength:	393.7	Dry Strength: 451.6	TSR:	0.87	13
Hamburg (T324):	Finial Rut Depth (mm):	19.10		Number of Passes:	19682
Cracking Tolerance Index (D8225):	CI:	87			

Comments: Recommended and compaction temperatures are for lab purposes only; field production temperatures will vary; Evotherm or rediset added in at 0.3-0.5% of total AC as a cold

Project 5

Reviewed By: Jeffery. R. Anderson

RR0408 4 MT 58-28 S 249 Submittal.xlsx

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

WisDOT Project #:	0250-11-11	Design Lab or Company:		WisDOT Mix Design ID:	
Mix Design ID:	RR0408	*Mix Designer:		WisDOT Design Verification Date:	
Mix Type:	MT	Designer HTCP Cert ID#:			
NMAS:	4 - 12.5 mm	Producer:			
Virgin Binder PG:	58-28	Plant #/location:		Design Amended Date:	
Binder Designation:	S	Design Date:	3/31/2022	Last JMF Change Date:	
Virgin Binder Gb:	1.031		*Note: Typed not Signature Block		
Virgin Binder Source:	Flint Hills Resources				

Primary AC Source/ Type

Instructions: Cells that are light blue are data field for user to enter data all other cells are locked.

AGGREGATE COMPONENT GRADATION DATA

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Blend %s (0.1)			15.0	9.0		24.0	24.0	1.0	24.0	3.0			100.0
Material Description			5/8" Stone R18E; Waukesha	3/8" Stone T6N R18E;		WMS R18E; Waukesha	BS T6N R18E;	Dust Wolf	1/2" RAP Wolf	RAS Wolf			
Source ID/Name (needs to match 225 report)			P	P		P	P	MF					
P or Q or MF or Dust (RAM plant ID)			225-0102-2017	225-0102-2017		225-0102-2017	225-0102-2017					Gse:	2.75
WisDOT Agg Test ID (225-xxxx-xxxx)												SE:	98
RAM Extracted % Binder									4.9	24.5		(T112)	
												PI (T89/90)	

Sieve	(mm)	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)	(mm)	JMF BLEND
1 1/2"	37.5			100.0	100.0		100.0	100.0	100.0	100.0	100.0		37.5	100.0
1"	25.0			100.0	100.0		100.0	100.0	100.0	100.0	100.0		25.0	100.0
3/4"	19.0			100.0	100.0		100.0	100.0	100.0	100.0	100.0		19.0	100.0
1/2"	12.5			85.0	100.0		100.0	98.7	100.0	99.6	100.0		12.5	97.3
3/8"	9.5			31.0	96.4		100.0	96.4	100.0	95.8	100.0		9.5	87.5
#4	4.75			1.9	24.8		100.0	90.3	100.0	77.2	99.4		4.75	70.7
#8	2.36			1.7	3.8		65.9	85.9	100.0	57.4	98.8		2.36	54.8
#16	1.18			1.6	3.1		40.0	79.8	100.0	42.2	81.9		1.18	42.9
#30	0.60			1.6	2.8		23.0	65.0	100.0	30.4	59.2		0.60	31.7
#50	0.30			1.5	2.6		18.0	25.0	100.0	18.7	52.3		0.30	17.8
#100	0.15			1.4	2.5		6.0	6.4	98.0	12.2	44.5		0.15	8.7
#200	0.075			1.2	2.2		2.9	3.2	91.0	8.1	33.4		0.075	5.7

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Gsb:			2.748	2.719		2.717	2.654	2.700	2.698	2.501		Gsb:	2.695
CAA 1F (%):			97.8	100			37		97			CAA 1F (%):	93.3
CAA 2F (%):			95.9	100			28.6		92.1			CAA 2F (%):	90.8
FAA:						46	42		43	45		FAA:	44
Moisture Abs. (%):			1.1	1.4		1.2	1.1		1.1			Abs. (%):	1.1
Thin/Elong. (%):												T/E. (%):	

JMF PROPERTIES AT OPTIMUM % BINDER FOR 4.0% AIR VOIDS HMA OR 4.5% AIR VOIDS FOR SMA

Laboratory	HMA/SMA	Warm Mix
Rec. Mix Temp(F):	300	
Compact Temp(F):	275	

*Type Additive: (WMA, Anti-Strip, Cellulose Fibers)

*Amt. Additive:

* Additive used in initial bid

Additional additives may be added in the comments section or "Alternate AC Sources"

SMA Draindown (%)	* Temp. of Plant
*Temp.°C	
1	
2	
Avg.	
plus 15°C	15
1	
2	
Avg.	

Pbr calc. with Opt. AC% at either 4.0% Av HMA or 4.5% Av SMA

Pbr:	34.9	
Pbe:	4.7	min. 5.5% (SMA)
Pba:	0.8	
Dust/Binder (DP):	1.2	0.6-1.2/1.2-2.0
Gmm Dryback Corr.:		

Alternate AC Sources (* additive for alternate Binder can be done using JMF form)

Alternate AC Source	AC Type	Gb	TSR **	# of Gry.(N)	Additive*	Amt. Additive
Interstate Asphalt	58-28 S	1.031		75		
Flint Hills Resources	58-28 H	1.035		75		
Seneca	58-28 S	1.031		75		

** TSR Values are required when a change in source is from a modified AC to a unmodified AC or per CMM 866.2.3.2

TRIAL AC DATA

	Total %	Added % Binder	Gmm	Gmb	% Air Voids	% VMA	%VFB/VFA
Trial 1	4.5	2.90	2.558	2.383	6.8	15.4	55.8
Trial 2	5.0	3.41	2.542	2.401	5.5	15.2	63.8
Trial 3	5.5	3.92	2.518	2.421	3.9	14.9	73.8
Trial 4	6.0	4.43	2.499	2.438	2.4	14.8	83.5
OPT. @ 4.0% Va	5.5	3.41	2.520	2.419	4.0	14.9	73.2
OPT. @ 3.0% Va	5.8	3.76	2.507	2.432	3.0	15.0	80.0

COMPACTION EFFORT/LEVELS -Primary Binder (TSR & Performance Test Results)

		Nini		Nmax	
	# of Gyrations (N)	7	---	75	
TSR T283 (psi)	%Gmm at Optimum	89.8	---	97.4	# of Gry.(N)
Wet Strength:	97.6	Dry Strength: 124.8	TSR:	0.78	21
Hamburg (T324):	Finial Rut Depth (mm):		Number of Passes:		
Cracking Tolerance Index (D8225):	CI:				
Comments:					

Project 6

Reviewed By: Jeffery. R. Anderson

Copy of (Project 6)147-21-4MTR301(249 form)

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

WisDOT Project #:	1074-00-72	Design Lab or Company:	
Mix Design ID:	147-21-4MTR301	*Mix Designer:	
Mix Type:	MT	Designer HTCP Cert ID#:	
NMAS:	4 - 12.5 mm	Producer:	
Virgin Binder PG:	58-28	Plant #/location:	
Binder Designation:	S	Design Date:	8/25/2021
Virgin Binder Gb:	1.029		
Virgin Binder Source:	MIA - La Crosse		

Primary AC Source/ Type

*Note: Typed not Signature Block

WisDOT Mix Design ID:	
WisDOT Design Verification Date:	
Design Amended Date:	
Last JMF Change Date:	

Instructions: Cells that are light blue are data field for user to enter data all other cells are locked.

AGGREGATE COMPONENT GRADATION DATA

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)
Blend %s (0.1)	18.0	21.0	22.0	19.0					20.0		
Material Description	3/4 X 3/8 Bit Agg(1221)	3/16" Washed Man Sand(1403)	1/4" Washed Man Sand(3402)	3/16 Screened Sand(5505)					RAP(7230)		
Source ID/Name (needs to match 225 report)	Wiedl 29,16,2W Monroe	Donskey 11,16,3W Monroe	Merrillan-734 13,23,3W Clark	Levis Pines 6,21,3W Jackson					I-90 Millings		
P or Q or MF or Dust (RAM plant ID)	Q	Q	Q	P					RAP		
WisDOT Agg Test ID	225-261-2021	225-18-2020	225-19-2021								
RAM Extracted % Binder									6.1		

	JMF BLEND
	100.0
Gse:	2.71
SE:	87
(T112)	0.5
PI (T89/90)	

Sieve	(mm)	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)	(mm)	JMF BLEND
1 1/2"	37.5	100.0	100.0	100.0	100.0					100.0			37.5	100.0
1"	25.0	100.0	100.0	100.0	100.0					100.0			25.0	100.0
3/4"	19.0	100.0	100.0	100.0	100.0					100.0			19.0	100.0
1/2"	12.5	63.0	100.0	100.0	100.0					94.0			12.5	92.1
3/8"	9.5	33.0	100.0	100.0	100.0					82.0			9.5	84.3
#4	4.75	8.8	99.0	96.0	97.0					54.0			4.75	72.7
#8	2.36	6.4	73.0	60.0	89.0					40.0			2.36	54.6
#16	1.18	5.9	47.0	31.0	77.0					31.0			1.18	38.6
#30	0.60	5.6	34.0	15.0	51.0					23.0			0.60	25.7
#50	0.30	5.3	26.0	7.0	16.0					16.0			0.30	14.2
#100	0.15	4.4	11.0	3.0	1.8					12.0			0.15	6.5
#200	0.075	3.1	3.0	1.5	0.8					8.2			0.075	3.3

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Gsb:	2.588	2.650	2.670	2.620					2.672			Gsb:	2.642
CAA 1F (%):	100	100	100	34					100			CAA 1F (%):	98.6
CAA 2F (%):	100	100	100	33					100			CAA 2F (%):	98.6
FAA:		49	51.7	40.2					53.7			FAA:	43.5
Moisture Abs. (%):	2.4	2.2	0.8	0.8					0.98			Abs. (%):	1.4
Thin/Elong. (%):	1.7	0.8	0.5	1.3					0.1			T/E. (%):	0.3

JMF PROPERTIES AT OPTIMUM % BINDER FOR 4.0% AIR VOIDS HMA OR 4.5% AIR VOIDS FOR SMA

Laboratory	HMA/SMA	Warm Mix
Rec. Mix Temp(F):	275-300	
Compact Temp(F):	275	

*Type Additive: (WMA, Anti-Strip, Cellulose Fibers)

*Amt. Additive:

* Additive used in initial bid

Additional additives may be added in the comments section or "Alternate AC Sources"

SMA Draindown (%)	*Temp. of Plant
*Temp.°C	
1	
2	
Avg.	
plus 15°C	15
1	
2	
Avg.	

Pbr:	21.8	Pbr calc. with Opt. AC% at either 4.0% Av HMA or 4.5% Av SMA
Pbe:	4.7	min. 5.5% (SMA)
Pba:	1.0	
Dust/Binder (DP):	0.7	0.6-1.2/1.2-2.0
Gmm Dryback Corr.:		

Alternate AC Sources (* additive for alternate Binder can be done using JMF form)

Alternate AC Source	AC Type	Gb	TSR **	# of Gry.(N)	Additive*	Amt. Additive
MIA - La Crosse	PG 58H-28	1.03				
MIA - La Crosse	PG 52S-34	1.023				
MIA - La Crosse	PG 58S-34	1.023				
MIA - La Crosse	PG 58H-34	1.02				

** TSR Values are required when a change in source is from a modified AC to a unmodified AC or per CMM 866.2.3.2

TRIAL AC DATA

	Binder	Added % Binder	Gmm	Gmb	% Air Voids	% VMA	%VFB/VFA
Trial 1	5.0	3.8	2.505	2.357	5.9	15.2	61.2
Trial 2	5.5	4.3	2.487	2.378	4.4	14.9	70.8
Trial 3	6.0	4.8	2.468	2.393	3.0	14.8	79.5
Trial 4	6.5	5.3	2.450	2.406	1.8	14.8	87.9
OPT. @ 4.0% Va	5.6	4.4	2.483	2.383	4.0	14.9	73.1
OPT. @ 3.0% Va	6.0	4.83	2.467	2.393	3.0	14.9	79.8

COMPACTION EFFORT/LEVELS -Primary Binder (TSR & Performance Test Results)

		Nini	---	Nmax	
	# of Gyrations (N)	7	---	115	
TSR T283 (psi)	%Gmm at Optimum	89.9	---	97.1	# of Gry.(N)
Wet Strength: 94.3	Dry Strength:	99	TSR:	0.95	23
Hamburg (T324):	Finial Rut Depth (mm):			Number of Passes:	
Cracking Tolerance Index (D8225):	CI:				

Comments: Note: 0.2% Evotherm added as a compaction aid.

Project 7

Reviewed By: Jeffery. R. Anderson

Copy of (Project 7)158-22-5MTRW301(249 form)

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

WisDOT Project #:	1560-00-72	Design Lab or Company:		WisDOT Mix Design ID:	
Mix Design ID:	158-22-5MTRW301	*Mix Designer:		WisDOT Design Verification Date:	
Mix Type:	MT	Designer HTCP Cert ID#:			
NMAS:	5 - 9.5 mm	Producer:			
Virgin Binder PG:	58-28	Plant #/location:		Design Amended Date:	
Binder Designation:	S	Design Date:	5/31/2022	Last JMF Change Date:	
Virgin Binder Gb:	1.029	*Note: Typed not Signature Block			
Virgin Binder Source:	MIA - La Crosse				

Primary AC Source/ Type

Instructions: Cells that are light blue are data field for user to enter data all other cells are locked.

AGGREGATE COMPONENT GRADATION DATA

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Blend %s (0.1)	18.0	26.0	10.0	24.0					22.0				100.0
Material Description	3/8" Washed Chips(3238)	3/8" Bit Agg(3235)	3/16" Washed Man Sand(5403)	Washed Sand(5405)					RAP(7260)				
Source ID/Name (needs to match 225 report)	Highbridge North 16,45,3W Ashland	Highbridge North 16,45,3W Ashland	Crooked Lake 36,47,8W Bayfield	Crooked Lake 36,47,8W Bayfield					Ashland 1/2" RAP				
P or Q or MF or Dust (RAM plant ID)	Q	Q	P	P					RAP			Gse:	2.668
WisDOT Agg Test ID	225-33-2020	225-33-2020	225-58-2019	225-58-2019								SE:	81
RAM Extracted % Binder									5.1			(T112)	0.33
												PI (T89/90)	

Sieve	(mm)	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)	(mm)	JMF BLEND
1 1/2"	37.5	100.0	100.0	100.0	100.0					100.0			37.5	100.0
1"	25.0	100.0	100.0	100.0	100.0					100.0			25.0	100.0
3/4"	19.0	100.0	100.0	100.0	100.0					100.0			19.0	100.0
1/2"	12.5	100.0	100.0	100.0	100.0					100.0			12.5	100.0
3/8"	9.5	100.0	100.0	100.0	100.0					98.0			9.5	99.6
#4	4.75	25.0	77.0	96.0	99.0					80.0			4.75	75.5
#8	2.36	3.0	52.0	64.0	86.0					66.0			2.36	55.6
#16	1.18	2.5	36.0	41.0	72.0					55.0			1.18	43.3
#30	0.60	2.2	25.0	27.0	49.0					41.0			0.60	30.4
#50	0.30	1.8	17.0	15.0	20.0					25.0			0.30	16.5
#100	0.15	1.5	11.0	4.9	3.5					14.0			0.15	7.5
#200	0.075	1.0	7.2	1.7	1.1					10.0			0.075	4.7

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Gsb:	2.615	2.606	2.819	2.668					2.654			Gsb:	2.653
CAA 1F (%):	100	100	100	73					95			CAA 1F (%):	98.8
CAA 2F (%):	100	100	100	62					91			CAA 2F (%):	98.0
FAA:		49.9	47.7	40.3					41.3			FAA:	43.5
Moisture Abs. (%):	0.6	1	0.2	0.5					1			Abs. (%):	0.7
Thin/Elong. (%):	4.5	3.7	2.2	0.6					0.4			T/E. (%):	0.9

JMF PROPERTIES AT OPTIMUM % BINDER FOR 4.0% AIR VOIDS HMA OR 4.5% AIR VOIDS FOR SMA

Laboratory	HMA/SMA	Warm Mix
Rec. Mix Temp(F):		220-240
Compact Temp(F):		230

*Type Additive:	Evotherm (WMA, Anti-Strip, Cellulose Fibers)
*Amt. Additive:	0.30%

* Additive used in initial bid

Additional additives may be added in the comments section or "Alternate AC Sources"

SMA Draindown (%)	* Temp. of Plant
*Temp.°C	
1	
2	
Avg.	
plus 15°C	15
1	
2	
Avg.	

Pbr calc. with Opt. AC% at either 4.0% Av HMA or 4.5% Av SMA

Pbr:	20.0	
Pbe:	5.4	min. 5.5% (SMA)
Pba:	0.2	
Dust/Binder (DP):	0.9	0.6-1.2/1.2-2.0
Gmm Dryback Corr.:		

Alternate AC Sources (* additive for alternate Binder can be done using JMF form)

Alternate AC Source	AC Type	Gb	TSR **	# of Gry.(N)	Additive*	Amt. Additive
MIA - La Crosse	PG 58H-28	1.035				
MIA - La Crosse	PG 58S-34	1.025				
MIA - La Crosse	PG 58H-34	1.025				
MIA - La Crosse	PG 58V-34	1.027				

** TSR Values are required when a change in source is from a modified AC to a unmodified AC or per CMM 866.2.3.2

TRIAL AC DATA

	Binder	Added % Binder	Gmm	Gmb	% Air Voids	% VMA	%VFB/VFA
Trial 1	5.0	3.9	2.471	2.335	5.5	16.4	66.4
Trial 2	5.5	4.4	2.453	2.350	4.2	16.3	74.1
Trial 3	6.0	4.9	2.435	2.368	2.8	16.1	82.6
Trial 4	6.5	5.4	2.418	2.379	1.6	16.2	90
OPT. @ 4.0% Va	5.6	4.5	2.450	2.352	4.0	16.3	75.4
OPT. @ 3.0% Va	5.9	4.85	2.437	2.364	3.0	16.2	81.5

COMPACTION EFFORT/LEVELS -Primary Binder (TSR & Performance Test Results)

			Nini		Nmax	
	# of Gyrations (N)		7	---	115	
TSR T283 (psi)	%Gmm at Optimum		90.4	---	96.8	# of Gry.(N)
Wet Strength:	94.5	Dry Strength:	103.7	TSR:	0.91	20
Hamburg (T324):		Finial Rut Depth (mm):			Number of Passes:	
Cracking Tolerance Index (D8225):		CI:				

Comments: Note: This is a WARM MIX design. 0.3% Evotherm added as a WARM MIX additive.

Project 8

Reviewed By: Jeffery. R. Anderson

Copy of (Project 8)C-5 4HT 502321 NOT VERIFIED

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

WisDOT Project #:	250-11-11	Design Lab or Company:		WisDOT Mix Design ID:	
Mix Design ID:	502321	*Mix Designer:		WisDOT Design Verification Date:	
Mix Type:	HT	Designer HTCP Cert ID#:			
NMAS:	4 - 12.5 mm	Producer:			
Virgin Binder PG:	58-28	Plant #/location:		Design Amended Date:	
Binder Designation:	S	Design Date:	2/12/2021	Last JMF Change Date:	
Virgin Binder Gb:	1.017		*Note: Typed not Signature Block		
Virgin Binder Source:	CRM Milwaukee				

Primary AC Source/ Type

Instructions: Cells that are light blue are data field for user to enter data all other cells are locked.

AGGREGATE COMPONENT GRADATION DATA

		Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Blend %s (0.1)		14.0	12.0	22.0	25.0	11.5	0.5	#REF!	#REF!	15.0				#REF!
Material Description		5/8" Chips	3/8" Chips	MFG'D Sand	MFG'D Sand	Natural Sand	DEG			1/2" RAP				
Source ID/Name (needs to match 225 report)		Oregon	Oregon	Oregon	Waterloo (Michels)	Oregon	DEG			40005.00				
P or Q or MF or Dust (RAM plant ID)		P	P	P	Q	P	DEG			RAM1			Gse:	2.703
WisDOT Agg Test ID (225-xxxx-xxxx)		225-0050-2017	225-0050-2017										SE:	91
RAM Extracted % Binder										4.9			(T112)	0.6
													PI (T89/90)	
Sieve	(mm)												(mm)	
1 1/2"	37.5	100.0	100.0	100.0	100.0	100.0	100.0	#REF!	#REF!	100.0			37.5	#REF!
1"	25.0	100.0	100.0	100.0	100.0	100.0	100.0	#REF!	#REF!	100.0			25.0	#REF!
3/4"	19.0	100.0	100.0	100.0	100.0	100.0	100.0	#REF!	#REF!	100.0			19.0	#REF!
1/2"	12.5	80.0	100.0	100.0	100.0	100.0	100.0	#REF!	#REF!	100.0			12.5	#REF!
3/8"	9.5	23.0	97.0	100.0	100.0	100.0	100.0	#REF!	#REF!	98.0			9.5	#REF!
#4	4.75	3.0	19.0	97.0	100.0	94.0	100.0	#REF!	#REF!	81.0			4.75	#REF!
#8	2.36	2.0	4.0	64.0	77.0	72.0	100.0	#REF!	#REF!	63.0			2.36	#REF!
#16	1.18	2.0	3.0	41.0	46.0	56.0	100.0	#REF!	#REF!	50.0			1.18	#REF!
#30	0.60	2.0	3.0	27.0	27.0	42.0	100.0	#REF!	#REF!	41.0			0.60	#REF!
#50	0.30	1.5	2.0	15.0	13.0	16.0	100.0	#REF!	#REF!	27.0			0.30	#REF!
#100	0.15	1.5	2.0	5.0	4.0	4.0	100.0	#REF!	#REF!	18.0			0.15	#REF!
#200	0.075	1.2	1.6	2.4	2.0	1.8	100.0	#REF!	#REF!	13.3			0.075	#REF!
Gsb:		2.602	2.586	2.639	2.674	2.651	2.651	#REF!	#REF!	2.633			Gsb:	
CAA 1F (%):		99	99	#REF!	100	#REF!	#REF!	#REF!	#REF!	#REF!			CAA 1F (%):	
CAA 2F (%):		97	98	#REF!	#REF!	#REF!	#REF!	#REF!	#REF!	#REF!			CAA 2F (%):	
FAA:		#REF!	#REF!	47	48	41	#REF!	#REF!	#REF!	42			FAA:	46
Moisture Abs. (%):		1.9	2.3	1.3	0.7	0.7	#REF!	#REF!	#REF!	1			Abs. (%):	#REF!
Thin/Elong. (%):		0.5	0.5	#REF!	#REF!	#REF!	#REF!	#REF!	#REF!	#REF!			T/E. (%):	

JMF PROPERTIES AT OPTIMUM % BINDER FOR 4.0% AIR VOIDS HMA OR 4.5% AIR VOIDS FOR SMA

Laboratory	HMA/SMA	Warm Mix
Rec. Mix Temp(F):	280-320	
Compact Temp(F):	255-295	

*Type Additive:	(WMA, Anti-Strip, Cellulose Fibers)
*Amt. Additive:	

* Additive used in initial bid

Additional additives may be added in the comments section or "Alternate AC Sources"

SMA Draindown (%)	*Temp. of Plant
*Temp.°C	
1	
2	
Avg.	
plus 15°C	15
1	
2	
Avg.	

Pbr:	13.6	Pbr calc. with Opt. AC% at either 4.0% Av HMA or 4.5% Av SMA
Pbe:	5.4	min. 5.5% (SMA)
Pba:		
Dust/Binder (DP):		0.6-1.2/1.2-2.0
Gmm Dryback Corr.:		

Alternate AC Sources (* additive for alternate Binder can be done using JMF form)

Alternate AC Source	AC Type	Gb	TSR **	# of Gry.(N)	Additive*	Amt. Additive
CRM MKE/GRB/Gladstone	58-28 S/H/V/E					
CRM MKE/GRB/Gladstone	58-34 S/H/V/E					

** TSR Values are required when a change in source is from a modified AC to a unmodified AC or per CMM 866.2.3.2

TRIAL AC DATA

	Binder	Added % Binder	Gmm	Gmb	% Air Voids	% VMA	%VFB/VFA
Trial 1	5.0	4.30	2.496	2.365	5.3	14.8	64.2
Trial 2	5.5	4.80	2.477	2.384	3.8	14.5	73.8
Trial 3	6.0	5.30	2.458	2.416	1.7	13.9	87.8
Trial 4							
OPT. @ 4.0% Va	5.4	4.7	2.481	2.382	4.0	14.5	72.4
OPT. @ 3.0% Va	5.7	4.97	2.471	2.397	3.0		

COMPACTION EFFORT/LEVELS -Primary Binder (TSR & Performance Test Results)

		Nini		Nmax	
	# of Gyrations (N)	8	---	160	
TSR T283 (psi)	%Gmm at Optimum	88	---	96.5	# of Gry.(N)
Wet Strength: 103.6	Dry Strength:	93.8	TSR:	1.00	24
Hamburg (T324):	Finial Rut Depth (mm):	3.25		Number of Passes:	20000
Cracking Tolerance Index (D8225):	CI:	30			

Comments: Recommended and compaction temperatures are for lab purposes only; field production temperatures will vary; Evotherm or rediset added in at 0.3-0.5% of total AC as a cold

Project 9

Reviewed By: Jeffery. R. Anderson

Copy of (Project 9)360-22-4MTRW301(249 form)

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

WisDOT Project #:	1570-05-63	Design Lab or Company:		WisDOT Mix Design ID:	
Mix Design ID:	360-22-4MTRW301	*Mix Designer:		WisDOT Design Verification Date:	
Mix Type:	MT	Designer HTCP Cert ID#:			
NMAS:	4 - 12.5 mm	Producer:			
Virgin Binder PG:	58-28	Plant #/location:		Design Amended Date:	
Binder Designation:	S	Design Date:	4/19/2021	Last JMF Change Date:	
Virgin Binder Gb:	1.029				
Virgin Binder Source:	MIA - La Crosse				

Primary AC Source/ Type

*Note: Typed not Signature Block

Instructions: Cells that are light blue are data field for user to enter data all other cells are locked.

AGGREGATE COMPONENT GRADATION DATA

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Blend %s (0.1)	18.0	22.0	22.0	21.0					17.0				100.0
Material Description	3/4" X 3/8" Bit Gravel(5214)	3/8" Bit Rock(5225)	5/16" WMS(5401)	5/8" Screened Sand(5501)					RAP(7230)				
Source ID/Name (needs to match 225 report)	McLaine 9,35,13W Barron	McLaine 9,35,13W Barron	Safert 1,34,11W Barron	McLaine 9,35,13W Barron					USH8 Millings				
P or Q or MF or Dust (RAM plant ID)	P	P	P	P					RAP			Gse:	2.768
WisDOT Agg Test ID	225-177-2022	225-177-2022	225-77-2021	225-177-2022								SE:	84
RAM Extracted % Binder									5.2			(T112)	0.2
												PI (T89/90)	

Sieve	(mm)	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)	(mm)	JMF BLEND
1 1/2"	37.5	100.0	100.0	100.0	100.0					100.0			37.5	100.0
1"	25.0	100.0	100.0	100.0	100.0					100.0			25.0	100.0
3/4"	19.0	100.0	100.0	100.0	100.0					100.0			19.0	100.0
1/2"	12.5	70.0	100.0	100.0	95.0					97.0			12.5	93.0
3/8"	9.5	26.0	100.0	100.0	88.0					92.0			9.5	82.8
#4	4.75	1.9	65.0	100.0	74.0					72.0			4.75	64.4
#8	2.36	1.6	40.0	79.0	63.0					63.0			2.36	50.4
#16	1.18	1.4	28.0	53.0	51.0					51.0			1.18	37.5
#30	0.60	1.3	20.0	35.0	32.0					36.0			0.60	25.2
#50	0.30	1.2	14.0	19.0	11.0					20.0			0.30	13.2
#100	0.15	1.0	9.4	6.7	3.8					12.0			0.15	6.6
#200	0.075	0.8	6.3	3.0	2.4					9.2			0.075	4.3

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Gsb:	2.816	2.772	2.713	2.742					2.706			Gsb:	2.749
CAA 1F (%):	96	100		8					94			CAA 1F (%):	83.1
CAA 2F (%):	93	100		7					93			CAA 2F (%):	81.3
FAA:		49.2	47.9	42.1					42			FAA:	45.8
Moisture Abs. (%):	0.9	1.4	1.1	1					0.98			Abs. (%):	1.1
Thin/Elong. (%):	4	0.7		1.1					1.5			T/E. (%):	0.9

JMF PROPERTIES AT OPTIMUM % BINDER FOR 4.0% AIR VOIDS HMA OR 4.5% AIR VOIDS FOR SMA

Laboratory	HMA/SMA	Warm Mix
Rec. Mix Temp(F):		220-240
Compact Temp(F):		230
*Type Additive:	Evotherm	(WMA, Anti-Strip, Cellulose Fibers)
*Amt. Additive:	0.30%	

* Additive used in initial bid

Additional additives may be added in the comments section or "Alternate AC Sources"

SMA Draindown (%)	
*Temp.°C	
1	
2	
Avg.	
plus 15°C	15
1	
2	
Avg.	

* Temp. of Plant

Pbr:	18.0	Pbr calc. with Opt. AC% at either 4.0% Av HMA or 4.5% Av SMA
Pbe:	4.7	min. 5.5% (SMA)
Pba:	0.3	
Dust/Binder (DP):	0.9	0.6-1.2/1.2-2.0
Gmm Dryback Corr.:		

Alternate AC Sources (* additive for alternate Binder can be done using JMF form)

Alternate AC Source	AC Type	Gb	TSR **	# of Gry.(N)	Additive*	Amt. Additive
MIA - La Crosse	PG 58H-28	1.035				
MIA - La Crosse	PG 58S-34	1.025				
MIA - La Crosse	PG 58H-34	1.025				
MIA - La Crosse	PG 58V-34	1.027				

** TSR Values are required when a change in source is from a modified AC to a unmodified AC or per CMM 866.2.3.2

TRIAL AC DATA

	Binder	Added % Binder	Gmm	Gmb	% Air Voids	% VMA	%VFB/VFA
Trial 1	4.5	3.6	2.572	2.436	5.3	15.4	65.7
Trial 2	5.0	4.1	2.552	2.455	3.8	15.1	75
Trial 3	5.5	4.6	2.532	2.476	2.2	14.9	85.1
Trial 4	6.0	5.1	2.513	2.479	1.3	15.2	91.2
OPT. @ 4.0% Va	4.9	4.0	2.556	2.454	4.0	15.1	73.5
OPT. @ 3.0% Va	5.3	4.41	2.540	2.464	3.0	15.1	80.2

COMPACTION EFFORT/LEVELS -Primary Binder (TSR & Performance Test Results)

		Nini		Nmax	
	# of Gyrations (N)	7	---	115	
TSR T283 (psi)	%Gmm at Optimum	89.6	---	96.6	# of Gry.(N)
Wet Strength: 103.9	Dry Strength:	130.8	TSR:	0.79	26
Hamburg (T324):	Finial Rut Depth (mm):			Number of Passes:	
Cracking Tolerance Index (D8225):	CI:				

Comments: Note: This is a WARM MIX.

Project 10

Reviewed By: Jeffery. R. Anderson

Copy of (Project 10)1145-22-4HTRW301(281)

WisDOT MIX DESIGN STANDARD DATA INPUT FORM/REPORT 249

WisDOT Project #:	1166-07-79	Design Lab or Company:		WisDOT Mix Design ID:	
Mix Design ID:	1145-22-4HTRW301(281)	*Mix Designer:		WisDOT Design Verification Date:	
Mix Type:	HT	Designer HTCP Cert ID#:			
NMAS:	4 - 12.5 mm	Producer:			
Virgin Binder PG:	58-28	Plant #/location:		Design Amended Date:	
Binder Designation:	S	Design Date:	5/12/2022	Last JMF Change Date:	
Virgin Binder Gb:	1.029				
Virgin Binder Source:	MIA-Lacrosse				

Primary AC Source/ Type

*Note: Typed not Signature Block

Instructions: Cells that are light blue are data field for user to enter data all other cells are locked.

AGGREGATE COMPONENT GRADATION DATA

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Blend %s (0.1)	14.0	15.0	16.0	27.0	13.0				15.0				100.0
Material Description	5/8x3/8-3226	3/8 Bit-3235	3/8x1/8-3250	1/8MS-3404	Washed Sand-5405				Millings-7230				
Source ID/Name (needs to match 225 report)	Seven Sisters 36,20,7E Adams	Seven Sisters 36,20,7E Adams	Cisler 5,26,7E Marathon	Cisler 5,26,7E Marathon	Heyn 22,19,8E Waushara				Plant Stockpile				
P or Q or MF or Dust (RAM plant ID)	Q	Q	Q	Q	P							Gse:	2.718
WisDOT Agg Test ID	225-0036-2022	225-0036-2022	225-0037-2022	225-0037-2022	225-191-2021							SE:	71
RAM Extracted % Binder									4.3			(T112)	
												PI (T89/90)	

Sieve	(mm)	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)	(mm)	JMF BLEND
1 1/2"	37.5	100.0	100.0	100.0	100.0	100.0				100.0			37.5	100.0
1"	25.0	100.0	100.0	100.0	100.0	100.0				100.0			25.0	100.0
3/4"	19.0	100.0	100.0	100.0	100.0	100.0				100.0			19.0	100.0
1/2"	12.5	77.0	100.0	100.0	100.0	100.0				97.0			12.5	96.3
3/8"	9.5	36.0	100.0	100.0	100.0	99.0				93.0			9.5	89.9
#4	4.75	3.2	70.0	34.0	100.0	90.0				73.0			4.75	66.0
#8	2.36	1.9	41.0	9.0	96.0	84.0				54.0			2.36	52.8
#16	1.18	1.7	25.0	4.2	60.0	79.0				41.0			1.18	37.3
#30	0.60	1.5	17.0	2.3	34.0	66.0				33.0			0.60	25.8
#50	0.30	1.4	12.0	1.5	16.0	24.0				24.0			0.30	13.3
#100	0.15	1.3	9.0	1.1	4.9	2.2				15.0			0.15	5.6
#200	0.075	1.1	6.8	1.0	2.6	1.0				10.4			0.075	3.7

	Agg 1	Agg 2	Agg 3	Agg 4	Agg 5	Agg 6	Agg 7	Agg 8	RAM 1 (RAP)	RAM 2 (RAS)	RAM 3 (FRAP)		JMF BLEND
Gsb:	2.697	2.686	2.690	2.668	2.679				2.691			Gsb:	2.683
CAA 1F (%):	100	100	100		82.3				98.3			CAA 1F (%):	99.1
CAA 2F (%):	100	100	100		76.1				96.7			CAA 2F (%):	98.7
FAA:		49.9		48.1	38.3				43.5			FAA:	45.4
Moisture Abs. (%):	0.2	0.35	0.39	0.54	0.3				1.01			Abs. (%):	0.5
Thin/Elong. (%):	1.8	4.5	7.4		0.9				0.13			T/E. (%):	1.2

JMF PROPERTIES AT OPTIMUM % BINDER FOR 4.0% AIR VOIDS HMA OR 4.5% AIR VOIDS FOR SMA

Laboratory	HMA/SMA	Warm Mix
Rec. Mix Temp(F):		225-245
Compact Temp(F):		230

*Type Additive: Evotherm (WMA, Anti-Strip, Cellulose Fibers)
*Amt. Additive: 0.35

* Additive used in initial bid

Additional additives may be added in the comments section or "Alternate AC Sources"

SMA Draindown (%)	*Temp. of Plant
*Temp.°C	
1	
2	
Avg.	
plus 15°C	15
1	
2	
Avg.	

Pbr:	11.1	Pbr calc. with Opt. AC% at either 4.0% Av HMA or 4.5% Av SMA
Pbe:	5.3	min. 5.5% (SMA)
Pba:	0.5	
Dust/Binder (DP):	0.7	0.6-1.2/1.2-2.0
Gmm Dryback Corr.:		

Alternate AC Sources (* additive for alternate Binder can be done using JMF form)

Alternate AC Source	AC Type	Gb	TSR **	# of Gry.(N)	Additive*	Amt. Additive
St Paul Park	58-28S	1.035				

** TSR Values are required when a change in source is from a modified AC to a unmodified AC or per CMM 866.2.3.2

TRIAL AC DATA

	Binder	Added % Binder	Gmm	Gmb	% Air Voids	% VMA	%VFB/VFA
Trial 1	5.0	4.4	2.512	2.353	6.3	16.7	62.2
Trial 2	5.5	4.9	2.493	2.370	5.0	16.5	70.3
Trial 3	6.0	5.4	2.474	2.384	3.9	16.5	78
Trial 4	6.5	5.9	2.456	2.400	2.3	16.4	86.1
OPT. @ 4.0% Va	5.8	5.2	2.478	2.379	4.0	16.5	75.8
OPT. @ 3.0% Va	6.3	5.64	2.464	2.390	3.0	16.5	81.8

COMPACTION EFFORT/LEVELS -Primary Binder (TSR & Performance Test Results)

		Nini		Nmax	
	# of Gyrations (N)	8	---	160	
TSR T283 (psi)	%Gmm at Optimum	88.7	---	97	# of Gry.(N)
Wet Strength:	2115	Dry Strength: 2436	TSR:	0.87	27
Hamburg (T324):	Finial Rut Depth (mm):			Number of Passes:	
Cracking Tolerance Index (D8225):	CI:				

Comments: Evotherm P-series used for warm mix.